HARPA

A Versatile Three-Dimensional Hamiltonian Ray-Tracing Program for Acoustic Waves in the Atmosphere Above Irregular Terrain

R. Michael Jones
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T.M. Georges



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Wave Propagation Laboratory
Boulder, Colorado
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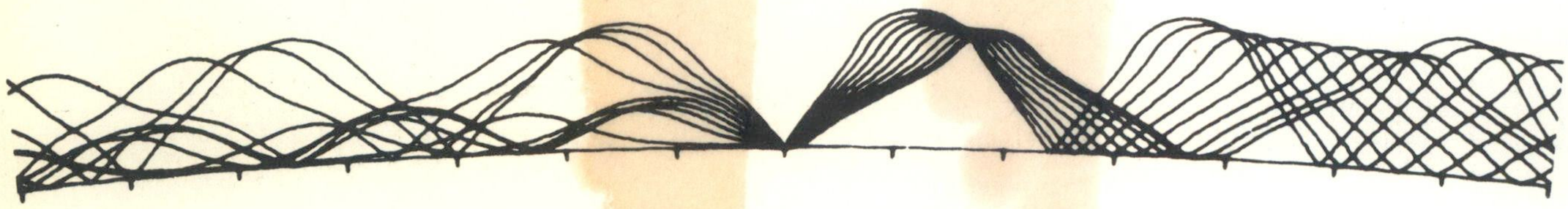

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Part of the organization of this program into subroutines follows that of the program of Dudziak (1961). Also, the coordinate transformation in subroutine PRINTR and the method for data input via the W array are taken from the program of Dudziak (1961). The term "rayset," the idea of outputting computer-readable results of each hop for each ray trace, and the idea of automatically plotting raypaths come from the program of Croft and Gregory (1963). Subroutine RKAM1 is a modification of subroutine RKAMSUB, written by G. J. Lastman, and is available through the CDC CO-OP library (the CO-OP identification is D2 UTEX RKAMSUB). Subroutine GAUSEL was written by L. David Lewis, NOAA Space Environment Laboratory. Judith Stephenson wrote much of the code for the original ionospheric ray-tracing program, upon which HARPA is based. Richard Lindzen devised the method upon which models TTANH5, CSTANH, and GTANH are based. We also thank the many users of earlier versions of the program who provided helpful feedback. Special thanks go to the Editorial Staff of Publication Services for extensive help in clarifying the expression of our ideas, and to Ms. Mildred Birchfield for her excellent typing and layout of the manuscript.

HARPA -- A VERSATILE THREE-DIMENSIONAL HAMILTONIAN RAY-TRACING PROGRAM FOR ACOUSTIC WAVES IN THE ATMOSPHERE ABOVE IRREGULAR TERRAIN

R. Michael Jones, J. P. Riley, and T. M. Georges

ABSTRACT

HARPA stands for Hamiltonian Acoustic Ray-tracing Program for the Atmosphere. This FORTRAN computer program traces the three-dimensional paths of acoustic rays through model atmospheres by numerically integrating Hamilton's equations, which are a differential expression of Fermat's principle. The user specifies an atmospheric model by writing closed-form formulas for its three-dimensional wind and temperature (or sound-speed) distribution, and by defining the height of the reflecting terrain as a function of geographic latitude and longitude. Some general-purpose models are provided, or users can easily design their own.

Because it uses continuous models, the Hamiltonian method avoids the false caustics and discontinuous raypath properties encountered in conventional ray-tracing methods, which use layers or cells where each acoustic-raypath segment can be computed in closed form. Furthermore, computational speed can be traded for accuracy, without changing the model of the medium, by specifying the maximum allowable integration error per step.

In addition to computing the geometry of each raypath, the program can calculate pulse travel time, phase time, Doppler shift (if the medium varies in time), absorption, and geometrical path length. Amplitude is not explicitly computed, but the contributions by absorption, reflection losses, and focusing are separately available for each ray. Only geometrical effects are accounted for; that is, no diffraction or partial-reflection corrections are applied. The program prints out a step-by-step account of each ray's progress, and it can plot the

projection of a set of rays on any vertical plane or on the ground. Furthermore, it can output each ray's properties in machine-readable form for further processing (amplitude calculations, for example).

This report describes the ray-tracing equations and the structure of the program and provides complete instructions for using it, illustrated by a sample case. The program is modular and can be adapted to model propagation through other media by changing the routine that defines the medium's dispersion relation.

PART I: WHAT THIS RAY-TRACING PROGRAM CAN DO

1. Introduction to Hamiltonian Ray Tracing

1.1 Rationale

Many practical problems in atmospheric acoustics submit to a straightforward application of geometrical acoustics, or ray theory. No other propagation-modeling tool provides such an intuitive and graphic portrayal of the paths that acoustic energy follows through inhomogeneous media. Even in situations where ray theory does not strictly apply, a picture of the acoustic raypaths often provides a useful first look at the way the waves and the medium interact, and it gives insight into where higher order computations are required. Some calculations cannot be easily made in any other way, for example, computing multipath pulse travel time or showing which parts of the medium affect each pulse arrival.

Yet most of the ray-tracing computer programs in common use fail to take full advantage of the power of geometrical acoustics. Many are essentially automated versions of graphical techniques that patch together closed-form raypath solutions for layers or cells with simple refractive-index gradients (Roberts, 1974; Cornyn, 1973). In such models, gradient discontinuities at cell boundaries can introduce false caustics and cause discontinuous behavior of ray properties as launch angle varies (Pederson, 1961). Furthermore, it is difficult to extend such models to three-dimensional media, to account for winds, and to compute reflections from complicated terrain models.

This report describes a general-purpose atmospheric acoustic ray-tracing program called HARPA -- for Hamiltonian Acoustic Ray-tracing Program for the Atmosphere -- that we have designed to overcome these limitations. It computes acoustic raypaths by numerically integrating Hamilton's equations, which are a differential expression of Fermat's principle. The user defines an atmospheric model by writing closed-form expressions for its temperature (or sound-speed) and wind distribution in three dimensions, and by defining the terrain height as a function of latitude and longitude. Several simple but generally useful models with user-definable parameters are described in this report; users can pattern their own models after them.

HARPA is the companion to a similar program we have developed for the ocean, known as HARPO. The main differences between the two programs are in the models available for the two media, in provisions for reflections from an upper boundary (in the ocean case), and in the program module that describes the media dispersion relations. HARPO is documented in a separate report (Jones et al., 1986).

1.2 What Is Ray Tracing?

Although ray tracing has a long history, many people outside the field do not know what ray tracing is or what it can do. In ray theory, waves are treated like particles (photons of light, phonons of sound) that travel along geometric trajectories called rays. In material media, the particles travel at a speed determined by the medium's "refractive index." Gradients in refractive index bend rays, giving rise to the problem of computing ray trajectories through a known spatial distribution of refractive index. Ray tracing is any method, graphical or numerical, for solving that problem.

Originally, lensmakers used ray tracing to find out how light rays travel through optical systems. They used graphical techniques based on Snell's law to compute the bending that light rays suffer when they encounter abrupt changes in refractive index, as at the surface of a lens. By constructing bundles of such rays, lensmakers could simulate the magnification, reduction, and focusing of their lens designs without actually building them.

Modern ray-tracing applications, whether acoustic or electromagnetic, serve basically the same function: they allow one to simulate the propagation of waves through media whose refractive-index structure varies in a complicated way, without actually performing the physical measurement. Modern ray-tracing computations are usually performed by programs written for digital computers that can graphically display the results of their computations in various informative ways.

Today's ray-tracing programs do much more than compute the bending of rays as they cross interfaces; they can model media whose refractive index varies continuously in space and even with time. In dissipative media, they integrate absorption along the raypath. They can also integrate phase and

pulse travel time, as well as wave amplitude. In time-varying media, they can integrate the rate of change of phase, or Doppler shift. Some programs (including HARPA) produce machine-readable output so that the results of many raypath computations can be processed by other programs to display field observables, such as amplitude.

The most advanced applications of ray-tracing computer programs have been to the fields of ionospheric radio propagation, seismic wave propagation, and the propagation of acoustic or sound waves in the ocean and the atmosphere. In the Hamiltonian formalism, the ray-tracing equations for acoustic, seismic, and electromagnetic waves are identical. General-purpose programs can thus be constructed in which only the modules that describe the wave dispersion relation and how the medium varies in space need be changed to go from one kind of ray-tracing program to another.

1.3 What Approximations Are Involved in Ray Tracing?

Solving a wave equation with arbitrary boundary conditions is still an impractical task, even for the most modern computers. Therefore, practical problems in wave propagation are often solved by making simplifying approximations to the wave equation. Examples of such approximations are the parabolic-equation (P.E.) method (Tappert, 1977), normal-mode theory (Tolstoy and Clay, 1966; Pierce, 1965), fast-field methods for numerical integration of the wave equation in range-independent environments (Raspet et al., 1985), and ray theory.

Ray theory, sometimes called the WKB or eikonal method, results from making a high-frequency approximation in the solution of arbitrary elliptic or hyperbolic partial differential equations (Budden, 1961). Ray tracing is related to the "method of characteristics" for solving such equations because the raypaths are the bi-characteristic rays of the differential equations in the infinite frequency, infinite wave-number limits. In some fields, ray tracing is called the "shooting method" because (as with shooting a gun) the location of the end point is found by trial and error while the initial conditions of a ray are varied.

In the case of the wave equation, the approximation gives rise to the fields of geometrical acoustics or geometrical optics, which are concerned

with the trajectories of bundles of acoustic or electromagnetic energy radiated in infinitesimal angular beams. Such rays experience no diffraction but produce sharp shadow boundaries when they encounter solid objects. Ray theory can be extended to include the effects of diffraction, for example, by using the Geometrical Theory of Diffraction (GTD) (Keller, 1962).

In ray theory, one assumes conservation of energy within a bundle of rays called a flux tube so that wave intensity is inversely proportional to the cross-sectional area of the flux tube. When that cross-sectional area becomes zero, ray theory predicts infinite energy density. At such "caustics," higher order corrections to ray theory can give more accurate field estimates when needed. For example, the field near a surface caustic can be calculated in terms of Airy functions (Ludwig, 1966; White and Pedersen, 1981).

Without such corrections, ray tracing accounts only for refraction by large-scale gradients in the medium and not for diffraction and scattering by changes in the medium over scales that are small compared to a Fresnel zone. Even so, ray theory provides a useful first look at many complicated propagation problems and gives a kind of graphical insight lacking in other propagation models.

1.4 When Should You Use Ray Tracing?

Ray tracing is best suited to modeling acoustic propagation in environments where the medium's refractive index can be described deterministically in one, two, or three dimensions, and where changes in refractive index are small in the WKB sense (roughly speaking, within an acoustic Fresnel zone). (This means that ray models are most accurate at high frequencies.) In such environments, ray tracing gives accurate information about the geometrical paths followed by acoustic rays (energy), about shadow boundaries and reflections from surfaces, and about phase, intensity, pulse travel time, absorption and Doppler shift (for time-varying media) integrated along those paths.

In environments where multiple rays reach a receiver location of interest, additional computations, external to the ray tracing, may be required to combine field information from multiple rays. When the number of multipath rays becomes large, alternative formulations of the problem (P.E. or normal-mode

theory, for example) are more appropriate for continuous-wave amplitude calculations. For pulse transmissions, ray theory is useful for describing the distinct geometric paths corresponding to each pulse arrival and for computing multipath travel times.

In situations where the applicability of ray theory is doubtful, a raypath picture can tell which regions must be treated with higher order methods, such as GTD or the Airy-function approximation to the field near a caustic. Furthermore, there are standard formulas to estimate how close to a caustic amplitude calculations are accurate (Budden, 1961; 1972).

Even when ray calculations of one wave quantity become inaccurate, they can give useful estimates of others. For example, when amplitude estimates break down (as at surface caustics), other information, such as travel time or phase, may still be reliable and can be tracked through caustics. Furthermore, Budden (1961, pp. 325-326) shows that the ray-computed phase must be advanced by 90° every time a ray passes through a line caustic.

1.5 What Is Hamiltonian Ray Tracing?

An alternative to cellular methods requires the medium to be modeled as a continuous three-dimensional function with continuous gradients and computes each raypath by numerically integrating Hamilton's equations with a different set of initial conditions. This method has been called Hamiltonian ray tracing. Hamilton's equations are the same for all kinds of wave propagation; only the definition of the Hamiltonian varies when going from one wave type to another.

Although Hamilton's equations are more familiar in mechanics, they have a long history of application to more general problems, including wave propagation. There, the point of view is that in a high-frequency limit, waves behave like particles and travel along rays, according to equations that exactly parallel those governing changes of position and momentum in mechanical systems (Lighthill, 1978, Sec. 4.5). Two steps show that integrating Hamilton's equations can lead to approximate solutions of a wave equation:

(1) The first step is to show that solutions to the wave equation are related to paths that satisfy a particular stationary principle, usually called

Fermat's principle. There are at least two standard methods for demonstrating that relation.

(a) First is the method of characteristics (see, for example, Courant and Hilbert, 1962; Garabedian, 1964), in which the solution is related to initial-value data chosen on some appropriate surface. Specifying a surface and constructing a solution requires first constructing the characteristic surfaces that are wave fronts of the wave. These characteristic surfaces can be constructed by first constructing bi-characteristic rays that satisfy a stationary principle. The bi-characteristic rays are the same as the geometrical raypaths whenever all terms in the wave equation are proportional to a derivative of the wave function, or in the limit of infinite frequency and wave number.

(b) Second is the path-integral method (see, for example, Feynman and Hibbs, 1965), in which a solution to the wave equation is constructed as an integral over all possible paths (not just raypaths) that connect the source and observer. Making a saddlepoint (or stationary phase) approximation to the path integral finds the paths that contribute most to the path integral. Such paths are those for which the action (phase) is stationary for variations of the path; that is, they satisfy Fermat's principle.

(2) The second step is to show that Hamilton's equations can be integrated to construct paths that satisfy a variational principle, such as Fermat's principle. This is done in standard texts (for example, Lighthill, 1978). First, the variational principle is expressed as an integral of a Lagrangian along the path (specified in terms of generalized coordinates, q_i). This determines the form of the Lagrangian for the problem, which for the wave equation is usually some simple function of the phase refractive index. Then the generalized momenta p_i are defined, which for the wave equation correspond to components k_i of the wave number vector. Then a Hamiltonian $H(q_i,p_i)$ is constructed from the Lagrangian. For the wave equation, the Hamiltonian is usually a function that gives the dispersion relation for the wave in question when it is set to zero. Integrating Hamilton's equations then gives a path that satisfies the variational (Fermat's) principle.

In Cartestian coordinates, Hamilton's equations take the particularly simple form (Lighthill, 1978)

$$\frac{dx_i}{d\tau} = \frac{\partial H}{\partial k_i} \quad ; \quad \frac{dk_i}{d\tau} = -\frac{\partial H}{\partial x_i} \quad , \quad i = 1 \text{ to } 3 \quad , \tag{1.1}$$

where τ is a parameter (sometimes proportional to time) whose physical meaning depends on the how the Hamiltonian, H, is defined, k_i are the wave-number components, and x_i are the coordinates of a point on the raypath. Transforming to spherical polar coordinates complicates the equations considerably. The full set of equations for spherical coordinates can be found in Chapter 6.

To solve (1.1) for the raypath, one chooses initial values for the six quantities x_i and k_i and performs a numerical integration of the system (1.1) of six total differential equations. For acoustic waves in the atmosphere, the Hamiltonian (which is constant along a raypath) is defined as

$$H(x_i, k_j) = [\omega - \vec{k} \cdot \vec{V}(x_i)]^2 - C^2(x_i)\, k^2 = 0 \quad , \tag{1.2}$$

where $\vec{V}(x_i)$ is the wind field, $C(x_i)$ is the sound-speed field, and ω is the angular wave frequency ($\vec{V}$ and C may also depend on time). Thus, the effects of a three-dimensional vector-wind field are automatically included in the definition of the Hamiltonian.

There is an alternative to Hamilton's equations for a differential form of the ray equation, namely the eikonal equation (see, for example, Garabedian, 1964, p. 166; Felsen and Marcuvitz, 1973, p. 126). The eikonal equation is derived by first assuming an approximate solution to the wave equation in terms of an asymptotic series. Substituting the asymptotic series into the wave equation leads to the eikonal equation, which determines the raypaths, and a transport equation, which determines an approximate solution to the wave equation. The eikonal equation is equivalent to Hamilton's equations for determining the raypath. The transport equation is equivalent to methods mentioned above for determining an approximate solution to the wave equation.

In addition to allowing continuous three-dimensional models of the refractive-index field and two-dimensional models of reflecting surfaces, Hamiltonian ray tracing by numerical integration permits the user to trade computing speed for accuracy by specifying the maximum allowed integration error per step. In other words, you can have a fast but crude ray trace or a

slower and more accurate one. The program automatically adjusts the integration step length along the raypath to keep the error within specified bounds. In regions where the refractive index varies quickly, small steps are required, but in regions where it varies slowly, large steps save computation. If the quantity being integrated varies monotonically along the raypath, the specified relative accuracy will be preserved in integrated quantities, such as travel time.

1.6 What This Program Does

HARPA computes the paths of acoustic rays, one at a time, through a user-defined model of the atmosphere, given initial conditions that include the source location (latitude, longitude, and height above the ground), wave frequency, direction of transmission (elevation and azimuth), the receiver-surface model, and the maximum number of hops (intersections with the receiver surface). The input data specification forms in Chapter 2 illustrate the generality of acceptable input.

The mechanics of the raypath calculation have been completely separated from the modeling of the medium (sound-speed, wind velocity, and terrain models). This allows the user to select models from those we have developed or to develop new models simply by writing new (or altering existing) subroutines to define those models.

The modular structure of the program allows the user to extend the program easily to other types of geophysical ray tracing (underwater acoustics, for example) simply by substituting new subroutines for defining the Hamiltonian and the model of the medium.

The method for inputting data into the program is easy to learn. The user simply specifies the magnitude and units of the elements of an Input Data File which correspond to physical or mathematical quantities that tell the program what models to use, what rays to trace, and in what form to present its results. We provide input parameter forms for making sure that all the required quantities are specified.

At the user's option, HARPA produces three kinds of output: (1) The printout reproduces the input data set and gives detailed information about

each raypath computed, in columnar form, with each line corresponding to a "snapshot" of the ray's progress after a specified number of integration steps. (2) Computer-readable output permits further processing of raypath data by supplementary programs, without recomputing the raypaths. (3) The raypath plots show projections of any part of the raypaths on any vertical plane or on any part of the ground, with any desired magnification. These plots give the user a quick view of the raypath geometries.

Chapter 2 illustrates more fully what the program does by going through the setup and execution of a representative application.

1.7 What This Program Does Not Do

HARPA's computations lie entirely within the scope of geometrical acoustics (ray theory). It applies no corrections for diffraction or partial reflections. The atmospheric model must be deterministic, not stochastic.

There are no provisions built into HARPA for explicit computations of acoustic amplitude. This would normally be done with a supplementary program that processes HARPA's machine-readable output. Total amplitude at a receiver would be computed by combining flux-tube focusing, reflection losses, and absorption, and the user would normally decide whether to add coherently or incoherently the contributions of multipath rays. Because there are so many ways to compute amplitude, we think it is best to keep the various factors separate and let the users combine them however they wish.

Because the numerical integration of Hamilton's equations requires media models with continuous gradients, HARPA cannot presently handle refraction at discontinuities of refractive index or its gradients. If such discontinuities are included in a model, the integration routine will attempt to handle them by taking extremely small steps when a ray encounters a discontinuity, and the results may not be reliable. In general, one can approximate discontinuous functions with continuous functions to any desired accuracy, and HARPA will adjust its step length to accommodate them. Our algorithms for reflecting rays from arbitrary terrain surfaces could be generalized to compute refraction at discontinuities in refractive index.

HARPA is not currently equipped to model penetration of rays into the ground or to account for partial reflections from subsurface layers. However, the user can specify a complex (to account for phase and amplitude) ground-reflection coefficient that is a function of frequency and angle of incidence. Since reflection coefficients do not affect the raypaths, their effects can be added after raypath calculations.

HARPA cannot directly compute the raypaths that connect a specified source and receiver. To find such "eigenrays," one usually launches a fan of rays at small increments in elevation and/or azimuth angle and linearly interpolates for the rays that reach the desired receiver location (range, azimuth and height). We have developed an eigenray program that processes the "rayset" output of HARPA, interpolating in elevation angle only, and that will be documented elsewhere. Some shortcuts for finding three-dimensional eigenrays when azimuthal deflections are small are described by Georges et al. (1986).

HARPA makes no checks to see if atmospheric models satisfy physical conservation laws and boundary conditions, or that wind and temperature models are geostrophically consistent. (Accurate raypaths can be computed through physically impossible models.) Therefore, users should make their models as physically realistic as their application demands.

1.8 History of the Program

HARPA has a long history of development. We started by learning from the programs of Dudziak (1961) and Croft and Gregory (1963). Jones (1966) documented our first version of a three-dimensional ray-tracing program for radio waves in the ionosphere, which included anisotropy caused by the earth's magnetic field. Jones (1968) documented improvements in the original program. Georges (1971) converted the ionospheric radio program to trace raypaths for acoustic-gravity waves in an atmosphere with winds and changed the ray-tracing equations into Hamiltonian form. Jones and Stephenson (1975) documented further significant improvements in the ionospheric program. Jones et al. (1982) documented a Hamiltonian acoustic ray-tracing program for an atmosphere over a spherical earth.

Through its history, HARPA and its predecessors have found application in the propagation of radio waves through the ionosphere (Georges, 1967; 1970;

Georges and Stephenson, 1968; Stephenson and Georges, 1969), acoustic propagation through the atmosphere (Georges, 1972; Georges and Beasley, 1977) and acoustic propagation in the ocean (Georges et al., 1986; Jones et al., 1984). In extending the utility of ray theory, Jones (1970) has treated ray propagation in lossy media (ray tracing in complex space), bending of rays in random, inhomogeneous media (Jones, 1981a), and the frequency shift suffered by pulses propagating in dispersive media (Jones, 1981b). Jones (1983) has also surveyed existing techniques for underwater acoustic ray tracing.

HARPA combines the improvements made by Jones and Stephenson with the acoustic-wave capability and atmospheric models developed by Georges. Although it does not include the capability for tracing acoustic-gravity-wave raypaths, it includes modularity features that make it easier to convert the program to trace rays in other media. It also includes algorithms developed by Jones (1982) for reflecting rays from arbitrary terrain surfaces. In addition, we have developed real-time graphics routines and facilitated operation from time-share graphics terminals as that technology has advanced.

1.9 Scope of This Report

This report documents only the ray-tracing program HARPA, its supporting subroutines, and its various forms of input and output. The main intent of this report is to show what HARPA can do and to explain how to use it. We illustrate its capabilities with a comprehensive sample case. We also show how to extend and modify the program to the user's specific needs.

Not documented here are supplementary programs that we have designed to plot properties of the atmospheric models and to process the computer-readable output of HARPA. Examples of such programs are packages to plot range vs. elevation angle of transmission, range vs. travel time, and amplitude calculations (Jones et al., 1984). We have not documented here our programs for editing input to HARPA or our procedure files for running it on our computer. Nevertheless, the package documented here is self-contained and has everything needed to compute and display raypaths through arbitrary three-dimensional model atmospheres.

Figure 1.1 shows an organization chart of HARPA in relation to its supporting modules. The dotted line encloses the portion documented in this

report. Separate reports will document the remaining modules, which are the same for both HARPA and HARPO.

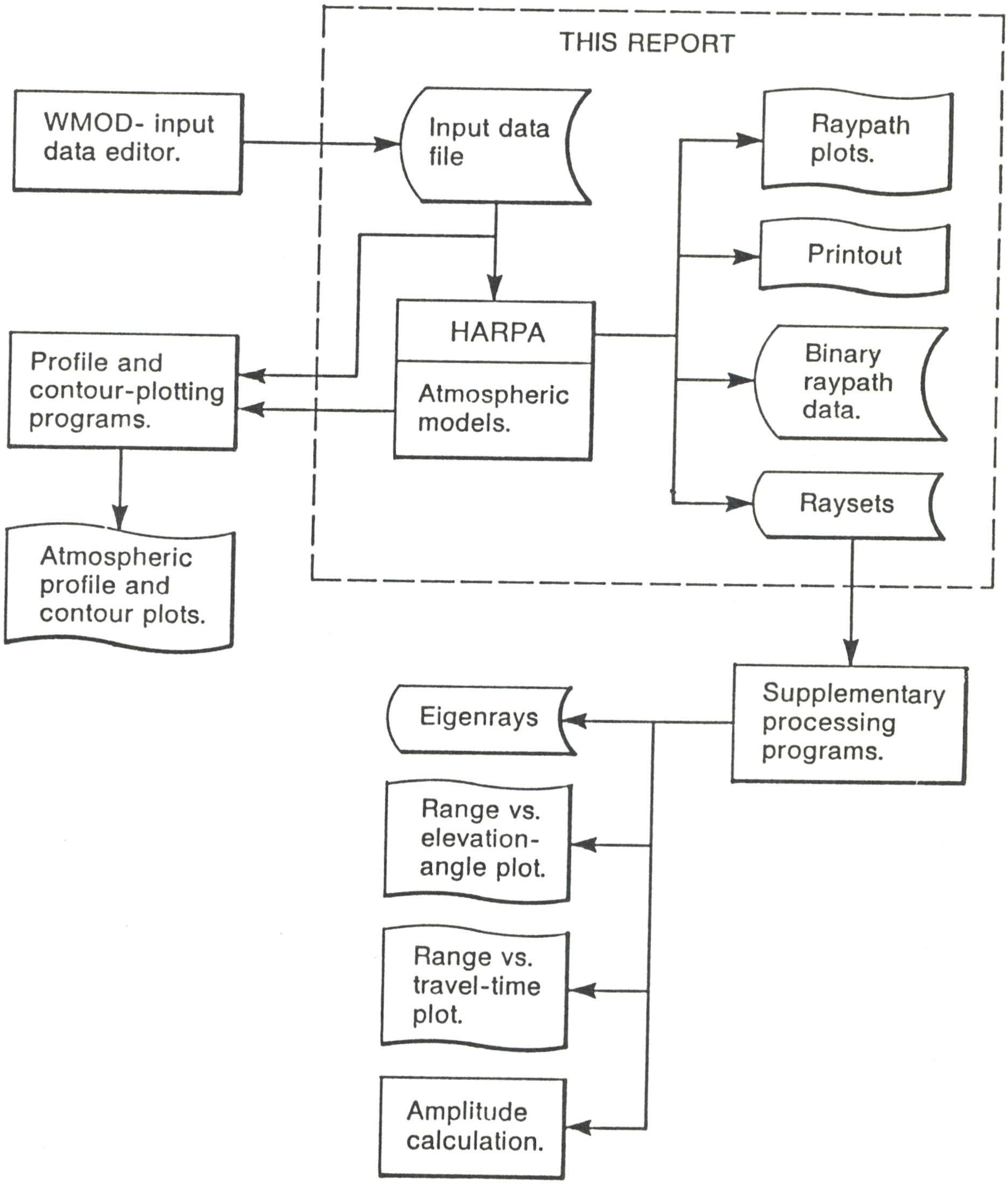


Figure 1.1. Relation of HARPA to its inputs and outputs, as well as its supporting and supplementary programs. The dashed line shows the scope of this report.

2. A Sample Run Illustrating an Application of HARPA

A sample case serves several purposes: it introduces new users to the capabilities of the program in terms of physical models they can understand; it shows new users how to set up and run the program and what output to expect; and it provides a comprehensive test case to exercise the program and make sure everything works on a new machine. New users should run the sample case (provided with the program) first and make sure that the program's output is identical to that shown in this report. Varying the input parameters, one by one, from the sample case is an instructive way to explore the program's capabilities.

The usual procedure for defining models is to fill out "order forms" corresponding to the wind, sound speed, temperature, molecular weight, viscosity/conductivity and terrain models you want to use, then create an "Input Data File" from the information on the order forms. Models can be selected from the general-purpose ones we have created, or you can design your own. The following pages show filled-out forms for the models used by the sample case; blank order forms for all our models are supplied in Appendix B. Using these forms is recommended, even for advanced users, because they make sure that you specify all the required model parameters. They also help you keep track of the models you create.

2.1 The Atmospheric Model for the Sample Case

The atmospheric model described here is designed more to exercise features of the program than to represent any physically realistic situation. It combines a three-dimensional wind and temperature field with a terrain model containing a Lorentzian-shaped ridge. The sample case also includes a simple absorption model based on models of atmospheric viscosity and thermal conductivity.

Refer now to the FORM TO SPECIFY AN ATMOSPHERIC MODEL (Figure 2.1). This form is filled in with the names of all the subroutines required to specify the atmospheric model, for the sample case, including the terrain model,

viscosity/ conductivity model and receiver-surface model. Data-set ID numbers uniquely identify the particular set of parameter values used by each subroutine for the sample case. The entire set of models and parameters that constitute the atmospheric model for the sample case is also given a unique ID number, which is S03. The references to W followed by numbers in these forms correspond to specific input data parameters, as described in Section 5.3.

The first subroutine name on this form specifies the acoustic-wave dispersion relation to be used. In the sample case, we specify AWWWL, which means "Acoustic, With Winds, With Losses." This means that we will use a model atmosphere with winds and will calculate acoustic absorption. More efficient versions of the dispersion relation should be selected when wind or absorption models are not used. The remaining subroutine names filled in on this form refer to the atmospheric model subroutines, to be discussed next.

Refer next to the FORM TO SPECIFY INPUT DATA FOR WIND VELOCITY MODEL ULOGZ2 (Figure 2.2). This wind-field model represents a wind profile for the atmospheric boundary layer, neglecting Coriolis forces. The wind has only an eastward component whose magnitude depends only on height above the terrain surface, according to the formula given on the ULOGZ2 order form.

ULOGZ2 requires the user to specify three parameters, z_0, u_*, and k. For the sample case, we choose k=0.35, z_0=1.0 km, and u_*=5.0 m/s. The resulting profile of wind speed is shown in Figure 2.1a. (The program that provided this plot is part of a set of peripheral programs that will be documented in another report.) Because we use no wind-perturbation model, we select the do-nothing wind-perturbation NPWIND.

Refer next to the FORM TO SPECIFY SOUND-SPEED MODEL GAMRTDM (Figure 2.3). We use this sound-speed model because we want to specify a background temperature distribution instead of a sound-speed model directly. GAMRTDM requires no input parameters, but it requires a molecular weight model, discussed next.

Refer next to the FORM TO SPECIFY INPUT DATA FOR ATMOSPHERIC MOLECULAR WEIGHT MODEL MCONST (Figure 2.4). For the sample case, we select the simplest possible model, namely a constant value of 29. Molecular weight is required to convert temperature to sound speed when temperature models are specified.

FORM TO SPECIFY AN ATMOSPHERIC MODEL
(including terrain model)

Name GEORGES RB3 X6437 Date 2-10-86

Atmospheric ID (3 characters) S03

Coordinates of the north pole of the computational coordinate system:

North geographic latitude: 90 rad, km, (deg) (W24)

East geographic longitude: 0 rad, km, deg (W25)

Models:

	Subroutine Name	Data set ID	
Dispersion relation	AWWWL		
Wind velocity	ULOGZ2	3.0	(W102)
Wind-velocity perturbation	NPWIND	0.0	(W127)
Sound speed	GAMRTDM	0.0	(W152)
Sound-speed perturbation	CBLOB2	2.0	(W177)
Temperature	TTANH5	1.0	(W202)
Temperature perturbation	TBLOB2	2.0	(W227)
Molecular weight	MCONST	29.0	(W252)
Terrain	GLORENZ	2.0	(W302)
Terrain perturbation	NPTERR	0.0	(W327)
Viscosity/conductivity	MUARDC	1.0	(W502)
Viscosity/conductivity perturbation	NPABSR	0.0	(W527)
Pressure	PEXP	1.0	(W552)
Pressure perturbation	NPPRES	0.0	(W557)
Receiver surface*	RTERR		
Plot-annotation model*	FULANN		

*The receiver-surface model and plot-annotation model are not considered part of the atmospheric ID

Figure 2.1. Sample of completed form to specify an atmospheric model (including terrain model).

FORM TO SPECIFY INPUT DATA
FOR WIND-VELOCITY MODEL ULOGZ2

A logarithmic wind profile of the atmospheric boundary layer neglecting Coriolis forces. The eastward wind is given by

$$u_\phi = \frac{u_*}{k} \ln \frac{z}{z_0} \qquad \text{for} \qquad z > z_0 e$$

$$u_\phi = \frac{u_*}{k} \frac{z}{z_0 e} \qquad \text{for} \qquad z \leqslant z_0 e \ ,$$

where $z = G(r,\theta,\phi)$ is determined by the terrain model and is the height above or some kind of distance from the terrain, depending on the terrain model, and r is the radial coordinate of the ray point.

Specify--

the model check for ULOGZ2 = 6.0 (W100)

the input data-format code = _____ (W101)

an input data-set identification number = 3.0 (W102)

an 80-character description of the wind velocity profile:

LOGARITHMIC EASTWARD WIND PROFILE, $U^* = .5$ M/S, $Z\emptyset = 1$ KM

the reference wind speed, u_* = 5 km/s, (m/s) (W103)

von Kármán's constant, k = .35 (W104) (.35 recommended)

the roughness height, z_0 = 1 km (W105)

OTHER MODELS REQUIRED: Any wind-perturbation model. Use NPWIND if no perturbation is desired.

($\overline{uw} = -u_*^2$ is the surface stress at the ground.)

Figure 2.2. Sample of completed form to specify input data for wind-velocity model ULOGZ2.

FORM TO SPECIFY
SOUND-SPEED MODEL GAMRTDM

This model specifies sound speed in terms of a background temperature model using

$$C^2 = \frac{\gamma RT}{M} \quad ,$$

where $\gamma = 1.4$, R is the universal gas constant, T is the absolute temperature in Kelvins, and $M(r,\theta,\phi)$ is a model of the mean molecular weight of the atmosphere. See Sec. 6.3 for further description of this model.

Specify --

The model check for GAMRTDM = ___1.0___(W150)

OTHER MODELS REQUIRED: Any background temperature model; any molecular weight model.

Figure 2.3. Sample of completed form to specify sound-speed model GAMRTDM.

FORM TO SPECIFY INPUT DATA FOR
ATMOSPHERIC MOLECULAR-WEIGHT MODEL MCONST

A constant molecular weight (independent of height, longitude, latitude, and time)

Specify--

the model check for MCONST = 1.0 (W250)

the input data-format code = _____ (W251)

an input data-set identification number = 29 (W252)

an 80-character description of the molecular weight:

MOLECULAR WEIGHT = 29

the value of the constant molecular weight, M = 29 (W253)

OTHER MODELS REQUIRED: none.

Figure 2.4. Sample of completed form to specify input data for atmospheric molecular-weight model MCONST.

FORM TO SPECIFY INPUT DATA FOR
TEMPERATURE MODEL TTANH5

This model represents the temperature profile by a sequence of linear segments that are smoothly joined by hyperbolic functions:

$$T = T_o + \frac{c_1}{2}(z-z_o) + \sum_{i=1}^{n} \delta_i \left(\frac{c_{i+1} - c_i}{2}\right) \ln\left\{\frac{\cosh\left(\frac{z-z_i}{\delta_i}\right)}{\cosh\left(\frac{z_i-z_o}{\delta_i}\right)}\right\} + \frac{c_{n+1}}{2}(z-z_o)$$

$$\frac{dT}{dz} = c_1 + \sum_{i=1}^{n} \left(\frac{c_{i+1} - c_i}{2}\right) \left\{\tanh\left(\frac{z-z_i}{\delta_i}\right) + 1\right\}$$

$$c_i = (T_i - T_{i-1})/(z_i - z_{i-1}) \quad .$$

$z = r - r_e$, where r_e is the Earth radius, and r is the radial coordinate of the ray point. Thus, δ_i is the half-thickness of a region centered at approximately z_i km, in which dT/dz changes from c_i to c_{i+1}. Start by drawing a profile using linear segments and get T_i and z_i from the corners. Then select δ_i to round the corners. The final profile will not go through (T_i, z_i).

Specify--

the model check for TTANH5 = 7.0 (W200)

the input data-format code = _____ (W201)

an input data-set identification number = 1.0 (W202)

an 80-character description of the model with parameters:

U.S. STANDARD ATMOSPHERE 1962 TEMPERATURE PROFILE

and the profile values:

the number of points in the profile -2 = n = 4

the profile:

i	z_i (km,m)	T_i (°K)	δ_i (km,m)
0	0	288	0
1	15	190.5	10
2	52	320	7.5
3	95	191	10
4	165	1451	50
5	300	1586	0

OTHER MODELS REQUIRED: Any temperature-perturbation model. Use NPTEMP if no perturbations are desired. FUNCTION ALCOSH.

Figure 2.5. Sample of completed form to specify input data for temperature model TTANH5.

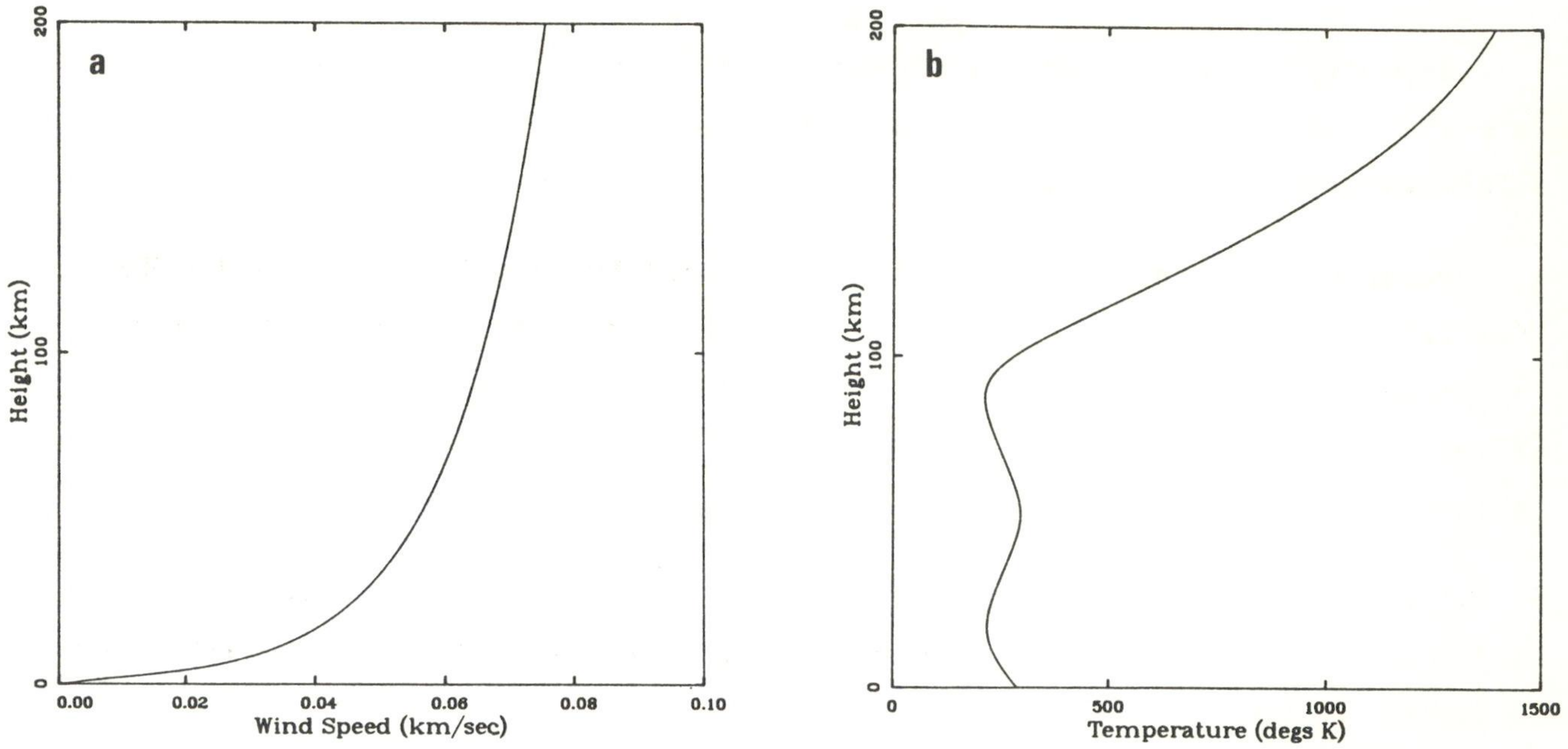


Figure 2.6. Profiles of background (a) eastward wind speed, (b) temperature, and (c) sound speed used in the sample case. The program for plotting these profiles is not supplied with HARPA but is part of a set of supplementary programs documented elsewhere.

Refer next to the FORM TO SPECIFY INPUT DATA FOR TEMPERATURE MODEL TTANH5 (Figure 2.5). This "background" temperature model is a continuous approximation to the 1962 U.S. Standard Atmosphere (USSA) temperature profile (Valley, 1965). The model's parameters, shown on the TTANH5 form, have been selected to give a smooth representation of the USSA profile, which actually has "corners." Figures 2.6b and 2.6c show the resulting temperature and sound-speed profiles. TTANH5 is a very flexible model that can be used to match virtually any temperature profile with linear segments that join smoothly.

Superimposed on the height-dependent background temperature model (TTANH5) are two "perturbations." One is expressed as a temperature perturbation (TBLOB2), and the other is expressed as a sound-speed perturbation (CBLOB2).

Refer now to the FORM TO SPECIFY INPUT DATA FOR ATMOSPHERIC TEMPERATURE-PERTURBATION MODEL TBLOB2 (Figure 2.7). This temperature-perturbation model is in general a three-dimensional blob with Gaussian cross sections in all three dimensions, centered at any latitude, longitude, and height. The formula is given on the TBLOB2 order form.

For the sample case, we suppress the vertical temperature dependence (by setting W_z=0), making the perturbation a vertical cylinder with Gaussian cross sections in the two horizontal dimensions. For the sample case, we locate the cylinder at longitude 50 km east and latitude 105 km north, and set its E-W (zonal) Gaussian width at 25 km and its N-S (meridional) width at 50 km. Its maximum fractional temperature perturbation is 0.5 (50%). Notice that the form allows us to specify some of the model parameters in various units (such as latitude in kilometers); the program will automatically convert to the units (radians, in this example) it uses for computations.

Refer next to the FORM TO SPECIFY INPUT DATA FOR SOUND-SPEED PERTURBATION MODEL CBLOB2 (Figure 2.8). This sound-speed perturbation model is of the same form as TBLOB2, and its formula is shown on the CBLOB2 order from. For the sample case, we center a 50% increase in sound speed at 125 km height, longitude 250 km east, and latitude 335 km north. The Gaussian widths are 25 km in height, 50 km N-S, and 25 km E-W.

Figure 2.9 shows sound-speed contours in a horizontal slice at 125 km height, and Figure 2.10 shows sound-speed contours in a vertical slice near the centers of the two perturbations. (The contour-plotting routine is also part of the supplementary program set.)

The final part of the atmospheric model specifies the method used to compute acoustic absorption parameters required by the dispersion-relation subroutine AWWWL. In the sample case, we use a viscosity/conductivity subroutine called MUARDC, which requires a model of pressure.

FORM TO SPECIFY INPUT DATA FOR
ATMOSPHERIC TEMPERATURE-PERTURBATION MODEL TBLOB2

An increase (or decrease) in temperature in a localized region that decays in a Gaussian manner in all three spatial directions.

$$T(r,\theta,\phi) = T_o(r,\theta,\phi)\ \{1 + \Delta\ \exp\left[-\left(\frac{z-z_o}{W_z}\right)^2 - \left(\frac{\theta-\theta_o}{W_\theta}\right)^2 - \left(\frac{\phi-\phi_o}{W_\phi}\right)^2\right]\}$$

$T_o(r,\theta,\phi)$ is the temperature specified by a temperature model. (r,θ,ϕ) are the coordinates of the ray point in an Earth-centered spherical polar coordinate system. $\theta_o = \pi/2 - \lambda_o$ and $z = r - r_e$, where r_e is the Earth radius. Specify--

the model check for subroutine TBLOB2 = 2.0 (W225)

the input data-format code = _____ (W226)

an input data-set identification number = 2.0 (W227)

an 80-character description for the temperature-perturbation model, including description of parameter values:

50% CYLINDRICAL INCREASE IN TEMPERATURE AT 105 KM N., 105 KM W

the strength of the increase (or decrease), Δ = 0.5 (W228)

the height of maximum effect, z_o = 100 km (W229)

the latitude of maximum effect, λ_o = 105 rad, deg, (km) N (W230)

the longitude of maximum effect, ϕ_o = -105 rad, deg, (km) E (W231)

the Gaussian width in height of the effect, W_z = 0 km (W232)*

the meridional width of the effect, W_θ = 50 rad, deg, (km) (W233)*

the zonal width of the effect, W_ϕ = 25 rad, deg, (km) (W234)*

OTHER MODELS REQUIRED: none.

---

* Setting W_z, W_θ, or W_ϕ = zero results in no space variation in that direction.

Figure 2.7. Sample of completed form to specify input data for atmospheric temperature perturbation model TBLOB2.

FORM TO SPECIFY INPUT DATA FOR SOUND-SPEED
PERTURBATION MODEL CBLOB2

An increase (or decrease) in sound speed in a localized region that decays in a Gaussian manner in all three spatial directions.

$$C^2(r,\theta,\phi) = C_o^2(r,\theta,\phi)\left(1 + \Delta \exp\left\{-\left(\frac{z-z_o}{W_z}\right)^2 - \left(\frac{\theta-\theta_o}{W_\theta}\right)^2 - \left(\frac{\phi-\phi_o}{W_\phi}\right)^2\right\}\right)$$

$C_o^2(r,\theta,\phi)$ is the square of the sound speed specified by a sound-speed model. (r,θ,ϕ) are the coordinates of the ray point in an Earth-centered spherical polar-coordinate system. $\theta_o = \pi/2 - \lambda_o$ and $z = r - r_e$, where r_e is the Earth radius.

Specify--

the model check for subroutine CBLOB2 = 2.0 (W175)

the input data-format code = _____ (W176)

an input data-set identification number = 2.0 (W177)

an 80-character description for the sound-speed perturbation model, including description of parameter values:

50% INCREASE IN SQ. SOUND SPEED AT 125 KM HT, 335 KM N, 125 KM E

the strength of the fractional increase (or decrease), Δ = 0.5 (W178)

the height of maximum effect, z_o = 125 km (W179)

the latitude of maximum effect, λ_o = 335 rad, deg, (km) N (W180)

the longitude of maximum effect, ϕ_o = 125 rad, deg, (km) E (W181)

the Gaussian width in height of the effect, W_z = 25 km (W182)*

the meridional width of the effect, W_θ = 50 rad, deg, (km) (W183)*

the zonal width of the effect, W_ϕ = 25 rad, deg, (km) (W184)*

OTHER MODELS REQUIRED: none.

---

* Setting W_z, W_θ, or W_ϕ = zero results in no space variation in that direction.

Figure 2.8. Sample of completed form to specify input data for sound-speed perturbation model CBLOB2.

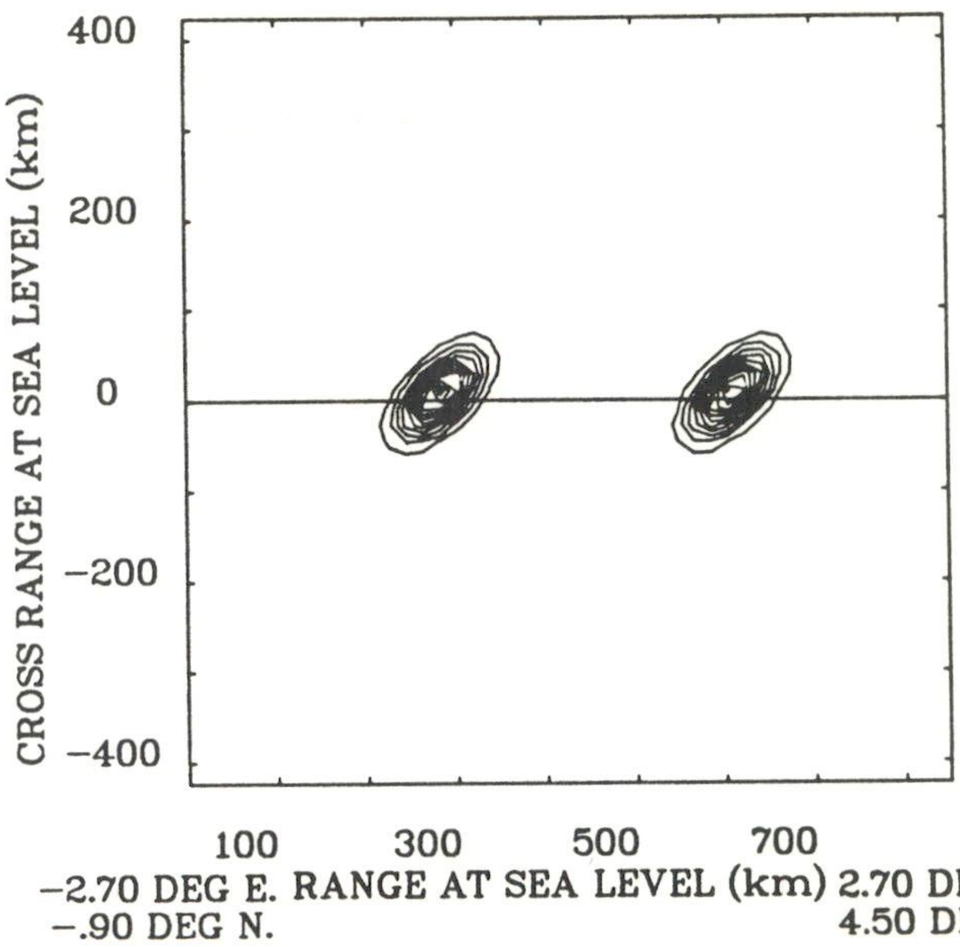


Figure 2.9. A plan view of the sound-speed contours in a horizontal slice through the sample-case atmospheric model at an altitude of 125 km above sea level. The contours show the perturbations caused by TBLOB2 (left) and CBLOB2 (right). The horizontal line across the center of the plot corresponds to the line L-R in Figure 2.18.

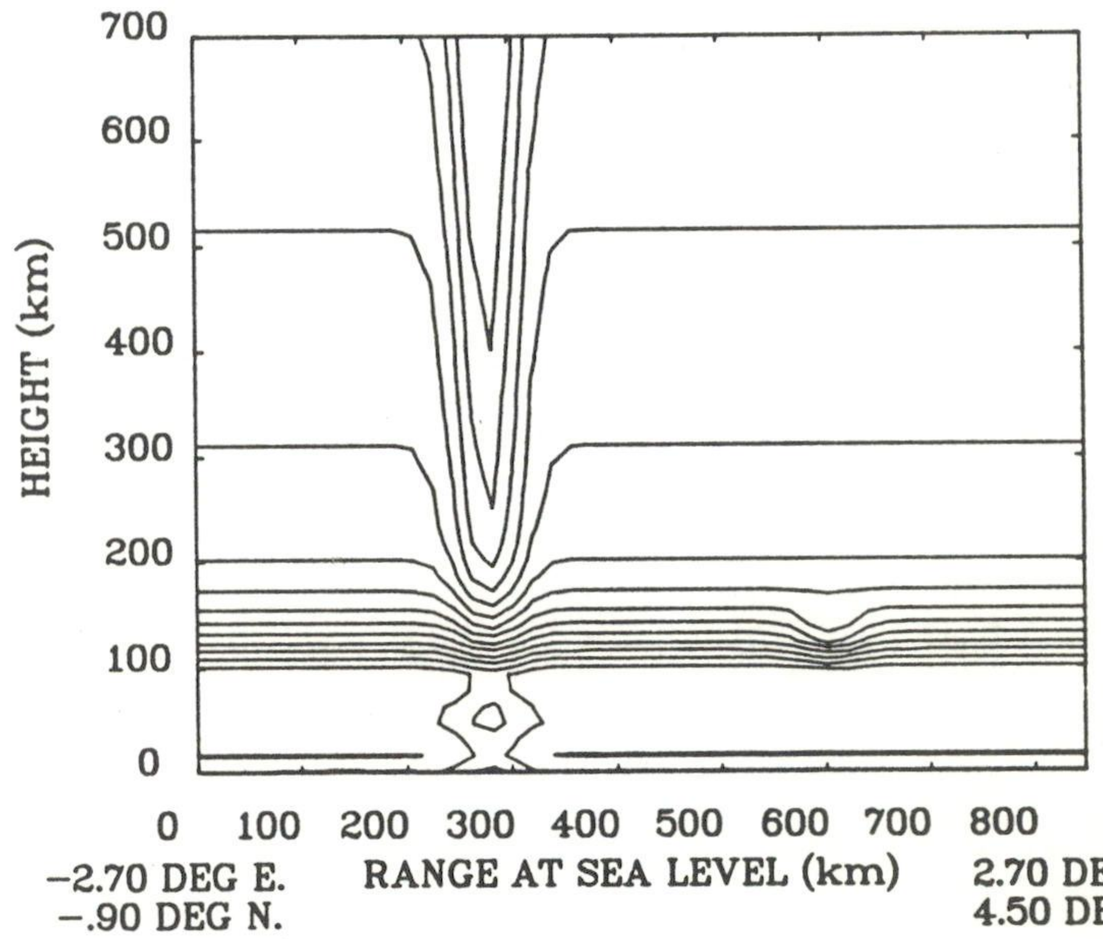


Figure 2.10. Sound-speed contours in a vertical slice through the sample-case model, showing the perturbations caused by models TBLOB2 (left) and CBLOB2 (right) to an otherwise horizontally stratified atmosphere. The plane of the figure corresponds to the line L-R in Figure 2.18.

Refer next to the FORM TO SPECIFY INPUT DATA FOR VISCOSITY/CONDUCTIVITY MODEL MUARDC (Figure 2.11). This model gives a formula (shown on the form) devised by the Air Research and Development Command (ARDC) (NOAA et al., 1976) for atmospheric viscosity and thermal conductivity. Its variable parameters are viscosity constant (β), Sutherland's constant (S), and Prandtl number (P_n). For the sample case, $\beta = 1.45 \times 10^{-6}$, S = 110.4, and P_n=.733.

Refer next to the FORM TO SPECIFY INPUT DATA FOR PRESSURE MODEL PEXP (Figure 2.12). This model specifies an exponential decrease of pressure with height. The variable parameters are the pressure p_0 at sea level (in Newtons per square meter) and the pressure scale height H (in kilometers). For the sample case, $p_0 = 1.01328 \times 10^5$, and H=8.5 km.

Refer next to the FORM TO SPECIFY INPUT DATA FOR TERRAIN MODEL GLORENZ (Figure 2.13). This terrain model superimposes a Lorentzian-shaped ridge on a spherical earth. The ridge, defined by the formula on the GLORENZ order form, runs along a latitude line chosen to be the equator for the sample case. The half width of the ridge is 30 km, and its height is 2 km.

This completes the specification òf the atmosphere (and terrain) model for the sample case. Now we specify what raypaths we want to calculate through this model.

2.2 The Ray-Tracing Order Form for the Sample Case

Refer now to the FORM TO SPECIFY INPUT DATA FOR A THREE-DIMENSIONAL RAYPATH CALCULATION (Figure 2.14). The form has been filled out with the values for the sample case. We want to transmit rays from a height 13 km above the earth's surface (as specified in the terrain model), at a latitude of 200 km north, and longitude of zero. The acoustic frequency is 0.05 Hz (infrasound), with no stepping in frequency. The azimuth angle of transmission is 45° (northeastward), with no stepping in azimuth. The elevation angle is stepped from -20° to +140° in steps of 5°. (If azimuth and frequency stepping were used, elevation-angle stepping would be performed first, then azimuth angle, then frequency.)

We want to keep track of ray intersections with a receiver surface 5 km above the terrain, and we want to stop tracing rays that go above 500 km alti-

FORM TO SPECIFY INPUT DATA FOR
VISCOSITY/CONDUCTIVITY MODEL MUARDC

This subroutine calculates the atmospheric molecular viscosity using the ARDC formula for viscosity and calculates atmospheric thermal conductivity from the value of viscosity using a Prandtl number specified by the user. This model is used only to calculate acoustic absorption when either AWWWL or ANWWL is used.

The ARDC formula for viscosity is (U.S. Standard Atmosphere, 1976, p. 19, NOAA, NASA, USAF, U.S. Government Printing Office, Washington, D.C., October 1976)

$$\mu = \beta\ T^{3/2}/(S+T)\ ,$$

where T is the atmospheric temperature in Kelvins.

The atmospheric thermal conductivity using the Prandtl approximation (e.g., Francis Weston Sears, Thermodynamics, Addison-Wesley, 1956, pp. 267-9) is

$$\kappa = \gamma\ R\mu/((\gamma-1)M\ Pr),$$

where γ is the ratio specific heats = 1.4,
R is the universal gas constant,
and M is the mean atmospheric molecular weight.
Specify --

the model check for subroutine MUARDC = 1.0 (W500)

the input data-format code = _____(W501)

an input data-set identification number = 1.0 (W502)

an 80-character description for the absorption model, including description of parameter values:

ARDC VISCOSITY/THERMAL CONDUCTIVITY MODEL

the viscosity constant, β = 1.458×10^{-6} kg s^{-1} m^{-1} $K^{-1/2}$ (W503)

(1.458×10^{-6} kg s^{-1} m^{-1} $K^{-1/2}$ suggested)

Sutherland's constant, S = 110.4 Kelvins (W504)

(110.4 Kelvins suggested)

Prandtl number, Pr = .733 (W505) (0.733 suggested)

OTHER MODELS REQUIRED: Any atmospheric temperature model and any atmospheric molecular weight model.

Figure 2.11. Sample of completed form to specify input data for viscosity/conductivity model MUARDC.

FORM TO SPECIFY INPUT DATA FOR
PRESSURE MODEL PEXP

This model is used only to calculate absorption when either AWWWL or ANWWL is used. The pressure is given by

$$P = P_0 \exp(-z/H),$$

where z is the height above sea level.

Specify --

the model check for subroutine PEXP = 1.0 (W550)

the input data-format code = _____ (W551)

an input data-set identification number = 1.0 (W552)

an 80-character description for the pressure model, including description of parameter values:

EXPONENTIAL PRESSURE MODEL, SCALE HEIGHT = 8.5 KM

the pressure at sea level, P_0 = 101328. Newtons/m^2 (W553)

(1.01328 × 10^5 Newtons/m^2 suggested)

the pressure scale height, H = 8.5 (km) m (W554)

OTHER MODELS REQUIRED: Any pressure-perturbation model. Use NPPRES if no perturbation is desired.

Figure 2.12. Sample of completed form to specify input data for pressure model PEXP.

FORM TO SPECIFY INPUT DATA FOR
TERRAIN MODEL GLORENZ

An east-west Lorentzian-shaped ridge.

$$g(r,\theta,\phi) = h - z \ ,$$

where $$h = r - r_e \ ,$$

$$z = z_o/(1 + ((\theta-\theta_o)/\Delta\theta)^2) + z_B \ ,$$

$$\theta_o = \pi/2 - \lambda_o \ ,$$

and r_e is the radius of the Earth.

Specify--

the model check number for GLORENZ = 4.0 (W300)

the input data-format code number = _____ (W301)

the input data-set identification number = 2.0 (W302)

an 80-character description of the model including parameters:

RIDGE 2-KM HIGH, 30-KM WIDE ALONG EQUATOR

the height of the ridge, z_o = 2 (km), m (W303)

the latitude of the ridge center, λ_o = 0 rad, deg, km (W304)

the half-width of the ridge, $\Delta\theta$ = 30 rad, deg, (km) (W305)

base of the ridge (negative if below sea level) z_B = 0 m, km (W306)

OTHER MODELS REQUIRED: Any terrain-perturbation model. Use NPTERR if no perturbation is desired.

Figure 2.13. Sample of completed form to specify input data for terrain model GLORENZ.

FORM TO SPECIFY INPUT DATA FOR A
THREE-DIMENSIONAL RAYPATH CALCULATION

Name _____
Date 2-10-86

Atmospheric ID (3 characters) S03

Title (77 characters) SAMPLE CASE FOR HARPA DOCUMENTATION

Transmitter: Height
- 13 (km) nm, ft (W3)
- ✓ above terrain
- _____ above sea level

Latitude: 200 rad, deg, km (W4)
Longitude: 0 rad, deg, km (W5)
Frequency, initial: .05 rad/s, Hz, s (W7)
final: _____ (W8)
step: _____ (W9)
Azimuth angle, initial: 45 rad, (deg) clockwise of north (W11)
final: _____ (W12)
step: _____ (W13)
Elevation angle, initial: -20 rad, (deg) (W15)
final: 140 (W16)
step: 5 (W17)

Receiver: Height
- 5 (km), nm, ft (W20)
- _____ above sea level (rcvr model RHORIZ)
- ✓ above terrain (rcvr model RTERR)

Distance from origin: _____ rad, deg, km (W30) (rcvr model RVERT)
Latitude of origin: _____ rad, deg, km (W31) (rcvr model RVERT)
Longitude of origin: _____ rad, deg, km (W32) (rcvr model RVERT)

Stop frequency stepping when ray goes out of bounds: 0 (W21 = 1.)
Maximum height: 500 km (W26)
Minimum height: -1 km (W27)
Maximum range: 1000 km (W28)
Maximum number of hops: 3 (W22)
Maximum number of steps per hop: 1000 (W23)
Maximum allowable error per step: 10^{-6} (W42)

Additional calculations:
= 1. to integrate
= 2. to integrate and print

Phase path: 2 (W57)
Absorption: 2 (W58)
Doppler shift: _____ (W59)
Path length: 2 (W60)

Printout: Every 50 steps of the ray trace (W71)

Computer readable output (raysets): 1 (W72 = 1.)
Diagnostic printing: _____ (W73 = 1.)
Suppress all printout: _____ (W74 = 1.)

Figure 2.14. Sample of completed form to specify input data for a three-dimensional raypath calculation.

tude, 1 km below the terrain (all rays should reflect from the terrain surface, however), or beyond 1000-km range. We want to stop the ray trace after 3 hops, a hop being defined as an intersection with the receiver surface.

Because we have selected a receiver surface at a fixed height above the terrain, we also fill out the FORM TO SPECIFY INPUT DATA FOR RECEIVER-SURFACE MODEL RTERR, as shown in Figure 2.15.

We set the maximum number of steps per hop to 1000 (usually a large number that we don't expect to be exceeded under normal conditions but which guards against accidents). We set the maximum allowable integration error per step to 10^{-6}, which means that integrated quantities (that vary monotonically) are computed with at least that relative accuracy. We want to integrate and print phase path, path length, and absorption, but not to calculate Doppler shift (zero for the sample case, which has no time-dependent models). The printed output will display the raypath status every 50th step, in addition to printing at special events, such as reflections, apogees (turnovers), and perigees. Machine-readable "raysets" will also be produced.

2.3 Rayplot Order Form for the Sample Case

Two kinds of raypath plots are available and are specified for the sample case on the FORM TO SPECIFY INPUT PARAMETERS FOR PLOTTING A PROJECTION OF THE RAYPATH (Figures 2.16 and 2.17). The same form is used twice: once for a projection of raypaths on a vertical plane and once for a projection on a horizontal plane.

The vertical plane is specified by the geographic coordinates of its left and right edges and the height above ground of the bottom of the graph. In the sample case, we want the left edge to be at latitude -100 km (south) and longitude -300 km (west); the right edge is to be at latitude 500 km (north), longitude 300 km (east). Thus, the plane of the vertical projection coincides with the plane of initial ray transmission. The bottom of the graph is to be at ground level. We specify tick marks every 100 km, and we want registration marks (the top of the graph) at 300 km height.

The horizontal projection plane is specified by the location of the centers of its left and right edges. For the sample case, we select the left and

FORM TO SPECIFY INPUT DATA
FOR RECEIVER-SURFACE MODEL RTERR

A receiver-surface model in which the receiver surface is a fixed height above the terrain surface.

$$f(r,\theta,\phi) = g(r,\theta,\phi) + z_R$$

$$\frac{\partial f}{\partial r} = \frac{\partial g}{\partial r}\ ,\ \frac{\partial f}{\partial \theta} = \frac{\partial g}{\partial \phi}\ ,\ \frac{\partial f}{\partial \phi} = \frac{\partial g}{\partial \phi}\ ,$$

where $g(r,\theta,\phi)$ and its derivatives are specified in common block /GG/ by the terrain model.

Specify--

the model check number for subroutine RTERR = 3.0 (W275)

the input data-format code number = _____ (W276)

an 80-character description of the model including parameters:

RECEIVER SURFACE 5 KM ABOVE TERRAIN

the height of the receiver surface above the terrain, z_R = 5 km (W20)

OTHER MODELS REQUIRED: Any terrain model.

Figure 2.15. Sample of completed form to specify input data for receiver-surface model RTERR.

FORM TO SPECIFY INPUT PARAMETERS FOR PLOTTING A
PROJECTION OF THE RAYPATH

Model ID: S03

Plot directly during raypath calculations ✓, or

plot from precomputed raypaths _____

in disk file _____

Normal or apogee plots:

Normal ✓ (W80=0.0)

Plot apogees only _____ (W80=1.0)

Projection:

Vertical plane, polar plot, rectangular expansion ✓ (W81=1.0)

Horizontal plane, lateral expansion _____ (W81=2.0)

Vertical plane, polar plot, radial expansion _____ (W81=3.0)

Vertical plane, rectangular plot _____ (W81=4.0)

Superimpose these raypath plots on the graph of the previous runset:

Yes _____ (W81 negative.)

No ✓ (W81 positive.)

Vertical or lateral expansion factor 1 (W82)

Coordinates of the left edge of the graph:

Latitude = -100 (rad, deg, (km)) north (W83)

Longitude = -300 (rad, deg, (km)) east (W84)

Coordinates of the right edge of the graph:

Latitude = 500 (rad, deg, (km)) north (W85)

Longitude = 300 (rad, deg, (km)) east (W86)

Distance between horizontal tick marks = 100 rad, deg, (km) (W87)

Height above sea level of bottom of graph = 0 km (W88)

Height above sea level of top of graph = 300 km (W89)

Distance between vertical tick marks = 100 km (W96)

Figure 2.16. Sample of completed form to specify input parameters for plotting a projection of the raypath.

FORM TO SPECIFY INPUT PARAMETERS FOR PLOTTING A PROJECTION OF THE RAYPATH

Model ID: S03

Plot directly during raypath calculations ✓, or

plot from precomputed raypaths _____

in disk file _____

Normal or apogee plots:

Normal ✓ (W80=0.0)

Plot apogees only _____ (W80=1.0)

Projection:

Vertical plane, polar plot, rectangular expansion _____ (W81=1.0)

Horizontal plane, lateral expansion ✓ (W81=2.0)

Vertical plane, polar plot, radial expansion _____ (W81=3.0)

Vertical plane, rectangular plot _____ (W81=4.0)

Superimpose these raypath plots on the graph of the previous runset:

Yes _____ (W81 negative.)

No ✓ (W81 positive.)

Vertical or lateral expansion factor 3 (W82)

Coordinates of the left edge of the graph:

Latitude = -100 (rad, deg, (km)) north (W83)

Longitude = -300 (rad, deg, (km)) east (W84)

Coordinates of the right edge of the graph:

Latitude = 500 (rad, deg, (km)) north (W85)

Longitude = 300 (rad, deg, (km)) east (W86)

Distance between horizontal tick marks = 100 rad, deg, (km) (W87)

Height above sea level of bottom of graph = _____ km (W88)

Height above sea level of top of graph = _____ km (W89)

Distance between vertical tick marks = _____ km (W96)

Figure 2.17. Sample of completed form to specify input parameters for plotting a projection of the raypath.

right edges of the horizontal plot to coincide with the coordinates of the left and right edges of the vertical plot, as specified above.

Figure 2.18 shows a plan view of the region of the earth's surface near latitude zero, longitude zero, including the transmitter location, the ray-launch azimuth, the locations of the centers of the CBLOB2 and TBLOB2 perturbations, the ridge along the equator, and the locations of the left and right edges of the two plot projections.

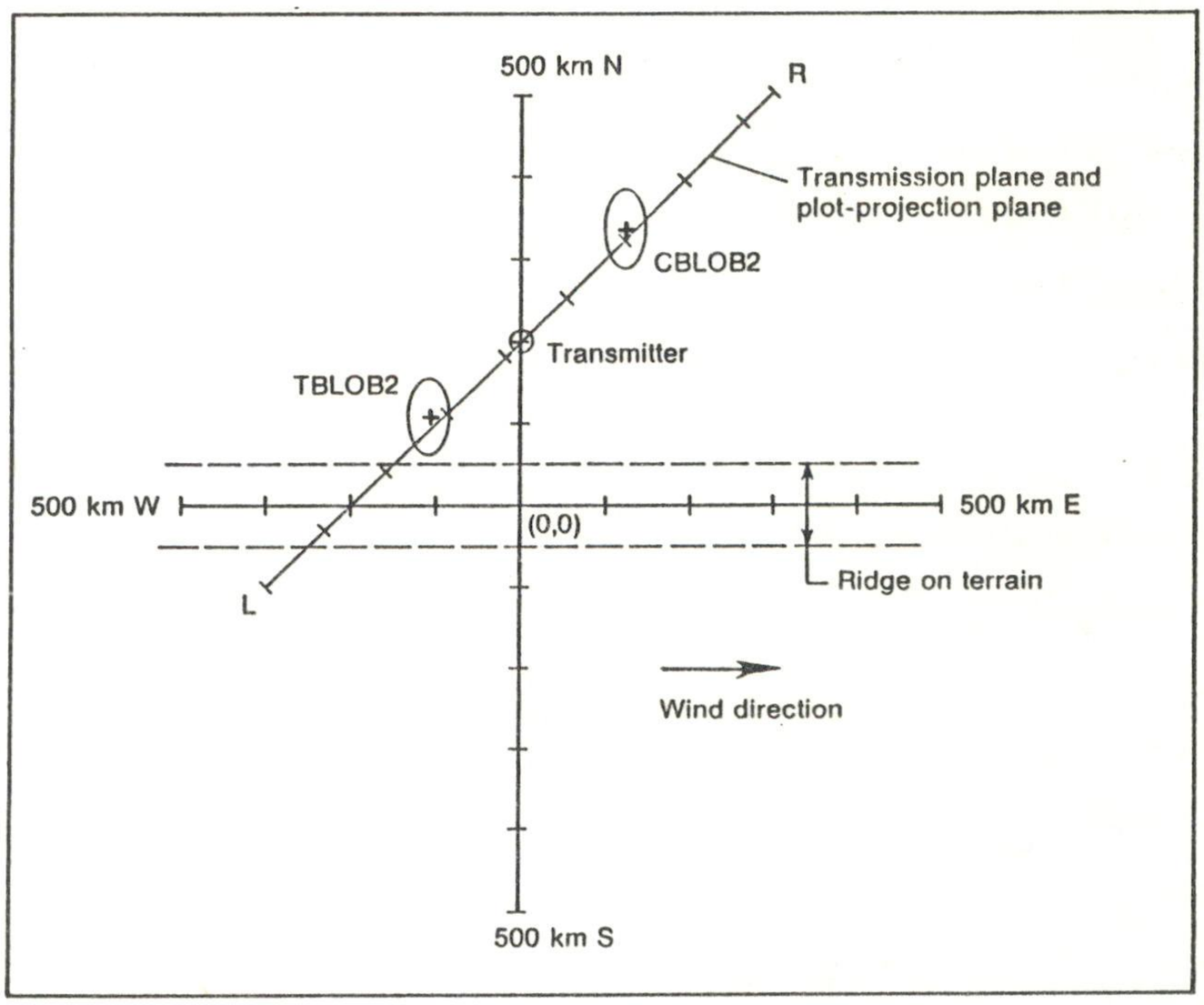


Figure 2.18. Plan view of the major features of the sample-case model, the transmitter location, the transmission direction, and the plot-projection plane.

2.4 Setting Up the Input Data File (W Array) for the Sample Case

Now that we have defined all the parameters needed to specify the atmospheric model, the raypaths desired, as well as the printed, plotted and machine-readable output, we can look at the form in which these input data are communicated to HARPA. To run HARPA, you have to create a file like the one shown for the sample case in Figure 2.19. (Such a file for the sample case comes with the program.) HARPA reads this file into an array named W(n), where n, the array subscript, is the first value on each line (columns 1-3), and W(n) is the second value on each line (columns 4-17).

The values of n corresponding to each input parameter are indicated on each of the input parameter forms we have just looked at. You will notice that not all values of n are listed in the input table for the sample case; those not explicitly defined in the Input Data File assume an initial value that is usually (but not always) zero. The initialization scheme is explained in Section 5.3.1.

Besides the values of n and W(n), the figure contains in columns 18-24 provisions for unit conversion on input, that is, for entering data in various units. For example, the notation AN KM means that angular data has been entered in kilometers and will be converted to radians by the program. For W(3), the height of the transmitter, a T in column 17 converts the height specified to height above the terrain model. Finally, in columns 25-80, descriptive comments identify the data for easy data entry.

There are special values of n (such as zero or negative values) that contain instructions for reading what follows. They will be described in detail in Chapter 5. A negative number in columns 1-3 indicates that tabular or text data follow. A zero in columns 1-3 indicates the end of tabular data or the end of a "run set," the name we give to the input data for a set of ray calculations. For example, the rays for one run set will all appear on a single rayplot. A new run set is necessary to create different plots or to change model parameters. In Figure 2.19, new run sets start with the lines that begin with "S03." For the sample case, each of the two run sets generates a different plot projection of the raypaths through the same atmospheric model. Only the W values that change from the previous run set need be specified; the others remain unchanged.

For now, you need only be aware of this tabular procedure for entering data into HARPA; it would also be instructive to verify that the values entered into the order forms for the sample case correspond to the entries in the W(n) Input Data File.

When you run the program with this input data set, three kinds of output will be produced: a step-by-step printed account of each ray's progress, plots of the raypaths on vertical and horizontal planes, and machine-readable data, including "raysets."

```
col.     col.      col.        col.
1-3      4-17      18-24       25-80
 n       W(n)      UNITS       DESCRIPTION
```

```
GEORGES     RB3    X6437
S03-1     SAMPLE CASE FOR HARPA DOCUMENTATION        REV. 2-10-86
  1      6370.              EARTH RADIUS, KM (6370.)
  3        13.             TTRANSMITTER HEIGHT, KM (T=ABOVE TERRAIN)
  4       200.     AN KM    N. TRANSMITTER LATITUDE, KM
  5         0.     AN KM    E. TRANSMITTER LONGITUDE, KM
  7       .05      FQ HZ    INITIAL FREQUENCY, HZ
 11        45.     AN DG    INITIAL AZIMUTH ANGLE, DEG
 15       -20.     AN DG    INITIAL ELEVATION ANGLE, DEG
 16       140.     AN DG    FINAL   ELEVATION ANGLE, DEG
 17         5.     AN DG    STEP IN ELEVATION ANGLE, DEG
 20         5.              RECEIVER HEIGHT, KM
 22         3.              MAXIMUM NUMBER OF HOPS (1.0)
 23      1000.              MAXIMUM NUMBER OF STEPS PER HOP (1000.)
 26       500.              MAXIMUM RAY HEIGHT, KM (500.)
 27        -1.              MINIMUM RAY HEIGHT, KM
 28      1000.              MAXIMUM RANGE, KM
 29  0000100.              DO: EIGRAY/RNG-TIM/RNG-ELV/NEW-PROJ/RAYTRC/CONT/PROF
 33   999.999               MAXIMUM ABSORPTION, DB (999.999)
 42         1.0E-6          SINGLE-STEP INTEGRATION ERROR (1.0E-4)
 44         .1              INITIAL INTEGRATION STEP SIZE, KM (1.0)
 57         2.              PHASE PATH (0=NO; 1=INTEGRATE; 2=INTEGRATE/PRINT)
 58         2.              ABSORPTION (0=NO; 1=INTEGRATE; 2=INTEGRATE/PRINT)
 60         2.              PATH LENGTH (0=NO; 1=INTEGRATE; 2=INTEGRATE/PRINT)
 71        50.              NUMBER OF INTEGRATION STEPS PER PRINT [1.E31]
 72         1.              OUTPUT RAYSETS (1=YES; 0=NO)
 73         0.              DIAGNOSTIC PRINTOUT (1=YES; 0=NO)
 74         0.              PRINT RAY STEPS (0=YES; 1=NO)
 75        .15              FULANN LETTER HEIGHT [0.15 IN]
 76         0.              BINARY RAY OUTPUT (1=YES; 0=NO)
 77        57.              LINES PER PAGE IN PRINTOUT (66.)
 81         1.              RAYPLOT PROJECTION (1=VERT; 2=HORIZ) PLANE
 82         1.              PLOT-EXPANSION FACTOR [1.0]
 83      -100.     AN KM    N. LATITUDE  OF LEFT PLOT EDGE, KM
 84      -300.     AN KM    E. LONGITUDE OF LEFT PLOT EDGE, KM
 85       500.     AN KM    N. LATITUDE  OF RIGHT PLOT EDGE, KM
 86       300.     AN KM    E. LONGITUDE OF RIGHT PLOT EDGE, KM
 87       100.     AN KM    DISTANCE BETWEEN TIC MARKS, KM
 88         0.              HEIGHT ABOVE SEA LEVEL OF BOTTOM OF GRAPH, KM
 89       300.              HEIGHT ABOVE SEA LEVEL OF TOP OF GRAPH, KM
 96       100.              DISTANCE BETWEEN VERTICAL TIC MARKS, KM
100         6.              ULOGZ2 WIND MODEL CHECK NUMBER
102         3.               BACKGROUND WIND DATA SET ID
103         5.     LN  M     REFERENCE WIND SPEED, M/S
104        35                VON KARMAN'S CONSTANT
105         1.               ROUGHNESS HEIGHT, KM
150         1.              GAMRTDM SOUND SPEED MODEL CHECK NUMBER
175         2.              CBLOB2 MODEL CHECK NUMBER
177         2.               SOUND SPEED PERTURBATION DATA SET ID
178        .5                FRACTIONAL INCREASE OF SQUARED SOUND SPEED
```

Figure 2.19. Input Data File for the sample case.

```
179       125.                HEIGHT OF MAXIMUM INCREASE, KM
180       335.     AN KM      N. LATITUDE OF MAXIMUM INCREASE, KM
181       125.     AN KM      E. LONGITUDE OF MAXIMUM INCREASE, KM
182        25.                GAUSSIAN WIDTH IN HEIGHT OF INCREASE, KM
183        50.     AN KM      N-S WIDTH OF THE INCREASE, KM
184        25.     AN KM      E-W WIDTH OF THE INCREASE, KM
200         7.               TTANH5 TEMPERATURE MODEL CHECK NUMBER
202         1.                BACKGROUND TEMPERATURE DATA SET ID
225         2.               TBLOB2 MODEL CHECK NUMBER
227         2.                TEMPERATURE PERTURBATION DATA SET ID
228         .5                FRACTIONAL TEMPERATURE INCREASE
229         0.                HEIGHT OF MAXIMUM INCREASE, KM
230       105.     AN KM      N. LATITUDE OF MAXIMUM INCREASE, KM
231      -105.     AN KM      E. LONGITUDE OF MAXIMUM INCREASE, KM
232         0.                GAUSSIAN WIDTH IN HEIGHT OF INCREASE, KM
233        50.     AN KM      N-S WIDTH OF THE INCREASE, KM
234        25.     AN KM      E-W WIDTH OF THE INCREASE, KM
250         1.               MCONST MOLECULAR WEIGHT MODEL CHECK NUMBER
252        29.                MOLECULAR WEIGHT DATA SET ID
253        29.                MOLECULAR WEIGHT
275         2.               RTERR RECEIVER MODEL CHECK NUMBER
300         4.               GLORENZ TERRAIN MODEL CHECK NUMBER
302         2.                TERRAIN MODEL DATA SET ID
303         2.                HEIGHT OF THE RIDGE, KM
304         0.                N. LATITUDE OF THE RIDGE CENTER
305        30.     AN KM      HALF-WIDTH OF THE RIDGE, KM
325         0.               NPTERR NO TERRAIN PERTURBATION
500         1.               MUARDC VISC/COND MODEL CHECK NUMBER
502         1.                VISC/COND MODEL DATA SET ID
503     1.458E-06             VISCOSITY COEFFICIENT BETA
504     110.4                 SUTHERLAND'S CONSTANT, KELVINS
505      .733                 PRANDTL NUMBER
525         0.               NPABS NO VISC/COND PERTURBATION
550         1.               PEXP PRESSURE MODEL CHECK NUMBER
552         1.                BACKGROUND PRESSURE MODEL DATA SET ID
553    101328.                PRESSURE AT SEA LEVEL, N/SQ.M.
554       8.5                 PRESSURE SCALE HEIGHT, KM
575         0.               NPPRES   NO PRESSURE PERTURBATION
 -1                          DATA SUBSET FOR BACKGROUND WIND MODEL
  A  LOGARITHMIC EASTWARD WIND PROFILE, U*=.5 M/S, Z0=1 KM
  0      RETURN TO W ARRAY DATA SET
 -2                          DATA SUBSET FOR WIND PERTURBATION MODEL
 A  NO WIND PERTURBATION
 0      RETURN TO W ARRAY DATA SET
 -3                          DATA SUBSET FOR BACKGROUND SOUND-SPEED MODEL
 A  SOUND SPEED IN TERMS OF TEMPERATURE MODEL
 0      RETURN TO W ARRAY DATA SET
 -4                          DATA SUBSET FOR SOUND-SPEED PERTURBATION MODEL
 A  50% INCREASE IN SQ. SOUND SPEED AT 125KM HT, 335KM N, 125KM E
 0      RETURN TO W ARRAY DATA SET
 -5                          DATA SUBSET FOR TEMPERATURE MODEL
 A  U.S. STANDARD ATMOSPHERE 1962 TEMPERATURE PROFILE
 3     999.0
 LN KM                       LN KM
  0.           288.000        0.
```

Figure 2.19. Input Data File (continued).

```
 15.0000       190.500       10.0000
 52.0000       320.000        7.50000
 95.0000       191.000       10.0000
165.0000      1451.000       50.0000
300.0000      1586.000        0.
999.0000
 0       RETURN TO W ARRAY DATA SET
-6                          DATA SUBSET FOR TEMPERATURE PERTURBATION MODEL
 A  50% CYLINDRICAL INCREASE IN TEMPERATURE AT 105KM N., 105 KM W
 0       RETURN TO W ARRAY DATA SET
-7                          DATA SUBSET FOR MOLECULAR WEIGHT MODEL
 A  MOLECULAR WEIGHT = 29
 0       RETURN TO W ARRAY DATA SET
-8                          DATA SUBSET FOR RECEIVER SURFACE MODEL
  A  RECEIVER SURFACE 5 KM ABOVE TERRAIN
  0       RETURN TO W ARRAY DATA SET
 -9                         DATA SUBSET FOR TERRAIN MODEL
  A  RIDGE 2-KM HIGH, 30-KM WIDE ALONG EQUATOR
  0       RETURN TO W ARRAY DATA SET
-10                         DATA SUBSET FOR TERRAIN PERTURBATION MODEL
  A  NO TERRAIN PERTURBATION
  0       RETURN TO W ARRAY DATA SET
-17                         DATA SUBSET FOR VISC/COND MODEL
  A  ARDC VISCOSITY AND THERMAL CONDUCTIVITY MODEL
  0       RETURN TO W ARRAY DATA SET
-18                         DATA SUBSET FOR VISC/COND PERTURBATION MODEL
  A  NO VISCOSITY/CONDUCTIVITY PERTURBATION
  0       RETURN TO W ARRAY DATA SET
-19                         DATA SUBSET FOR BACKGROUND PRESSURE MODEL
  A  EXPONENTIAL PRESSURE MODEL, SCALE HEIGHT = 8.5 KM
  0       RETURN TO W ARRAY DATA SET
-20                         DATA SUBSET FOR PRESSURE PERTURBATION MODEL
  A  NO PRESSURE PERTURBATION
  0       RETURN TO W ARRAY DATA SET
  0                         **********  END OF RUN SET NUMBER 1  **********
S03-2     SAMPLE CASE FOR HARPA DOCUMENTATION          REV. 2-10-86
 71         0.              NUMBER OF INTEGRATION STEPS PER PRINT
 72         0.              OUTPUT RAYSETS  (1=YES; 0=NO)
 73         1.              DIAGNOSTIC PRINTOUT (1=YES; 0=NO)
 81         2.              RAYPLOT PROJECTION (1=VERT; 2=HORIZ) PLANE
 82         3.              PLOT-EXPANSION FACTOR
 0                          **********  END OF RUN SET NUMBER 2  **********
```

Figure 2.19. Input Data File (continued).

2.5 Printed Output for the Sample Case

Appendix A shows the complete printed output, or "printout," for the sample case. Sections 2.5.1 and 2.5.2 define the terms and quantities used in the printout.

Page 1 of the printout contains the program title block and a list of all the models used for the first run set. The model list includes subroutine names, a number identifying the set of parameters defining that particular model, and comments describing each model.

Pages 2-4 of the printout reproduce the Input Data File for run set number 1.

Page 5 of the printout is a list of n and W(n) for all nonzero W(n). The values of W(n) have been converted to the units used by the program; for example, angles (like latitude and longitude) input in kilometers have been converted to radians. The standard set of units used by the program are: angles in radians, distances in kilometers, and frequency in radians per second.

Pages 6-10 of the printout are in a columnar format that gives a step-by-step account of each ray's progress, with each line showing important raypath quantities at user-specified intervals along the raypath. The meanings of the quantities printed out are explained in Section 2.5.1. The user can specify how often along the ray a line is printed (we specified every 50 integration steps). In addition, a line is printed out every time a ray experiences a "special event," such as a ground reflection, a turnover (apogee) or turnunder (perigee), crosses the receiver height, or a few other events. Section 2.5.2 explains the exact meanings of all the special events.

Each ray calculation terminates when one of the termination conditions is met, such as the maximum number of hops, maximum range, or maximum number of integration steps, whichever occurs first. In the sample case, all of the rays terminate either because they reached the maximum number of hops specified (3) or because the absorption reached the maximum specified. At the end of each ray calculation, the printout shows how much CPU time was used for that ray computation (2.009 s, in this case).

Look at page 1 of the printout in Appendix A. Verify that the models indicated at the bottom of the page coincide with those we specified as input. Verify that the wave frequency and initial azimuth and elevation angles on page 6 are what we want. Look down the first (ERROR) column of the tabular printout (page 6) and verify that none of the numbers in this column exceeds the maximum allowable single-step integration error, W(42), which for the sample case is 10^{-6}. This means that the numerical integration is proceeding correctly.

Look at the first entries in the ELEVATION columns and verify that the ray starts at the correct height above the terrain (13.00 km in this case), as well as the correct height above sea level (slightly more than 13 km in this case, because of the terrain model). The RANGE column should begin with zero range from the transmitter and indicate the range from the transmitter with successive steps.

A general idea of the sequence of events along this ray can be read in the EVENT column. These notations mark the special events along the raypath, which cause printout regardless of the step number. Reading down this column, we see that this ray begins at the transmitter (XMTR), then crosses the receiver (RCVR) height at 5 km altitude above the terrain, then reflects from the ground (GRND REF), passes through the receiver (RCVR) height once again, then executes an APOGEE, or turnover, and stops when it reaches the receiver height (RCVR) a third time. The ray stopped because we specified a maximum of three hops, or intersections with the receiver height (MAX HOPS).

The numbers in the AZIMUTH DEVIATION columns indicate that the ray deviates from the azimuth of transmission because of the wind. The ELEVATION ANGLE columns show changes in the local wave-normal direction and the elevation of the ray point measured from the transmitter.

PULSE TIME gives the time for a pulse or wave packet to reach that point, and PHASE TIME gives the time for a wave phase front to reach that point. The wave phase can be derived from PHASE TIME by multiplying by the wave frequency in appropriate units (cycles per second to get wave phase in cycles, etc.) and removing the integer part. The PATH LENGTH gives the physical length of the ray path.

The second run set shown in the sample-case printout uses the same initial ray conditions, but it changes the rayplot to a horizontal projection, and it adds diagnostic printout that can be useful for studying the details of terrain or receiver-surface intersections.

2.5.1 Definitions of Quantities Listed in Printout (Appendix A)

AZIMUTH ANGLE OF TRANSMISSION -- Azimuth angle (degrees clockwise from north) of the initial ray-launch direction.

ELEVATION ANGLE OF TRANSMISSION -- Elevation angle (degrees upward) between the initial ray-launch direction and local horizontal at the transmitter.

TRANSMITTER LATITUDE -- East latitude of the transmitter in geographic coordinates.

TRANSMITTER LONGITUDE -- North longitude of the transmitter in geographic coordinates.

FREQUENCY -- Acoustic wave frequency in hertz.

SINGLE-STEP ERROR -- Maximum allowable single-step integration error.

ERROR -- Normalized difference between the wave number k computed by numerical integration and k computed from the dispersion relation [Eq. (6.32)].

EVENT -- Nature of special event along the raypath (see Sec. 2.5.2).

HEIGHT -- Height of the ray point above sea level (or above the terrain).

RANGE -- Great-circle distance, measured at sea level between the transmitter and the ray point.

AZIMUTH DEVIATION (XMTR) -- Azimuth angle of the direction of transmission in degrees clockwise from the great circle between the transmitter and the ray point.

AZIMUTH DEVIATION (LOCAL) -- Azimuth angle of the wave normal in degrees clockwise from the great circle between the transmitter and the ray point.

ELEVATION (XMTR) -- Elevation angle (degrees) of the ray point from local horizontal at the transmitter.

ELEVATION (LOCAL) -- Elevation angle (degrees) of the wave normal from the local horizontal at the ray point.

PULSE TIME -- The time (seconds) required for a wave packet (pulse) to travel from the transmitter to the ray point (Sec. 6.1).

PHASE TIME -- The time (seconds) required for a wave front to travel from the transmitter to the ray point (Sec. 6.1.1).

ABSORPTION -- Decrease in acoustic intensity (dB) from the transmitter to the ray point caused by atmospheric dissipation only (Sec. 6.1.2).

PATH LENGTH -- Geometric length of the ray path (kilometers) from the transmitter to the ray point (Sec. 6.1.3).

2.5.2 Meanings of Special Events Along a Raypath

XMTR -- Ray is at the transmitter.

RCVR -- Ray is at the receiver surface.

GRND REF -- Ray has reflected from the terrain surface.

APOGEE -- Ray has passed through a maximum in height.

PERIGEE -- Ray has passed through a minimum in height.

WAVE REV -- Vertical, southward, or eastward component of the wave vector has changed sign.

MAX LAT -- Ray has passed through a maximum (or minimum) in latitude.

MAX LONG -- Ray has passed through a maximum (or minimum) in longitude.

EXTINC -- Absorption has exceeded the maximum allowable.

MAX HOP -- Ray has executed the requested number of hops (receiver-surface crossings).

MAX RANG -- Ray has exceeded the maximum allowable ground range.

MAX HT -- Ray has exceeded the maximum allowable height.

MIN HT -- Ray has gone below the minimum allowable height.

MIN DIST -- Ray has made a closest approach to the receiver surface.

ADDITIONAL EVENTS IN DIAGNOSTIC PRINTOUT

BACK UP0 -- At call to subroutine BACKUP.

BACK UP1 -- Before each numerical integration step in subroutine BACKUP.

GRAZE 0 -- At call to ENTRY point GRAZE in subroutine BACKUP.

GRAZE 1 -- Before each numerical integration step after ENTRY point GRAZE.

BACK UP2 -- After unsuccessfully trying to find a closest approach to the receiver surface.

BACK UP3 -- Before each numerical integration step after BACK UP2.

2.6 Rayplots for the Sample Case

We requested two rayplots, a projection on a vertical plane and a projection on a horizontal plane. These two plots are shown in Figures 2.20 and 2.21. Because we selected the FULANN (full annotation) option in W(75), we have produced a plot with publication-quality lettering. This capability requires the DISSPLA plotting package.

Rayplots are often the most useful output from a ray-tracing program, particularly when the medium is complicated. Depending on the user's plotting and display facilities, rayplots can be produced on paper, microfilm, or video displays.

Because the atmospheric and terrain models used in the sample case cause the acoustic raypaths to behave in complicated ways, a few features of the two rayplot projections call for some explanation. Figure 2.18 shows how the planes of these plots are related to the transmitter location and the features of the atmospheric and terrain models. The letters L and R show the locations of the left and right edges of the two plots; the line connecting the L and R represents the plane of the vertical projection (Figure 2.20) as well as the line across the center of the horizontal projection (Figure 2.21).

The two rayplots show the gross refracting features of this atmospheric model, namely that the temperature gradient bends upgoing rays back toward the ground, and that the eastward wind deflects rays generally downwind. The wind direction is to the right in Figure 2.20 (though not in the plane of the plot) and is down and to the right in Figure 2.21. In the absence of wind, the rays shown in Figure 2.21 would all be coplanar and so would appear as a single straight, horizontal line in that projection, and the plot of Figure 2.20 would exhibit left-right symmetry. By comparing corresponding rays in Figures 2.20 and 2.21, one can get a rough three-dimensional perspective of the raypaths.

The effects of the ridge in the terrain model are not evident in the scales of these plots because the ridge is only 2 km high. The peak of the

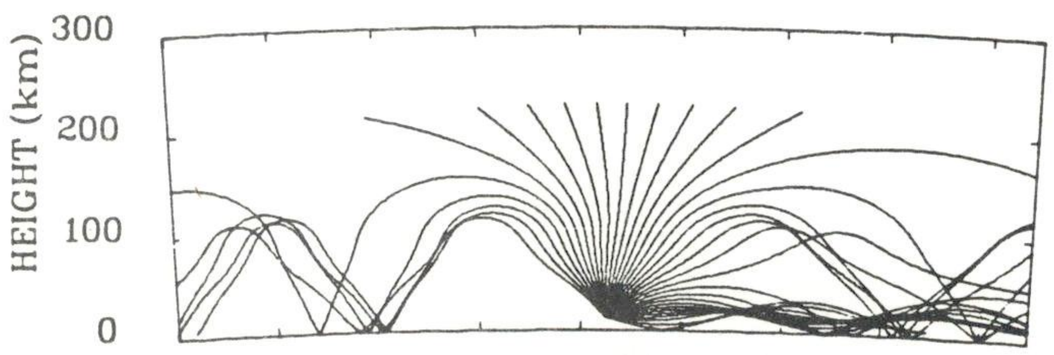


Figure 2.20. Projection of the rays of the sample case onto the vertical plane shown in Figure 2.18.

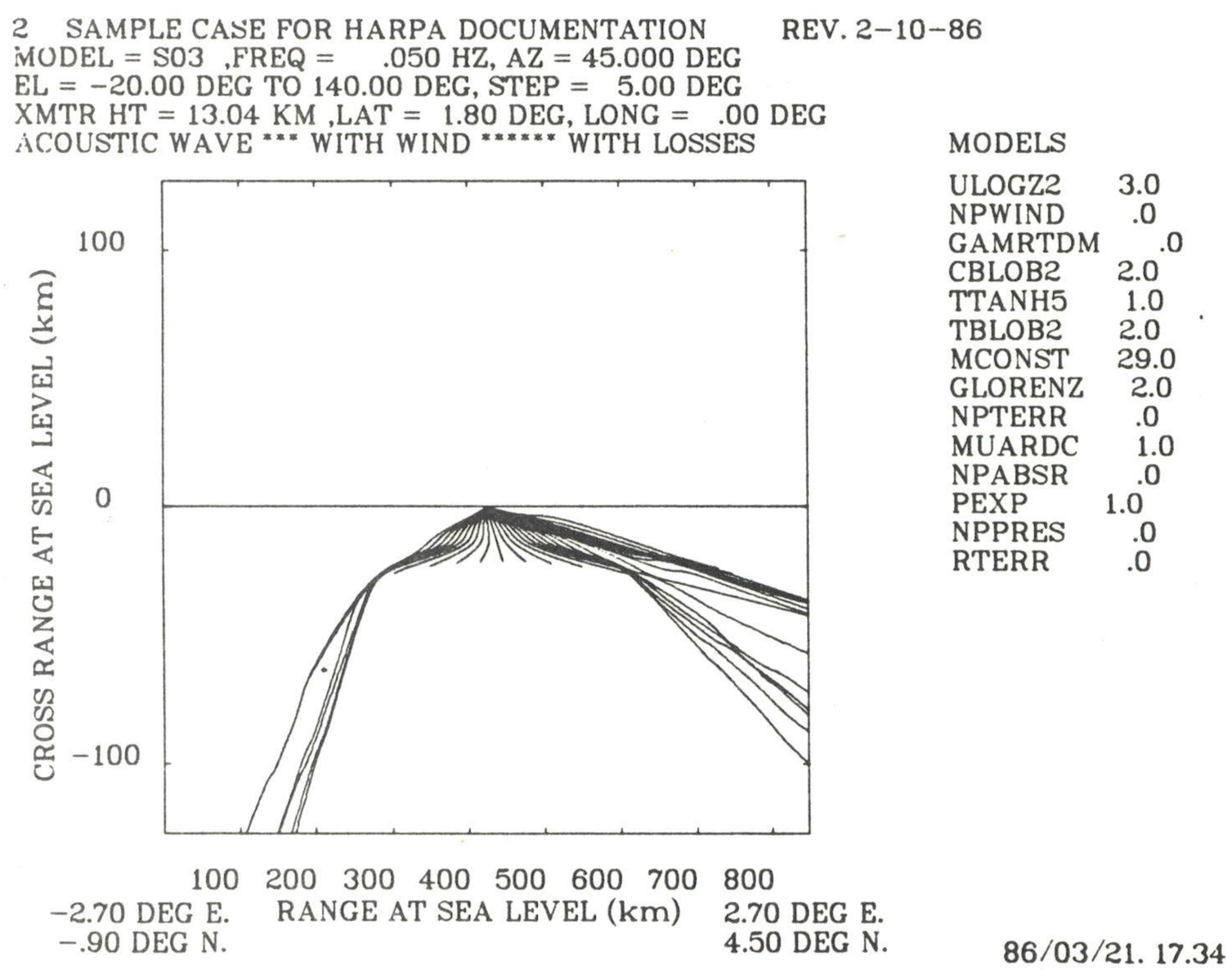


Figure 2.21. Projection of the rays of the sample case onto a horizontal plane whose axis (the horizontal line across the middle of the plot) is shown in Figure 2.18.

ridge intersects the plane of the vertical projection at about 300 km to the left of the transmitter, and rays launched between about 120 and 130 deg elevation reflect from the terrain near the peak of the ridge. They can be observed in detail by launching a dense fan of rays between 120 and 130 deg elevation and magnifying the vertical-projection plot in the vicinity of the ridge. This could be done with just a few modifications of the Input Data File and will be left as an exercise for the user.

2.7 Machine-Readable Output for the Sample Case

HARPA produces two kinds of machine-readable output. One form is called "raysets," which summarize in compressed form some useful ray parameters at each special event (as defined above) along the raypath. The other form of machine-readable output is called "binary raypath data," which permits a complete reconstruction of the raypaths by a supplementary processing program. When stored in machine-readable form (punched cards, magnetic tape, disk files), raysets (as a file named PUNCH) and binary raypath data (as a file named TAPE6) form the input to supplementary processing programs and extend the utility of ray-tracing calculations. Examples are supplementary programs to plot model profiles and contours, to compute amplitude, to plot range versus elevation angle of transmission and range versus travel time, as well as programs that interpolate in elevation angle to estimate eigenrays that reach a specified range. These supplementary capabilities will be documented in another report.

Figure 2.22 shows a portion of the printout of the raysets for the sample case. The complete rayset output for the sample case is given in Appendix A. Each ray begins with a "transmitter rayset," the lines beginning with "S03" in the example. Additional 80-column lines are produced whenever a ray reflects from the terrain surface or crosses the receiver height and at the end of each ray trace. Because of the way hops are counted, two identical raysets are produced each time a ray executes a closest approach to the receiver height.

The compressed rayset format is generally meant to be read by machines, not humans, so it can be rather difficult to inspect for information.

```
S03-1    SAMPLE CASE FOR HARPA DOCUMENTATION        REV.9-23-85
ULOGZ2       3.0 NPWIND        .0   GAMMA RT      .0 CBLOB2       2.0
TTANH5       1.0 TBLOB2       2.0   MCONST      29.0 NO MODL       .0
PEXP         1.0 NPPRES        .0   MUARDC       1.0 NPABSR        .0
GLORENZ      2.0 NPTERR        .0   RTERR         .0 NO MODL       .0
  LOGARITHMIC EASTWARD WIND PROFILE
  50% INCREASE IN SQUARED SOUND SPEED AT 125KM HT, 335KM N, 125KM E.
  U.S. STANDARD ATMOSPHERE 1962 TEMPERATURE PROFILE
  50% CYLINDRICAL INCREASE IN TEMPERATURE AT 105KM N., 105 KM W.
  MOLECULAR WEIGHT = 29
  RIDGE 2-KM HIGH, 30-KM WIDE ALONG EQUATOR
S03    130440  1799     0    50000     3142   4500000  -2000000          0   0 3T
    50367   294887 -3840 -3838-12169   9196124   9196123      0     0    0   0 1R
      313   563108 -2735 -2735 10693  17228767  17228768      0     0    0   0 2G
    50270   831414 -2343 -2340 12148  25260761  25260764      0     0    0   0 2R
    50112  3073288 -4374 -4375-12129  94307633  94307634      0     0    0   0 3R
S03    130440  1799     0    50000     3142   4500000           0        0   0 3T
   130453  2250470 -4938 -4939    -3  68990961  68990962      0     0    0   0 1M
   130453  2250470 -4938 -4939    -3  68990961  68990962      0     0    0   0 2M
   130423  4501421 -4932 -4941    -1 137987009 137987013      0     0    0   0 3M
S03    130440  1799     0    50000     3142   4500000   2000000          0   0 3T
    50170  1946869 -5322 -5324-12129  59828119  59828103      0     0    0   0 1R
      152  2215510 -4860 -4863 10665  67882811  67882797      0     0    0   0 2G
    50137  2484283 -4498 -4500 12121  75937724  75937711      0     0    0   0 2R
    50070  4727741 -4790 -4799-12126 145006034 145006027      0     0    0   0 3R
S03    130440  1799     0    50000     3142   4500000   4000000          0   0 3T
    50103  3741414 -9536 -4137-35775 117807866 117807837      3     0    0   0 1R
      101  3814687 -9488 -4092 34998 120425195 120425167      3     0    0   0 2G
    50099  3887966 -9442 -4046 35772 123042513 123042487      3     0    0   0 2R
    50043  7937415-10564 -5185-35793 249875267 249875381      6     0    0   0 3R
S03    130440  1799     0    50000     3142   4500000   6000000          0   0 3T
    50104  3788921-10259 -3574-59417 113854747 113854834    840     0    0   0 1R
      103  3820800-10249 -3572 58548 115617591 115617680    840     0    0   0 2G
    50102  3852681-10240 -3563 59414 117380431 117380523    840     0    0   0 2R
    50049  7425637-11689 -5024-59423 230295002 230295121   1573     0    0   0 3R
S03    130440  1799     0    50000     3142   4500000   8000000          0   0 3T
  2245590   880081-14390-14394 64191  50090000  50089965999999      0     0    0   0 1E
S03    130440  1799     0    50000     3142   4500000  10000000          0   0 3T
  2238850   451046208869 28867 65050  49890000  49889964999999      0     0    0   0 1E
S03    130440  1799     0    50000     3142   4500000  12000000          0   0 3T
    53003  2990950200125   978-57476 115367955 115368106   2511     0    0   0 1R
     2797  3023605200153   553 54429 117198670 117198821   2511     0    0   0 2G
    52607  3056827200187   580 56842 119028620 119028770   2511     0    0   0 2R
    50134  5991692205807  6198-56730 234573129 234573354   3731     0    0   0 3R
S03    130440  1799     0    50000     3142   4500000  14000000          0   0 3T
    58098  2555846202632 -6592-36018 108393614 108393701     11     0    0   0 1R
     6338  2633761202904 -6666 28584 111287389 111287482     11     0    0   0 2G
    55009  2713368203173 -6406 33954 114170553 114170650     11     0    0   0 2R
    50143  5658781212816  3229-33478 231386220 231386499     18     0    0   0 3R
```

Model Identification Header

Transmitter Raysets

Receiver Raysets

Figure 2.22. Rayset output for the first run set of the sample case, using an elevation-angle increment of 20°.

However, since this is occasionally necessary, Figures 2.23 and 2.24 provide the key for reading rayset printouts.

Notice that the last 3 columns preceding the hop identifier in the receiver raysets contain all zeroes for the sample case. The first of these columns is for Doppler shift, which is zero because we did not use a time-varying model atmosphere. The transverse polarization is always zero for pure acoustic waves, but is nonzero for acoustic-gravity waves (Jones et al., 1982, Sec. 4.1).

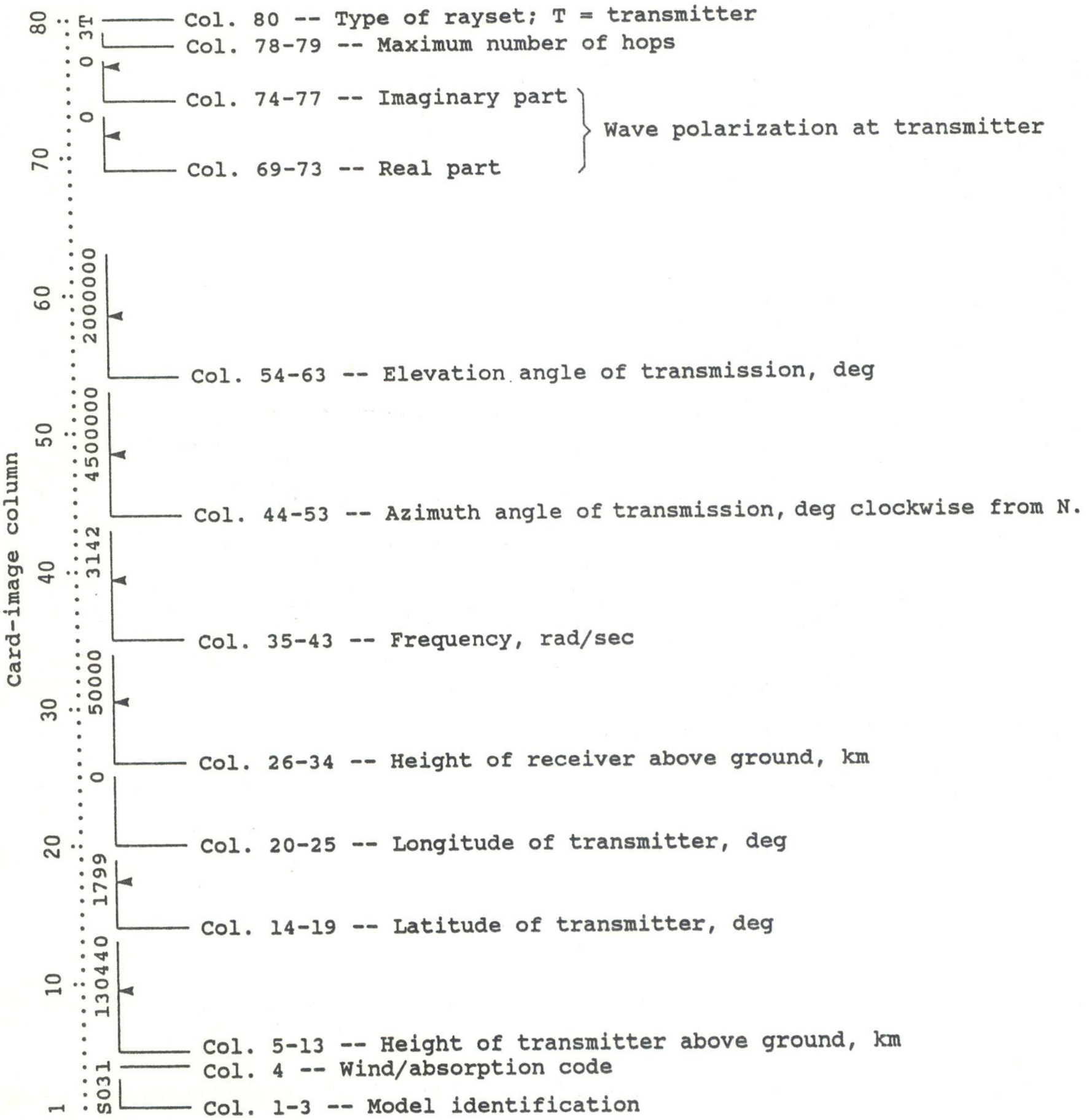


Figure 2.23. Definitions and format for a transmitter rayset. *Wind/absorption code: 0 = no wind, no absorption; 1 = with wind, no absorption; 2 = no wind, with absorption; 3 = with wind, with absorption and ▲ = decimal point.

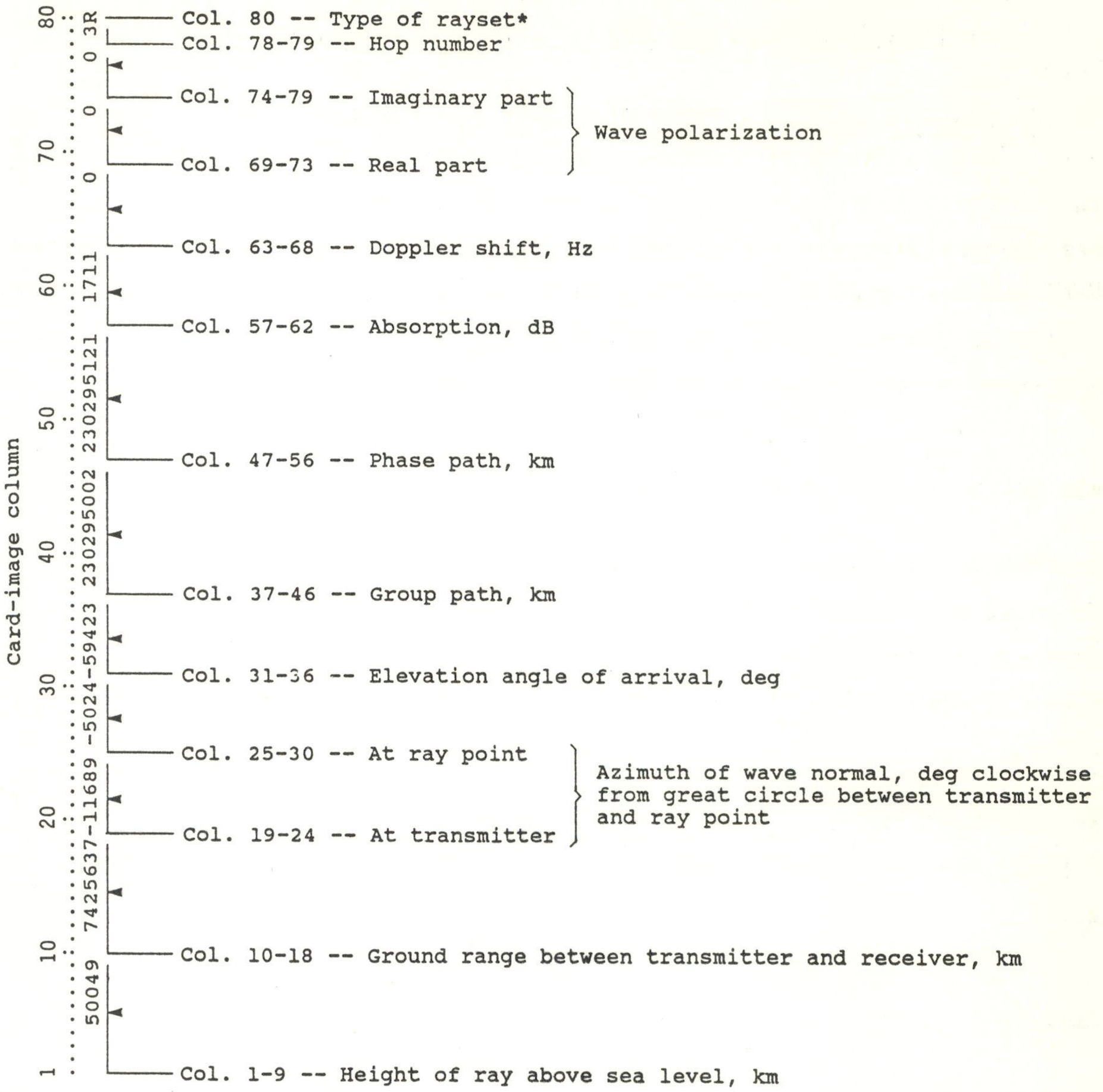


Figure 2.24. Definitions and format for a receiver rayset. * Type of rayset: G = ground reflection; M = closest approach to receiver height; P = penetrated range or height limit; R = at receiver height; S = maximum number of steps; E = extinction; F = exceeded maximum range; U = exceeded maximum height; D = went below minimum height; ▲ = decimal point.

PART II: HOW TO USE THIS PROGRAM

3. How to Get This Program Running on Your Computer

This chapter explains how to get the FORTRAN source code off the distribution tape and onto your computer, and how to get as far as running the sample case. It also deals with the machine-dependent aspects of running HARPA and suggests ways to deal with different computing environments.

3.1 How To Get a Copy of the Program

The FORTRAN source code for the version of HARPA documented in this report and the Input Data File for the sample case are available on magnetic tape. For ordering information, contact the authors at the Wave Propagation Laboratory, Propagation Studies Program Area, 325 Broadway, Boulder, Colorado 80303.

The format of the distribution tape is 0.5 in × 1200 ft, 9 track, 1600 bpi, ASCII character set, block size 1600 bytes, logical record length 80 bytes, no parity.

3.2 ANSI-FORTRAN 77 Compatibility

HARPA was designed to run on a Control Data Corp. (CDC) CYBER 700-800 series with a CDC FORTRAN 77 compiler. It should compile with any FORTRAN compiler that adheres to the ANSI FORTRAN 77 standard, including microcomputer FORTRAN compilers that claim such compatibility.

To ensure portability, we have made many changes in portions of the program that were written before the ANSI standard was established. However, where such changes would have been arduous, and where de facto standards that exist on many systems permit deviations from the ANSI standard, we have retained some non-ANSI code. Following are some exceptions to the ANSI standard:

(1) Some variable and subroutine names have seven characters (six is the ANSI standard).

(2) Some alphanumeric characters are stored eight characters per word in numeric (not character) variables and are output using A8 format.

(3) Some machine-dependent constants are entered in nonstandard format (see the following section).

(4) Sometimes a function is called as though it were a subroutine.

(5) Some real variables are EQUIVALENCEd to integer variables.

(6) In some models and other subroutines, data statements are used to initialize variables contained in labeled-common blocks. For systems that do not permit this, such data statements must be put into separate BLOCK DATA modules. Sequence numbers in the source-code listing identify such statements.

3.2.1 Machine- and System-Dependent Code

We have tried to consolidate any machine- or operating-system-dependent code into two subroutines to make it easier to identify and adapt to new environments.

Before attempting to run HARPA, the user must modify SUBROUTINE DFCNST, which defines machine-dependent constants. The version supplied on the distribution tape is for the CYBER 700-800 series with NOS 2x. Instructions for modifying this routine for several popular machines are included as comments in SUBROUTINE DFCNST (Appendix D).

Another subroutine, DFSYS, contains some operating-system-dependent functions, such as clock and date functions and system-dependent I/O. Users should also check DFSYS and make changes appropriate to their own operating systems.

3.2.2 Word Length

Some problems may arise with machines that have word lengths shorter than the 60-bit word used in our CYBER 840. The numerical integration subroutine (RKAM1) uses double-precision arithmetic to accumulate numerically integrated quantities, but this is almost certainly not necessary with a 60-bit word for ordinary precision requirements. We have not investigated what errors might

occur if less precision were used. We recommend testing the precision on a different machine by running the sample case for smaller and smaller values of the single-step integration error, W(42), and verifying that the error value in the first column of the printout maintains at least the accuracy specified by W(42). The level where that accuracy first breaks down is probably the precision limit imposed by the computer's word length.

3.2.3 Execution Speed

For many applications, HARPA runs fast enough on our CYBER 840 to allow virtually interactive (machine load permitting) ray tracing using a graphics terminal for editing program input and for viewing graphical output. Although HARPA may compile and run on smaller machines, its speed may be so slow that interactive ray tracing may no longer be practical. The run times shown on the printout (Appendix A) for the sample case (at the end of each ray) allow you to compare run times between your computer and ours. Tests on a CRAY XMP-48 indicate a factor of 7 speedup over a CYBER 840.

3.2.4 Graphics

The graphics programs included with HARPA were designed to run on the CYBER 700-800 series computer and use the DISSPLA graphics package (by ISSCO, Inc.) and a CDC 250 Microfilm Potting Unit. However, HARPA will run regardless of the plotting facilities you have.

If you have DISSPLA, you can produce the graphic output by running the supplementary program DDSPLA, supplied as File 6 of the distribution tape. This program reads a graphics metafile called TAPE5, which HARPA produces when plots are requested (see Fig. C1).

If you don't have DISSPLA, you can still run HARPA and get the printed and machine-readable outputs, but you won't get any graphics output. Just ignore the TAPE5 file. If you have other graphics devices, you can modify the DD-prefix plotting routines to drive them. PROGRAM DDALT (file 7 of the distribution tape) provides a framework for inserting custom plot-command calls. The functions of these routines and further details about the CDC 250 plot package and the DISSPLA interface are given in Appendix C.

3.3 Unpacking the Program Tape and File Organization

The distribution tape contains the seven files listed in Section 3.3.1. Section 7.1 gives a list of the programs and subroutines on the distribution tape. Normally, you would transfer all tape files to punched cards or permanent disk files, depending on which medium you will use to run the program.

Although HARPA continues to evolve, the source code on the distribution tape will always correspond exactly with the version described in this report. Updates and errata will be documented separately and included in a dated update tape file.

3.3.1 Files on the HARPA Distribution Tape

File #:

1. FORTRAN source code for the Sample Case, including its models, ready to compile, with common and data blocks included.

2. Input Data File for the Sample Case.

3. FORTRAN source code for the "Ray-tracing Core" programs, including plotting (graphics-write) routines.

4. FORTRAN source code for four dispersion-relation routines.

5. FORTRAN source code for all atmospheric-model routines.

6. FORTRAN source code for program DDSPLA for reading the Graphics Output File (TAPE5) for users with DISSPLA.

7. FORTRAN source code for program DDALT, a skeleton routine for reading the Graphics Output File (TAPE5), allowing users to insert plotting modules for their own plotting system.

3.3.2 Setting Up a Run Module

A run module is the subset of programs that you submit to your computer to run a particular application, along with the job-control commands your computer needs to compile and/or run a program. Files 1 and 2 of the distribution tape constitute the run module (minus the job-control cards) for the sample case. It consists of a core of routines (Sec. 7.1.1) that must always be present to trace rays, and a set of selectable routines (Secs. 7.1.2 and 7.1.3) that describe the particular model (those for the sample case in this example). Figure 3.1 shows a representative run module.

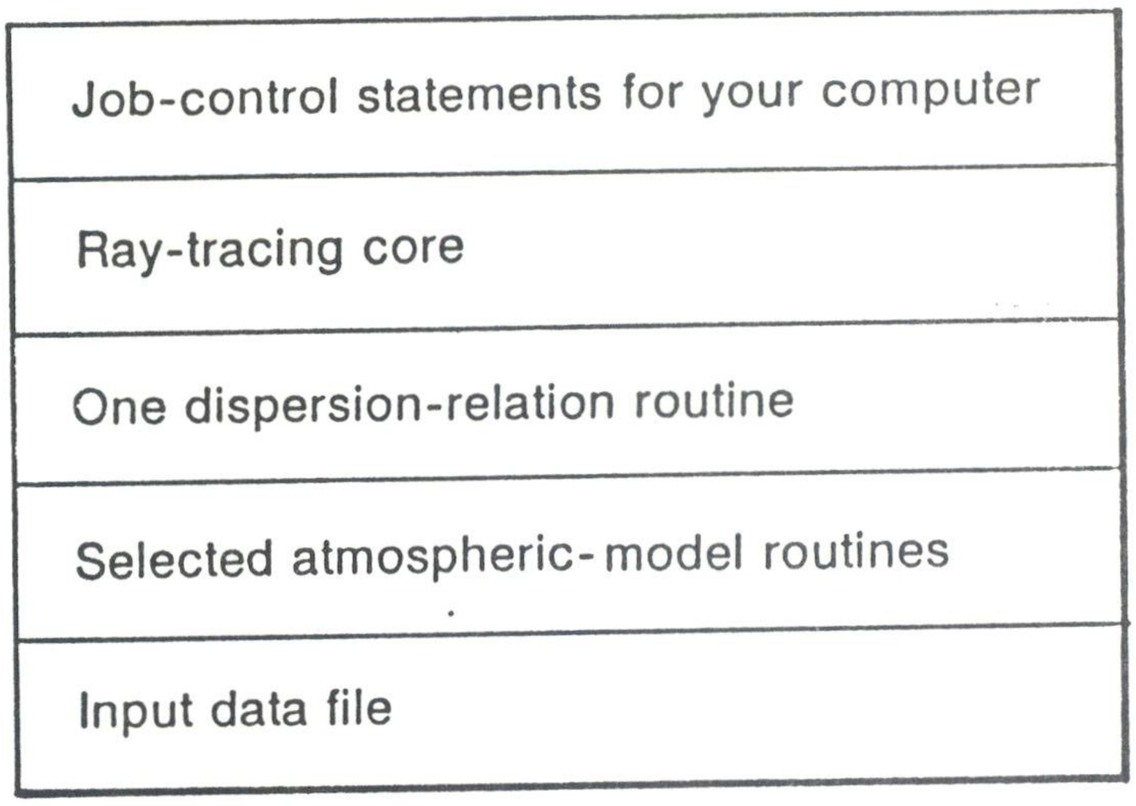


Figure 3.1. Configuration of a run module, assembled from parts consisting either of disk-file modules or punched-card decks.

The selectable part of the run module means that you select only the routines that describe the model you want to use. The run module must contain <u>one and only one</u> (with exceptions noted) of the following kinds of model routines:

- a dispersion-relation routine
- a background sound-speed model
- a background wind model (if you use dispersion models AWWWL or AWWNL)
- a background terrain model
- a perturbation sound-speed model (NPSPEED does nothing)
- a perturbation wind model (NPWIND does nothing) (if you use dispersion models AWWWL or AWWNL)
- a perturbation terrain model (NPTERR does nothing)
- a receiver-surface model.

In addition, you need any other models that are called by any of the above routines, for example, background and temperature-perturbation models called by a sound-speed model (such as GAMRTDM). If you are using a version of the dispersion-relation routine that includes absorption (AWWWL or ANWWL), you will also need models for viscosity/thermal conductivity and pressure, or whatever other parameters it requires. Look at the bottom of the model input parameter forms (Appendix B) to see what other models a given model needs.

3.3.3 If You Are Using Cards To Input Data

If you have no permanent disk storage on your computer, you can load a previously compiled version of HARPA (if you don't change the program itself) into your computer from tape each time you want to run it, and have it read the Input Data File from punched cards. For each run, you have to edit the Input Data File (Deck) by punching new cards for the data you change from a previous run. The Input Data File is arranged in an 80-column format with one input parameter per card so that the deck is easy to edit if you have the contents of the cards interpreted (printed across the card tops).

3.3.4 If You Are Using Permanent Disk Files

It is far more convenient to store both the program and the Input Data File in permanent disk files. A run module (Fig. 3.1) can be constructed by a batch or procedure program that selects the appropriate routines from the HARPA "library." Procedure (or batch) programs also simplify the manipulation of HARPA input and output, but because they depend on the operating system you use, you will generally have to write your own procedures.

4. How to Construct An Atmospheric Model

The easy way to set up an atmospheric model is to select from a general-purpose set of models we have designed (Table 4.1) and choose the model parameters that fit your needs. This requires no programming whatsoever and we encourage that choice whenever possible. Alternatively, you can design your own atmospheric models by writing a FORTRAN subroutine that defines the atmospheric property and its spatial derivatives in a form that is compatible with the rest of the program. This chapter describes both ways.

4.1 Choosing From the Available Atmospheric Models

We have designed some generic atmospheric models that can be adapted to represent common atmospheric structures simply by selecting the appropriate model and its parameters in the Input Data File. They are closed-form expressions for an atmospheric property as a function of geographic latitude, longitude, and height; some accept input parameters in tabular form. There are models for wind, sound-speed and temperature fields, viscosity and thermal conductivity, pressure, molecular weight and terrain surfaces. Though not strictly considered part of the atmospheric model, three models for the receiver surface are also provided. All of these models are described in Appendix B.

Most of the models come in two kinds, "background" and "perturbation." Perturbation models generally superimpose more structure on a background model. Table 4.1 lists the atmospheric models that come with HARPA. To run HARPA, you always have to specify one background model and one perturbation model for each required atmospheric property, even if the perturbation is a do-nothing version.

To put together an atmospheric model from the subroutines we have supplied, first copy the FORM TO SPECIFY AN ATMOSPHERIC MODEL from Appendix B and fill in the name of a model you want to use for each atmospheric parameter, selecting from the choices listed in Table 4.1. Full mathematical descriptions of each model can be found in Appendix B on the order form listed under the model name, and FORTRAN listings for the model subroutines can be found in Appendix D. For now, leave off the numbers of the Data Set ID column until you have selected the models' parameters.

Table 4.1--Available atmospheric models

Model type number	Start of W array parameter block	Model check number	Subroutine name	Description
1.	100			Background wind models:
		1.	WLINEAR	Constant upward and northerly wind, linear easterly wind profile
		6.	ULOGZ2	Logarmithmic atmospheric boundary layer profile
		9.	VVORTX3	Vertical, cylindrical wind vortex
		8.	WGAUSS2	Localized (Gaussian) zonal wind field
		5.	WTIDE	Zonal and meridional profiles that are harmonic in time and height and are in quadrature
2.	125			Wind-perturbation models:
		0.	NPWIND	Do-nothing version
				Sound-speed models:
3.	150	1.	GAMRTDM	$C^2 = \gamma RT/M$
		2.	CSTANH	Profile with linear segments joined by hyperbolic functions
4.	175			Sound-speed perturbation models:
		0.	NPSPEED	Do-nothing version
		2.	CBLOB2	Localized (Gaussian) temperature perturbation
5.	200			Background temperature models:
		0.	NTEMP	Do-nothing temperature model
		1.	TLINEAR	Linear temperature profile
		6.	TTABLE	Tabular temperature profile with cubic interpolation between points
		7.	TTANH5	Profile with linear segments joined by hyperbolic functions
6.	225			Temperature-perturbation models:
		0.	NPTEMP	Do-nothing version
		2.	TBLOB2	Localized (Gaussian) temperature perturbation
7.	250			Molecular weight models:
		1.	MCONST	Constant molecular weight

Table 4.1--Available atmospheric models (continued)

Model type number	Start of W array parameter block	Model check number	Subroutine name	Description
8.	275			Receiver-surface models:
		1.	RHORIZ	A sphere concentric with the earth
		2.	RTERR	A fixed height above the terrain
		3.	RVERT	A vertical surface at a specified fixed range from a specified geographic point
9.	300			Terrain models:
		1.	GHORIZ	A sphere concentric with the earth
		3.	GTANH	A profile of linear segments joined by hyperbolic functions
		4.	GLORENZ	An east-west Lorentzian-shaped ridge
10.	325			Terrain perturbations:
		0.	NPTERR	Do-nothing version
17.	500			Viscosity/thermal conductivity:
		1.	MUARDC	ARDC viscosity model, Prandtl number for thermal conductivity
18.	525			Viscosity/conductivity perturbation:
		0.	NPABS	Do-nothing version
19.	550			Atmospheric pressure:
		1.	PEXP	Exponential profile
20.	575			Pressure perturbation:
		0.	NPPRES	Do-nothing version

Next, select and copy the blank Input Parameter Forms from Appendix B for the models you have selected and fill in the values of the variable parameters that you want. Next transfer the input parameters to a new Input Data File, either constructing one from scratch, according to the format shown in Figure 2.5, or modifying an old one. (If you use an old one, make sure that unused parameters are removed.) Remember to assign an input data-set identification number (F7.3 FORMAT), which uniquely identifies that set of input parameters for each model, and to assign an Atmospheric Identification (ID) for the entire

set of models. Put these ID numbers on the FORM TO SPECIFY AN ATMOSPHERIC MODEL and save all these forms as a record of the models you have defined.

Here are a few guidelines for selecting models. If you want a model with no temperature variation, use TLINEAR and set the gradient to zero. If you want a model with no wind, use no wind model and select a dispersion-relation routine with no wind (ANWNL or ANWWL). If you specify any temperature model, you have to use model GAMRTDM, which simply converts temperature to sound speed. If you want to specify a sound-speed field only (such as CSTANH), don't use any temperature model, in which case you don't need GAMRTDM. You can also specify a background model in terms of temperature or sound speed (but not both), and perturbations in terms of temperature or sound speed or both (as in the sample case). If you want no perturbation model for wind speed, temperature, sound speed, or terrain, use the corresponding do-nothing perturbation models NPTEMP, NPWIND, NPSPEED, or NPTERR.

If you are storing HARPA on a permanent disk file, you have to select only the subroutines that define your atmospheric model (and the correct dispersion-relation routine) and assemble them into a separate "run module" (Section 3.3.2). If you are storing the programs on punched cards, you should select and submit only the decks for the model subroutines you want to use. It is convenient to think of HARPA as consisting of a core of ray-tracing routines that are always used, and a set of selectable model-related routines from which you select the ones appropriate to the models you want. The specific routines that fall into each category are listed in Chapter 7.

4.1.1 Model Check Numbers

To guard against accidentally selecting the wrong model subroutine for a run module, each model is assigned a permanent Model Check Number, which is entered on each model input data form (Appendix B). If a model subroutine is selected whose Check Number does not match that specified in the Input Data File, then the program will stop and give an error message.

Another number, called the Input Data Format Code, is not now being used or checked, but may be used in the future.

4.1.2 Tabular Input to Models

Some models, like TTANH5 and TTABLE, can accept so many input parameters that it is inconvenient to specify each one as a separate line in the Input Data File, so a general provision has been made for entering data in tabular form. The use of TTANH5 in the sample case is an example. Tabular data are entered into the Input Data File in a special format illustrated by Figure 2.19 and described fully in Chapter 5.

4.2 Designing Your Own Models

HARPA will accept any atmospheric model specification that provides the desired atmospheric property as a function of the earth-centered spherical-polar coordinates r,θ,ϕ and time t, as well as its spatial and temporal derivatives. There are three important considerations in writing model subroutines: (a) All spatial derivatives must be not only continuous but also analytically consistent with the formulas for the atmospheric property itself; any errors or approximations in those calculations will result in larger-than-desired integration errors, as displayed in the first column of the ray-tracing printout. (b) The input data for the models must come from the part of the W array assigned to that type of model (Table 4.1) and from the tabular-input common blocks assigned to those models (Table 4.2). (c) The output from the atmospheric model must go to the appropriate data-output common block (Table 4.3). Because the model routines are called many times, efficient programming here pays off in execution efficiency.

If you want a new model of wind, temperature, or sound speed that depends only on height, you would normally design a new background model. If you want a three-dimensional model, you could use one of the background models we have supplied and design a new perturbation model. Conceivably, you could design both a new background and a new perturbation model, but the safe way to proceed is to do one at a time.

Those designing a new model should pattern their subroutine after a similar one that comes with HARPA. We will use the model TTANH5 (Fig. 4.1), as an example and discuss its structure in detail to illustrate how to write a model subroutine. In the following paragraphs, general statements will be followed in square brackets by the specific examples from TTANH5.

Table 4.2--Allocation of common blocks for tabular input to the various atmospheric models*

Common block name	Atmospheric model
/B1/	Wind velocity
/B2/	Perturbation to the wind velocity
/B3/	Sound speed
/B4/	Perturbations to the sound speed
/B5/	Temperature
/B6/	Perturbations to the temperature
/B7/	Molecular weight
/B8/	Receiver surface
/B9/	Terrain
/B10/	Terrain perturbation
/B17/	Viscosity/thermal conductivity
/B18/	Viscosity/conductivity perturbation
/B19/	Pressure
/B20/	Pressure perturbation

* In the first 31 elements of each of these common blocks, each atmospheric model indicates the structure of the rest of the common block. Subroutine READW1 stores input data that it reads starting in element 32 of the common block.

Table 4.3--Allocation of common blocks for output from the various atmospheric models

Common block name	Location of description (table number)	Atmospheric model
/UU/	7.10	Wind velocity
/CC/	7.11	Sound speed
/TT/	7.12	Temperature
/MM/	7.13	Molecular weight
/RR/	7.14	Receiver surface
/GG/	7.15	Terrain
/AA/	7.16	Viscosity/thermal conductivity
/PP/	7.17	Atmospheric pressure

There are no restrictions on naming models, but it is useful to assign a name that suggests the model's function. [TTANH5 is the fifth temperature model that used TANH functions to smooth temperature profiles with linear segments. Square brackets enclose examples of parameters for the TTANH5 routine.] Each model subroutine has two entry points whose standard names are given in Table 4.4. These names must be used when designing new subroutines. The first entry point [ENTRY IPTEMP], whose name begins with an "I," is for initialization after new input data have been read in, and that entry point is called the first time the program enters the subroutine. The second entry point [ENTRY TEMP] enters the routine for subsequent computations of the atmospheric parameter [T] and its time and space derivatives [PTT, PTR, PTTH, PTPH] according to the formulas given on the model order from.

The input to each subroutine (geographic coordinates r,θ,ϕ) is through blank common, and output [temperature and its derivatives] is through the labeled common blocks [/TT/], named for each kind of model and listed in Table 4.3. If you need more input parameters than will fit in the assigned block of the Input Data Table [200-224], then you should use a tabular input format, which uses the labeled common blocks [B5] listed in Table 4.2. Tabular

```
      SUBROUTINE TTANH5                                                 TTANH5 9
C     TEMPERATURE PROFILE REPRESENTED BY A SEQUENCE OF LINEAR SEGMENTS  TTANH510
C     SMOOTHLY JOINED BY HYPERBOLIC FUNCTIONS. PARAMETERS ARE INPUT     TTANH511
C     AS TABULAR DATA WITH SLOPES COMPUTED FROM TEMPERATURE DATA.       TTANH512
C     REFERENCE TEMPERATURE T0 IS READ FROM TABULAR DATA.               TTANH513
      DIMENSION C(20), TM(19), Z(19), DL(19)                            TTANH514
C     COMMON DECK "RKAM" INSERTED HERE                                  RKAMCOM2
      REAL KR,KTH,KPH                                                   RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)       RKAMCOM5
C     COMMON DECK "TT" INSERTED HERE                                    CTT    2
      REAL MODT                                                         CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                            CTT    5
C     COMMON DECK "WW" INSERTED HERE                                    CWW    2
      PARAMETER (NWARSZ=1000)                                           CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         CWW2   6
     8 (RCVRH,W(20)),                                                   CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))        CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),        CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))              CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                   CWW2  16
      REAL MMODEL,MFORM,MID                                             CWW3   2
C                                                                       CWW3   3
C     WIND         100-124                                            CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)           CWW3   5
C                                                                       CWW3   6
C     DELTA WIND         125-149                                        CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)        CWW3   8
C                                                                       CWW3   9
C     SOUND SPEED 150-174                                               CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)           CWW3  11
      EQUIVALENCE (W(153),REFC)                                         CWW3  12
C                                                                       CWW3  13
C     DELTA SOUND SPEED 175-199                                         CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)        CWW3  15
C                                                                       CWW3  16
C     TEMPERATURE    200-224                                            CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)           CWW3  18
C                                                                       CWW3  19
C     DELTA TEMPERATURE    225-249                                      CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)        CWW3  21
C                                                                       CWW3  22
C     MOLECULAR   250-274                                               CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)           CWW3  24
C                                                                       CWW3  25
C     RECEIVER HEIGHT   275-299                                         CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)           CWW3  27
```

Figure 4.1. Listing for model temperature subroutine TTANH5.

```
C                                                                       CWW3  28
C     TOPOGRAPHY   300-324                                              CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)           CWW3  30
C                                                                       CWW3  31
C     DELTA TOPOGRAPHY   325-349                                        CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)        CWW3  33
C                                                                       CWW3  34
C     UPPER SURFACE TOPOGRAPHY   350-374                                CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)           CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                              CWW3  37
C                                                                       CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                       CWW3  39
C     ABSORPTION         500-524                                        CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)           CWW3  41
C                                                                       CWW3  42
C     DELTA ABSORPTION         525-549                                  CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)        CWW3  44
C                                                                       CWW3  45
C     PRESSURE         550-574                                          CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)           CWW3  47
C                                                                       CWW3  48
C     DELTA PRESSURE         575-599                                    CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)        CWW3  50
C                                                                       CWW3  51
C     COMMON DECK "B5" INSERTED HERE                                    CB5    2
      INTEGER TMX,TNTBL,TITBL,TFRMTBL,IDST(10)                          CB5    4
      COMMON/B5/TMX,TNTBL(10),TITBL(10),TFRMTBL(10),TGP(262)            CB5    5
      EQUIVALENCE (TGP,IDST),(ANT,TGP(11))                              CB5    6
      EQUIVALENCE                (Z0,TGP(12)),(TM,TGP(33))              TTANH519
      EQUIVALENCE (Z,TGP(13)),(C,TGP(32)),(DL,TGP(53))                  TTANH520
C                                                                       TTANH521
      DATA RECOGT,N/7.0,0/                                              TTANH522
      DATA ANT/0.0/                                                     TNH5BL 2
      DATA TMX/2/                                                       TNH5BL 3
      DATA TNTBL/1,11,72,7*0/                                           TNH5BL 4
      DATA TITBL/1,20,8*0/                                              TNH5BL 5
      DATA TFRMTBL/1,2,8*0/                                             TNH5BL 6
C                                                                       TTANH525
      COSH (X) = (EXP (X) + 1. / (EXP (X))) / 2.                        TTANH526
C                                                                       TTANH527
      ENTRY ITEMP                                                       TTANH528
C                                                                       TTANH529
      CALL IPTEMP                                                       TTANH530
C                                                                       TTANH531
C     IF HAD PREVIOUS CALL BUT NOTHING THIS TIME, EXIT NOW              TTANH532
C     RETAINING PREVIOUS TABULAR DATA COUNT                             TTANH533
      IF(N.GT.0 .AND. ANT.EQ.0.0) RETURN                                TTANH534
C                                                                       TTANH535
      IF(RECOGT .NE. TMODEL)                                            TTANH536
     1    CALL RERROR('TEMP    ','WRNG MODEL',RECOGT)                   TTANH537
C                                                                       TTANH538
      MODT(1)=7HTTANH5                                                  TTANH539
      MODT(2)=TID                                                       TTANH540
C                                                                       TTANH541
      N=(ANT+1)/3 - 2                                                   TTANH542
C                                                                       TTANH543
      IF(N.LE.0)                                                        TTANH544
     1    CALL RERROR('TTANH5','BAD N VALUE',FLOAT(N))                  TTANH545
C                                                                       TTANH546
```

Figure 4.1. Listing for model temprature subroutine TTANH5 (continued).

```
      ANT=0.0                                                          TTANH547
C                                                                      TTANH548
C                                                                      TTANH549
C     CONVERT 'T' ARRAY INPUT(OVERLAYS 'C' ARRAY) TO 'C' ARRAY         TTANH550
C                                                                      TTANH551
      T0=C(1)                                                          TTANH552
      TIM1=T0                                                          TTANH553
      ZIM1=0.0                                                         TTANH554
      NP1=N+1                                                          TTANH555
      DO 10 I=1,NP1                                                    TTANH556
         TI=TM(I)                                                      TTANH557
         ZI=Z(I)                                                       TTANH558
         C(I)=(TI-TIM1)/(ZI-ZIM1)                                      TTANH559
         TIM1=TI                                                       TTANH560
10       ZIM1=ZI                                                       TTANH561
C                                                                      TTANH562
      RETURN                                                           TTANH563
C                                                                      TTANH564
      ENTRY TEMP                                                       TTANH565
      H = R - EARTHR                                                   TTANH566
      SUM = 0.                                                         TTANH567
C                                                                      TTANH568
C     LOOP TO SUM OVER ALL COEFFICIENTS                                TTANH569
C     USE SPECIAL FUNCTION 'ALCOSH' WHICH ALLOWS FOR LARGE ARGUMENTS.  TTANH570
      DO 1 I = 1, N                                                    TTANH571
    1 SUM = SUM + DL(I) * (C(I + 1) - C(I)) / 2. *(ALCOSH((H - Z       TTANH572
     1(I)) / DL(I)) - ALCOSH((Z(I)-Z0) / DL(I)))                       TTANH573
      T = T0 + SUM + (C(1) + C(N + 1)) * (H - Z0) * 0.5                TTANH574
      SUM = 0.                                                         TTANH575
      DO 2 I = 1, N                                                    TTANH576
    2 SUM = SUM + (C(I + 1) - C(I)) / 2. * (1. + TANH ((H - Z(I)) /DL  TTANH577
     1 (I)))                                                           TTANH578
      PTT=0.0                                                          TTANH579
      PTR = C(1) + SUM                                                 TTANH580
      PTTH=0.0                                                         TTANH581
      PTPH=0.0                                                         TTANH582
C                                                                      TTANH583
      CALL PTEMP                                                       TTANH584
      RETURN                                                           TTANH585
      END                                                              TTANH586
```

Figure 4.1. Listing for model temperature subroutine TTANH5 (continued).

Table 4.4--Assignment of entry point names and input parameter blocks in the W array for the atmospheric models

Atmospheric model	Entry point names	Input parameter block in the W array
Wind	WINDR, IWINDR	100-124
Wind perturbation	PWINDR, IPWINDR	125-149
Sound-speed	SPEED, ISPEED	150-174
Sound speed perturbation	PSPEED, IPSPEED	175-199
Temperature	TEMP, ITEMP	200-224
Temperature perturbation	PTEMP, IPTEMP	225-249
Molecular weight	MOLWT, IMOLWT	250-274
Receiver surface	RECVR, IRECVR	275-299
Terrain	TOPOG, ITOPOG	300-324
Terrain perturbation	PTOPOG, IPTOPOG	325-349
Viscosity/thermal conductivity	ABSRP, IABSRP	500-524
Viscosity/thermal conductivity perturbation	PABSRP, IPABSRP	525-549
Pressure	PRES, IPRES	550-574
Pressure perturbation	PPRES, IPPRES	575-599

data are read into this common block from the Input Data File according to the format described in Chapter 5 and illustrated near the end of Figure 2.19 for the sample case.

4.2.1 How To Write an Atmospheric Model Subroutine So It Can Receive Tabular Data Read Into Common Blocks by READW1

If you want to write an atmospheric model subroutine that uses tabular input data, then you have to observe some special precautions. In what follows, general statements are exemplified in square brackets for the case of the temperature subroutine TTANH5. You can use this example as a guide in developing new model subroutines that use tabular data.

Tabular [temperature] data are read into a model-related common block [/B5/] by READW1. Table 4.3 gives the names of the common blocks associated with the different model types. The format of the tabular input data can be selected by the user and is determined by a code [3] in columns 1-3 of the Input Data File (see Figure 2.19). [In the case of TTANH5, a three-column format makes sense because there are three input parameters]. READW1 interprets this code according to the formats listed in Table 5.4. The model subroutine [TTANH5] must tell READW1 how it wants the tabular input data stored in the common block [B5] in an array [TGP]. It does so by setting (in DATA statements) the values in variable TMX and in arrays TNTBL, TITBL and TFRMTBL for temperature models (or corresponding names for other model types, in which the first letter is different). The model variables [ZO,TM,C,DL] are EQUIVALENCEd to elements of a GP (for general-purpose) array [called TGP for temperature models]. Table 4.5 defines the structure of common block /B5/, which transmits these variables between READW1 and TTANH5, and it explains how to set the data-block parameters.

4.2.2 Designing Your Own Terrain Models

A terrain model specifies a function $g(r,\theta,\phi)$ such that $g=0$ on the terrain, $g>0$ above the terrain, and $g<0$ below the terrain. To be an allowed model, g must be continuous through second derivatives. A subroutine for a terrain model must calculate g, its three first derivatives, and its six second derivatives for any values of r,θ,ϕ. All of our present terrain models define g to be the height above the terrain, but more general definitions are allowed to handle cliffs, overhangs, and caves. To design a simple model with a few parameters, follow the example of SUBROUTINE GLORENZ. To design a more elaborate model that needs tabular input data, follow the example of SUBROUTINE GTANH. Source-Code listings for these models are in Appendix D.

Table 4.5--Definitions of the parameters in common block /B5/*

Position common	Variable name	Definition
1	TMX	Maximum number of data blocks in /B5/
2-11	TNTBL	An array that contains the beginning location of data blocks within the common block
2	TNTBL(1)	Beginning location (in TGP array) of data block 1
3	TNTBL(2)	Beginning location (in TGP array) of data block 2
4	TNTBL(3)	Beginning location (in TGP array) of data block 3**
12-21	TITBL	An array that contains the iteration (or cycle) length of the data in the data blocks within the common block (if there is more than one array in the data block, then this is the dimension of the arrays)
12	TITBL(1)	Cycle length of data block 1
13	TITBL(2)	Cycle length of data block 2
22-31	TFRMTBL	An array that contains the input format numbers for the data blocks within the common block
22	TFRMTBL(1)	Format type*** for data block 1
23	TFRMTBL(2)	Format type*** for data block 2
32-	TGP	An array containing TMX number of data blocks for tabular input data for atmospheric models

* The values of the first 31 elements in /B5/ define the block structure for the array TGP, and they are defined in the atmospheric models and used in the data read-in routines READW and READW1. The common blocks /B1/, /B2/, /B3/, /B4/, /B6/, and /B7/ have the same structure as /B5/, but have different names for the variables.

** Only two data blocks are now available to use; however, the beginning location of the first data block not used must be specified to indicate the length of the last data block used.

*** Format type 1 implies format number 1 (see Table 5.3).
Format type 2 implies format numbers 2, 3, or 4 (see Table 5.3).

5. How to Specify the Input Data and Set Up an Input Data File

To give HARPA an atmospheric model and to tell it what rays to trace, you have to construct an Input Data File, like the one shown in Figure 5.1 (same as Figure 2.19, reproduced here for the user's convenience) for the sample case. An Input Data File may contain one or more "run sets," each of which can specify a different atmospheric model, different plotting modes, or different initial ray conditions, but which will all be executed as a single computer run. The sample case contains two run sets. After the first run set, only the parameters whose values differ from those specified in the preceding run set need be specified.

After setting up an Input Data File, you run HARPA by combining it with other ray-tracing modules to form a "run module," as explained in Section 3.3.2. All the necessary modules to run the sample case are contained in Files 1 and 2 of the distribution tape (Sec. 3.3.1).

5.1 Editing the Input Data File

Because HARPA contains no built-in way to construct or edit an Input Data File, you have to use an editor of your own to do so. We have designed a specialized editor, called WMOD, for this purpose. It not only permits editing the Input Data File, but it also sets up a "run module" that includes job-submission procedures for our computer. This program, which could run on a local microcomputer, will be documented in another report.

The Input Data File can take the form of either a deck of punched cards or a disk file to be read by HARPA. Some suggestions for those using punched cards are given in Section 3.3.3. Henceforth, we will assume that the Input Data File will be created as a disk file. There are no formal differences between the two methods, however.

Rather than start from scratch, we recommend that you modify an existing Input Data File. After you have run the sample case and have verified that its output agrees with that given in Appendix A, you can modify the Input Data File for the sample case to make the raypath calculations you want.

```
col.     col.      col.          col.
1-3      4-17      18-24         25-80
 n       W(n)      UNITS         DESCRIPTION
-------------------------------------------------------------------------------
GEORGES     RB3    X6437
S03-1     SAMPLE CASE FOR HARPA DOCUMENTATION          REV. 2-10-86
  1      6370.              EARTH RADIUS, KM (6370.)
  3        13.             TTRANSMITTER HEIGHT, KM (T=ABOVE TERRAIN)
  4       200.     AN KM    N. TRANSMITTER LATITUDE, KM
  5         0.     AN KM    E. TRANSMITTER LONGITUDE, KM
  7       .05      FQ HZ    INITIAL FREQUENCY, HZ
 11        45.     AN DG    INITIAL AZIMUTH ANGLE, DEG
 15       -20.     AN DG    INITIAL ELEVATION ANGLE, DEG
 16       140.     AN DG    FINAL   ELEVATION ANGLE, DEG
 17         5.     AN DG    STEP IN ELEVATION ANGLE, DEG
 20         5.              RECEIVER HEIGHT, KM
 22         3.              MAXIMUM NUMBER OF HOPS (1.0)
 23      1000.              MAXIMUM NUMBER OF STEPS PER HOP (1000.)
 26       500.              MAXIMUM RAY HEIGHT, KM (500.)
 27        -1.              MINIMUM RAY HEIGHT, KM
 28      1000.              MAXIMUM RANGE, KM
 29  0000100.              DO: EIGRAY/RNG-TIM/RNG-ELV/NEW-PROJ/RAYTRC/CONT/PROF
 33   999.999               MAXIMUM ABSORPTION, DB (999.999)
 42        1.0E-6           SINGLE-STEP INTEGRATION ERROR (1.0E-4)
 44         .1              INITIAL INTEGRATION STEP SIZE, KM (1.0)
 57         2.              PHASE PATH (0=NO; 1=INTEGRATE; 2=INTEGRATE/PRINT)
 58         2.              ABSORPTION (0=NO; 1=INTEGRATE; 2=INTEGRATE/PRINT)
 60         2.              PATH LENGTH (0=NO; 1=INTEGRATE; 2=INTEGRATE/PRINT)
 71        50.              NUMBER OF INTEGRATION STEPS PER PRINT [1.E31]
 72         1.              OUTPUT RAYSETS (1=YES; 0=NO)
 73         0.              DIAGNOSTIC PRINTOUT (1=YES; 0=NO)
 74         0.              PRINT RAY STEPS (0=YES; 1=NO)
 75        .15              FULANN LETTER HEIGHT [0.15 IN]
 76         0.              BINARY RAY OUTPUT (1=YES; 0=NO)
 77        57.              LINES PER PAGE IN PRINTOUT (66.)
 81         1.              RAYPLOT PROJECTION (1=VERT; 2=HORIZ) PLANE
 82         1.              PLOT-EXPANSION FACTOR [1.0]
 83      -100.     AN KM    N. LATITUDE  OF LEFT PLOT EDGE, KM
 84      -300.     AN KM    E. LONGITUDE OF LEFT PLOT EDGE, KM
 85       500.     AN KM    N. LATITUDE  OF RIGHT PLOT EDGE, KM
 86       300.     AN KM    E. LONGITUDE OF RIGHT PLOT EDGE, KM
 87       100.     AN KM    DISTANCE BETWEEN TIC MARKS, KM
 88         0.              HEIGHT ABOVE SEA LEVEL OF BOTTOM OF GRAPH, KM
 89       300.              HEIGHT ABOVE SEA LEVEL OF TOP OF GRAPH, KM
 96       100.              DISTANCE BETWEEN VERTICAL TIC MARKS, KM
100         6.              ULOGZ2 WIND MODEL CHECK NUMBER
102         3.               BACKGROUND WIND DATA SET ID
103         5.     LN  M     REFERENCE WIND SPEED, M/S
104       .35                VON KARMAN'S CONSTANT
105         1.                ROUGHNESS HEIGHT, KM
150         1.               GAMRTDM SOUND SPEED MODEL CHECK NUMBER
175         2.               CBLOB2 MODEL CHECK NUMBER
177         2.                SOUND SPEED PERTURBATION DATA SET ID
178        .5                 FRACTIONAL INCREASE OF SQUARED SOUND SPEED
```

Figure 5.1. Input Data File (W array) for the sample case.

```
179        125.                HEIGHT OF MAXIMUM INCREASE, KM
180        335.     AN KM      N. LATITUDE OF MAXIMUM INCREASE, KM
181        125.     AN KM      E. LONGITUDE OF MAXIMUM INCREASE, KM
182         25.                GAUSSIAN WIDTH IN HEIGHT OF INCREASE, KM
183         50.     AN KM      N-S WIDTH OF THE INCREASE, KM
184         25.     AN KM      E-W WIDTH OF THE INCREASE, KM
200          7.               TTANH5 TEMPERATURE MODEL CHECK NUMBER
202          1.                BACKGROUND TEMPERATURE DATA SET ID
225          2.               TBLOB2 MODEL CHECK NUMBER
227          2.                TEMPERATURE PERTURBATION DATA SET ID
228          .5                FRACTIONAL TEMPERATURE INCREASE
229          0.                HEIGHT OF MAXIMUM INCREASE, KM
230        105.     AN KM      N. LATITUDE OF MAXIMUM INCREASE, KM
231       -105.     AN KM      E. LONGITUDE OF MAXIMUM INCREASE, KM
232          0.                GAUSSIAN WIDTH IN HEIGHT OF INCREASE, KM
233         50.     AN KM      N-S WIDTH OF THE INCREASE, KM
234         25.     AN KM      E-W WIDTH OF THE INCREASE, KM
250          1.               MCONST MOLECULAR WEIGHT MODEL CHECK NUMBER
252         29.                MOLECULAR WEIGHT DATA SET ID
253         29.                MOLECULAR WEIGHT
275          2.               RTERR RECEIVER MODEL CHECK NUMBER
300          4.               GLORENZ TERRAIN MODEL CHECK NUMBER
302          2.                TERRAIN MODEL DATA SET ID
303          2.                HEIGHT OF THE RIDGE, KM
304          0.                N. LATITUDE OF THE RIDGE CENTER
305         30.     AN KM      HALF-WIDTH OF THE RIDGE, KM
325          0.               NPTERR NO TERRAIN PERTURBATION
500          1.               MUARDC VISC/COND MODEL CHECK NUMBER
502          1.                VISC/COND MODEL DATA SET ID
503     1.458E-06              VISCOSITY COEFFICIENT BETA
504      110.4                 SUTHERLAND'S CONSTANT, KELVINS
505       .733                 PRANDTL NUMBER
525          0.               NPABS NO VISC/COND PERTURBATION
550          1.               PEXP PRESSURE MODEL CHECK NUMBER
552          1.                BACKGROUND PRESSURE MODEL DATA SET ID
553     101328.                PRESSURE AT SEA LEVEL, N/SQ.M.
554         8.5                PRESSURE SCALE HEIGHT, KM
575          0.               NPPRES   NO PRESSURE PERTURBATION
 -1                           DATA SUBSET FOR BACKGROUND WIND MODEL
  A  LOGARITHMIC EASTWARD WIND PROFILE, U*=.5 M/S, Z0=1 KM
  0      RETURN TO W ARRAY DATA SET
 -2                           DATA SUBSET FOR WIND PERTURBATION MODEL
  A  NO WIND PERTURBATION
  0      RETURN TO W ARRAY DATA SET
 -3                           DATA SUBSET FOR BACKGROUND SOUND-SPEED MODEL
  A  SOUND SPEED IN TERMS OF TEMPERATURE MODEL
  0      RETURN TO W ARRAY DATA SET
 -4                           DATA SUBSET FOR SOUND-SPEED PERTURBATION MODEL
  A  50% INCREASE IN SQ. SOUND SPEED AT 125KM HT, 335KM N, 125KM E
  0      RETURN TO W ARRAY DATA SET
 -5                           DATA SUBSET FOR TEMPERATURE MODEL
  A  U.S. STANDARD ATMOSPHERE 1962 TEMPERATURE PROFILE
  3      999.0
 LN KM                              LN KM
  0.              288.000            0.
```

Figure 5.1. Input Data File (W array) for the sample case (continued).

```
 15.0000       190.500       10.0000
 52.0000       320.000        7.50000
 95.0000       191.000       10.0000
165.0000      1451.000       50.0000
300.0000      1586.000        0.
999.0000
 0       RETURN TO W ARRAY DATA SET
-6                        DATA SUBSET FOR TEMPERATURE PERTURBATION MODEL
 A  50% CYLINDRICAL INCREASE IN TEMPERATURE AT 105KM N., 105 KM W
 0       RETURN TO W ARRAY DATA SET
-7                        DATA SUBSET FOR MOLECULAR WEIGHT MODEL
 A  MOLECULAR WEIGHT = 29
 0       RETURN TO W ARRAY DATA SET
-8                        DATA SUBSET FOR RECEIVER SURFACE MODEL
 A  RECEIVER SURFACE 5 KM ABOVE TERRAIN
 0       RETURN TO W ARRAY DATA SET
-9                        DATA SUBSET FOR TERRAIN MODEL
 A  RIDGE 2-KM HIGH, 30-KM WIDE ALONG EQUATOR
 0       RETURN TO W ARRAY DATA SET
-10                       DATA SUBSET FOR TERRAIN PERTURBATION MODEL
  A  NO TERRAIN PERTURBATION
  0       RETURN TO W ARRAY DATA SET
-17                       DATA SUBSET FOR VISC/COND MODEL
  A  ARDC VISCOSITY AND THERMAL CONDUCTIVITY MODEL
  0       RETURN TO W ARRAY DATA SET
-18                       DATA SUBSET FOR VISC/COND PERTURBATION MODEL
  A  NO VISCOSITY/CONDUCTIVITY PERTURBATION
  0       RETURN TO W ARRAY DATA SET
-19                       DATA SUBSET FOR BACKGROUND PRESSURE MODEL
  A  EXPONENTIAL PRESSURE MODEL, SCALE HEIGHT = 8.5 KM
  0       RETURN TO W ARRAY DATA SET
-20                       DATA SUBSET FOR PRESSURE PERTURBATION MODEL
  A  NO PRESSURE PERTURBATION
  0       RETURN TO W ARRAY DATA SET
  0                       **********  END OF RUN SET NUMBER 1  **********
S03-2     SAMPLE CASE FOR HARPA DOCUMENTATION          REV. 2-10-86
 71         0.            NUMBER OF INTEGRATION STEPS PER PRINT
 72         0.            OUTPUT RAYSETS  (1=YES; 0=NO)
 73         1.            DIAGNOSTIC PRINTOUT (1=YES; 0=NO)
 81         2.            RAYPLOT PROJECTION (1=VERT; 2=HORIZ) PLANE
 82         3.            PLOT-EXPANSION FACTOR
 0                         **********  END OF RUN SET NUMBER 2  **********
```

Figure 5.1. Input Data File (W array) for the sample case (continued).

The best way to be sure you have input all the required data is to fill out the forms for specifying all the model and ray parameters, as discussed for the sample case in Chapter 2. Then translate the data from those forms into the format of the Input Data File. We provide blank forms for all models and procedures in Appendix B.

5.2 Input Data Formats

The Input Data File is read by a FORTRAN program and so must conform to precise format specifications. Originally, the Input Data File consisted of a deck of 80-column punched cards, with one input parameter per card, so the data format is still specified in terms of data fields in card-image columns, even though cards are no longer used. Figure 5.1 for the sample case is an example of the proper format.

Looking at Figure 5.1 you will notice that the first part of the file consists of a series of lines that begin with a positive integer. Each of these lines specifies an element of a Data Input Array, W(n). This format goes as far as the line that begins with 575. At the line beginning with -1, the data format changes to accept tabular input data. First, we will explain how to specify data to be read into W(n); then we will explain how to enter data in the tabular format.

5.3 Specifying the W-Array Input

The W-array input format consists of a single 80-column line with four data fields: n, W(n), unit conversion characters, and a description field.

The first three card-image columns contain the first data field in I3 format and specify the index, n, of the array W(n). The value of n must be between 0 and 999, and if there are fewer than three digits, the entry must be right-justified, or else trailing zeroes will be appended to fill out the three columns. If two or more lines begin with the same value of n, the last one prevails.

The second field, columns 4-17, contains the value of W(n) in E14.7 format. The value can be entered in either E or F format, but if the E format is used, the exponent must be right-justified within the 14 spaces, or else zeroes will be appended.

The third field, columns 18-24, contains characters that tell the program to convert the units of the data, as input, to units used by the program. The present choices available for input in this field are given in Table 5.1; the characters must be input in exactly the columnar format shown.

Table 5.1--Units conversion on input

Units of input value*	Meaning	Conversion needed	Value stored by read-in routine
AN RD	Angle in radians	None	V_i
AN DG	Angle in degrees	degs to radians or deg/s to rad/s	$V_i\ \pi/180$**
AN KM	Central earth angle in kilometers	km to rad	V_i/r_e***
LN KM	Length in kilometers	None	V_i
LN M	Length in meters	m to km	$V_i/1000$
LN NM	Length in nautical miles	nmi to km	$1.852\ V_i$
LN FT	Length in feet	ft to km	$3.048006096 \times 10^{-4}\ V_i$
FQ HZ	Frequency in hertz	Hz to rad/s	$2\pi V_i$
FQ S	Frequency expressed as a period in seconds	Period in s to frequency in rad/s	$2\pi/V_i$
T****	Transmitter height relative to terrain instead of sea level	Add terrain height to transmitter height	V_i (also, a flag is set)*****

* The five characters listed are to be put in card-image columns 18 through 22 of the W-array input value to be converted, or put above the data-input column of tabular input. For three-column tabular input, for example, the five characters should be in columns 1-13, 14-26 and 27-39. The five characters are automatically put in the appropriate place when using the WMOD editor.

** V_i is the input value.

*** r_e is the radius of the earth. The current value of W(1) in the W array is used for this conversion.

**** Applies only for input to W(3) (transmitter height). The "T" must be put in card-image column 24.

***** At the start of each ray, the status of the flag is checked. If the flag is set, then the terrain height at the longitude and latitude of the transmitter is added to the transmitter height. For general terrain models, the terrain height at a given longitude and latitude can only be estimated. For all of the presently available terrain models, the estimate gives an exact result, however, because $\partial g/\partial r$ is constant.

The fourth field (columns 25-80) contains descriptive comments, which aid the user in setting up the table. These comments are optional and arbitrary as far as HARPA is concerned, but for n ≥ 100 and divisible by 25, the first word in the comment field is read when WMOD is used for editing and must be a valid model name. This convention will be described in a report about the supplementary programs. Where practical, the comments should describe the function of all acceptable values of the parameter, not just the present value, so that the comment would not have to be changed when the parameter is changed. We have included nonzero initial values in the comment field, where applicable. To make it easier to see the model groupings, we have adopted the convention of indenting the comments that describe model parameters.

5.3.1 Initialization of the Input Data Parameters

Before reading the Input Data File, the program initializes all of the input parameters, W(n). Most are set to zero, but a few are given nonzero initial values that correspond to common usage. An example is the latitude of north pole of the computational coordinate system, W(24), which usually has a value of $\pi/2$. Section 5.3.2 denotes those nonzero initial values by parentheses. These initial values can be overridden by the Input Data File (including a value of zero), but if no value is specified for a W(n) in the Input Data File, then its initial value prevails.

In addition, some initial values are given "zero-override" priority, which means that W(n) assumes its nonzero initial value if no value is input, <u>but also if a zero is input</u>. This zero override operates when a zero value would produce meaningless results or cause difficulty in program execution. An example is the plot expansion factor, W(82). Section 5.3.2 denotes by square brackets the nonzero initial values that override zero.

To help the user keep track of the unit conversions and initializations, all nonzero W(n) values, in the units actually used by HARPA, are listed at the beginning of the printout (Appendix A). In the examples given above, if W(24) were given a value of zero in the Input Data File, no value would be printed for W(24). On the other hand, if W(82) is given a zero value in the Input Data File, a message is printed indicating "INPUT OVERRIDDEN," and the non-zero override value is printed.

5.3.2 Explanation of the Input Data Parameters

Because HARPA has evolved from ray-tracing programs for other media, some values of the input parameter index, n, are not used in HARPA, but may be used in other versions of the program. As far as possible, n is assigned consistently among the different versions, and blocks of n are assigned to groups of related parameters.

A list is given next of all the parameters used by HARPA, with a description of their meanings and idiosyncrasies. Those with nonzero initial values need not be entered in the Input Data File, if the value is what you want. If no initial value is indicated, a zero will be assigned if you leave it out of the Input Data File. The default units given in parentheses are those which are assumed if no unit conversions are put into columns 18-24. Also included in the table is the FORTRAN name (where one exists) assigned (in EQUIVALENCE statements) to each variable in the program. Those labeled "not used" can be assigned to additional input parameters, but those labeled "used by other programs" or "used internally" should not be used.

W(1) EARTHR (6370.) -- Radius (kilometers) of the earth. Can be set to a very large value for a "flat-earth" approximation.

W(2) RAY -- Used by other programs.

W(3) XMTRH -- Height (kilometers) of the transmitter (source) above sea level. If there is a T in column 24, it is the height above the terrain.

W(4) TLAT -- North geographic latitude (radians) of the transmitter. Can be entered in kilometers (or degrees) by putting AN KM (or AN DG) beginning in column 18.

W(5) TLON -- East geographic longitude (radians) of the transmitter. Can be entered in kilometers (or degrees) by putting AN KM (or AN DG) beginning in column 18.

W(6) OW -- Used internally.

W(7) FBEG -- Initial acoustic wave frequency (rad/s). Can be entered in Hz (or period in seconds) by putting FQ HZ (or FQ S) beginning in column 18.

W(8) FEND -- Final frequency (rad/s). Can be entered in Hz (or period in seconds) by putting FQ HZ (or FQ S) beginning in column 18.

W(9) FSTEP -- Step in frequency (rad/s). Can be entered in Hz (or period in seconds) by putting FQ HZ (or FQ S) beginning in col 18. Set = 0 for no stepping.

W(10) AZ1 -- Used internally.

W(11) AZBEG -- Initial azimuth angle (radians east of north) of transmission. Can be entered in degrees by putting AN DG beginning in column 18.

W(12) AZEND -- Final azimuth angle (radians east of north) of transmission. Can be entered in degrees by putting AN DG beginning in column 18.

W(13) AZSTEP -- Step in azimuth angle (radians east of north) of transmission. Can be entered in degrees by putting AN DG beginning in column 18. Set = 0 for no stepping.

W(14) BETA -- Used internally.

W(15) ELBEG -- Initial elevation angle (radians above horizontal) of transmission. Can be entered in degrees by putting AN DG beginning in column 18.

W(16) ELEND -- Final elevation angle (radians above horizontal) of transmission. Can be entered in degrees by putting AN DG beginning in column 18.

W(17) ELSTEP -- Step in elevation angle (radians) of transmission. Can be entered in degrees by putting AN DG beginning in column 18. Set = 0 for no stepping.

W(18)-W(19) -- Not used.

W(20) RCVRH -- Height (kilometers) above sea level of the receiver surface when model RHORIZ is used; height of the receiver surface above the terrain when model RTERR is used.

W(21) ONLY -- Set = 0 to stop frequency increment when ray goes out of bounds (applies only when elevation and azimuth angles are not stepped).

W(22) HOP -- Maximum number of ray hops (intersections with or closest approaches to the receiver surface); ray calculation stops when reached, printing MAX HOPS. Closest approaches count as two hops.

W(23) MAXSTP (1000.) -- Maximum number of integration steps per hop; ray calculation stops when reached, printing STEP MAX.

W(24) PLAT ($\pi/2$) -- Geographic latitude (radians) of the north pole of the computational coordinate system.

W(25) PLON -- Geographic longitude (radians) of the north pole of the computational coordinate system.

W(26) HMAX (500.) -- Maximum ray height (kilometers) above sea level; ray calculation stops if exceeded, printing MAX HT.

W(27) HMIN -- Minimum ray height (kilometers) above sea level; calculation stops if ray goes below this height, printing MIN HT.

W(28) RGMAX -- Maximum ground range (kilometers at sea level) of the ray from the transmitter; ray calculation stops if exceeded, printing MAX RANG.

W(29) RAYFNC -- A set of seven binary digits to select execution of HARPA and supplementary programs. To run HARPA, use 100. Setting = 0 is the same as all ones and will run HARPA.

W(30)-W(32) Used by other programs.

W(33) EXTINC (999.999) -- Maximum absorption (dB); ray calculation stops if value exceeded, printing EXTINC. Set = 0 for no maximum.

W(34)-W(40) -- Not used.

W(41) INTYP (3.): Integration type:
= 1 for Runge-Kutta integration without error checking;
= 2 for Adams-Moulton integration without error checking;
= 3 for Adams-Moulton integration with relative-error checking;
= 4 for Adams-Moulton integration with absolute-error checking.

W(42) MAXERR (1.E-4) -- Maximum allowable integration error per step. RKAM routine decreases step size to achieve this error.

W(43) ERATIO (50.) [50.] -- Ratio of maximum to minimum single-step integration error; RKAM increases step size when error is smaller that W(42) by this factor.

W(44) STEP1 (1.0) -- Initial integration step size (seconds).

W(45) STPMAX (100.) -- Maximum integration step size (seconds).

W(46) STPMIN (1.E-8) -- Minimum integration step size (seconds).

W(47) FACTR (.5) [0.5] -- Factor multiplying integration step size when decreasing step size.

W(48)-W(56) Not used.

W(57) -- Phase-time integration: 0 to not integrate; 1 to integrate; 2 to integrate and print.

W(58) -- Absorption integration: 0 to not integrate; 1 to integrate; 2 to integrate and print.

W(59) -- Doppler shift integration: 0 to not integrate; 1 to integrate; 2 to integrate and print.

W(60) -- Path-length integration: 0 to not integrate; 1 to integrate; 2 to integrate and print.

W(61)-W(70) -- Assigned to future integration options.

W(71) SKIP -- [1.E31] Number of integration steps between printed lines. Set = 1 to print every step; = 0 to suppress periodic printing.

W(72) RAYSET -- Write machine-readable raysets to file PUNCH -- 1 = yes; 0 = no.

W(73) PCNTRW -- Add diagnostic printout lines: 1 = yes; 0 = no.

W(74) PRTSRP -- Produce normal printout every W(71) steps -- 0 = yes; 1 = no.
Also produces printout at special events.

W(75) HITLET [.15] -- Height (inches on our plotter) of lettering on graphs.
"FULANN" in description field activates publication-quality lettering on graphs when read by WMOD. Any other comment in description field produces draft-quality lettering.

W(76) BINRAY -- Write binary raypath description to file TAPE6 -- 1 = yes;
0 = no.

W(77) PAGLIN (66.) -- Page length (lines) for printout.

W(78)-W(79) -- Not used.

W(80) APOG, PRIGEE -- 0 for normal rayplots; 1 for apogee plots.

W(81) PLT: Rayplot projection:
1 = vertical plane, polar projection, rectangular expansion;
2 = horizontal plane, lateral expansion;
3 = vertical plane, polar plot, radial expansion;
4 = vertical plane, rectangular plot.
Make negative to superimpose plot on that from previous runset.

W(82) PFACTW [1.] -- Vertical or lateral expansion factor for rayplot.

W(83) LLAT -- North latitude (radians) of left edge of plot. To enter in degrees (kilometers) put AN DG (AN KM) beginning in column 18.

W(84) LLON -- East longitude (radians) of left edge of plot. To enter in degrees (kilometers) put AN DG (AN KM) beginning in column 18.

W(85) RLAT -- North latitude (radians) of right edge of plot. To enter in degrees (kilometers) put AN DG (AN KM) beginning in column 18.

W(86) RLON -- East longitude (radians) of right edge of plot. To enter in degrees (kilometers) put AN DG (AN KM) beginning in column 18.

W(87) TIC -- Distance (radians) between tick marks on horizontal axis of plot.
To enter in kilometers, put AN KM beginning in column 18.

W(88) HB -- Height (kilometers) of the bottom of the graph above sea level.

W(89) HT -- Height (kilometers) of the top of the graph above sea level.

W(90)-W(95) -- Used by other programs.

W(96) TICV -- Distance (kilometers) between tick marks on vertical axis of plot. Notice that the default units are kilometers for the vertical ticks and radians for the horizontal ticks.

W(97)-W(99) -- Used by other programs.

W(100) UMODEL -- Check number for background wind model.

W(101) UFORM -- format code for background wind model.

W(102) UID -- Data-set ID for background wind model.

W(103)-W(124) -- Parameters for background wind model.

W(125) DUMODEL -- Check number for perturbation wind model.

W(126) DUFORM -- Format code for perturbation wind model.

W(127) DUID -- Data-set perturbation wind model.

W(128) W(149) -- Parameters for perturbation wind model.

W(150) CMODEL -- Check number for background sound speed model.

W(151) CFORM -- Format code for background sound speed model.

W(152) CID -- Data-set ID for background sound speed model.

W(153) W(174) -- Parameters for background sound speed model.

W(175) DCMODEL -- Check number for perturbation sound speed model.

W(176) DCFORM -- Format code for perturbation sound speed model.

W(177) DCID -- Data-set for perturbation sound speed model.

W(178) W(199) -- Parameters for perturbation sound speed model.

W(200) TMODEL -- Check number for background temperature model.

W(201) TFORM -- Format code for background temperature model.

W(202) TID -- Data-set ID for background temperature model.

W(203) W(224) -- Parameters for background temperature model.

W(225) DTMODEL -- Check number for perturbation temperature model.

W(226) DTFORM -- Format code for perturbation temperature model.

W(227) DTID -- Data-set ID for perturbation temperature model.

W(228) W(249) -- Parameters for perturbation temperature model.

W(250) MMODEL -- Check number for molecular weight model.

W(251) MFORM -- Format code for molecular weight model.

W(252) MID -- Data-set ID for molecular weight model.

W(253) W(274) -- Parameters for molecular weight model.

W(275) RMODEL -- Check number for receiver surface model.

W(276) RFORM -- Format code for receiver surface model.

W(277) RID -- Data-set ID for receiver surface model.

W(278) W(299) -- Parameters for receiver surface model.

W(300) GMODEL -- Check number for background terrain model.

W(301) GFORM -- Format code for background terrain model.

W(302) GID -- Data-set ID for background terrain model.

W(303) W(324) -- Parameters for background terrain model.

W(325) DGMODEL -- Check number for perturbation terrain model.

W(326) DGFORM -- Format code for perturbation terrain model.

W(327) DGID -- Data-set ID for perturbation terrain model.

W(328) W(349) -- Parameters for perturbation terrain model.

W(400) W(500) Parameters for supplementary programs.

W(500) AMODEL -- Check number for viscosity/conductivity model.

W(501) AFORM -- Format code for viscosity/conductivity model.

W(502) AID -- Data-set ID for viscosity/conductivity model.

W(503) W(524) -- Parameters for viscosity/conductivity model.

W(525) DAMODEL -- Check number for perturbation viscosity/conductivity model.

W(526) DAFORM -- Format code for perturbation viscosity/conductivity model.

W(527) DAID -- Data-set ID for perturbation viscosity/conductivity model.

W(528) W(549) -- Parameters for perturbation viscosity/conductivity model.

W(550) PMODEL -- Check number for background pressure model.

W(551) PFORM -- Format code for background pressure model.

W(552) PID -- Data-set ID for background pressure model.

W(553) W(574) -- Parameters for background pressure model.

W(575) DPMODEL -- Check number for perturbation pressure model.

W(576) DPFORM -- Format code for perturbation pressure model.

W(577) DPID -- Data-set ID for perturbation pressure model.

W(578) W(599) -- Parameters for perturbation pressure model.

W(600) W(999) -- Assigned to future atmospheric models

5.4 Specifying Tabular Input

In addition to providing values to the W(n) array, the Input Data File lets you enter tabular data to be used by atmospheric model subroutines. In the following discussion, refer to the Input Data File for the sample case (Fig. 5.1) for examples of tabular data.

5.4.1 Changing to the Tabular Format

When the sign of the W-array index n is read (in columns 1-3), it is checked for a valid negative value, which signals a change in the format of the data to follow. Any valid negative value selects a corresponding "input common block" that has been dedicated to a particular model subroutine. Table 5.2 shows which values select which common blocks. The line in Figure 5.1 that begins with -1 and has the comment "ENTER DATA SUBSET FOR BACKGROUND WIND MODEL" is an example selecting common block /B1/ to receive data. Because this line must conform to the W-array format, comments must begin after column 24.

Table 5.2--Description of the identifying numbers in the first three columns of the Input Data File

Code number	Prefix for common-block variables*	Description
1-999		Input to elements 1-999 of the W array as described in Table 4.4 and Section 5.3.2
-1	U	Signals start of tabular input to common block /B1/ (wind velocity) (see Table 4.2)
-2	DU	Signals start of tabular input to common block /B2/ (perturbation wind velocity)
-3	C	Signals start of tabular input to common block /B3/ (sound speed)
-4	DC	Signals start of tabular input to common block /B4/ (perturbation sound speed)
-5	T	Signals start of tabular input to common block /B5/ (temperature)
-6	DT	Signals start of tabular input to common block /B6/ (perturbation temperature)
-7	M	Signals start of tabular input to common block /B7/ (molecular weight)
-8	R	Signals start of tabular input to common block /B8/ (receiver surface)
-9	G	Signals start of tabular input to common block /B9/ (terrain)
-10	DG	Signals start of tabular input to common block /B10/ (terrain perturbation)
-17	V	Signals start of tabular input to common block /B17/ (viscosity/conductivity)
-18	DV	Signals start of tabular input to common block /B18/ (viscosity/conductivity perturbation)
-19	PR	Signals start of tabular input to common block /B19/ (pressure)
-20	DP	Signals start of tabular input to common block /B20/ (pressure perturbation)
0		Signals end of tabular input to one of the above common blocks, or if that is not appropriate, end of the input data

* See Table 4.5.

5.4.2 The Format Line

The line following the negative value of n begins with an integer that specifies the format of the data to follow. The formats are numbered according to the method shown in Table 5.3.

Format A is alphanumeric and lets you enter descriptive comments on the rest of the line that begins with the format number. That comment is reproduced at the beginning of the program printout. The comment "LOGARITHMIC EASTWARD WIND PROFILE" in Figure 5.1 is an example.

Formats 1, 2, and 3 specify 1, 2, and 3 columns, respectively, of floating-point numbers. If formats 1, 2, or 3 are selected, then columns 4-16 of the format line must contain an end-of-data terminator, such as 999.0 in the sample case. The rest of the format line can contain comments describing the tabular data.

5.4.3 The Units Line

The line following the format line is a line containing unit-conversion specifications for the columnar data to follow. The conversion specifications follow the conventions described in Table 5.1. The 5 characters must be placed in the same 13-character columns as the tabular data to be converted with the extra condition that at least one space must separate adjacent conversion specifications.

5.4.4 The Data Lines

Any number of data lines can follow the format line. They must contain numeric data in the format specified in the format line and must be terminated with the number given in the format line as specifying end-of-data. Data values are read until the terminator is encountered. The data following the "U.S. STANDARD ATMOSPHERE 1962 TEMPERATURE PROFILE" comment in Figure 5.1 is an example of 3-column data entry (format 3) into the common block /B5/, which contains data used by temperature model TTANH5. If the number of data values read in exceeds the maximum allocated in the model subroutine, an error will occur and the program will stop.

Table 5.3--Tabular input data formats available*

Format number	Data block	Format	Data read	Cycle length	Number of columns	Number of arrays in data block
0	1	I3	Indicates end of data read into the common block	NA	NA	NA
A	1	I3,10A8	Format number,** alphanumeric data that describe the atmospheric model	1	NA	1
1	1	I3,G13.6	Format number,*** terminator data read consecutively into the data block spaced by the cycle length	Equals dimension of arrays in data block	1	Usually 1
	last	G13.6	Terminator indicates end of data for this data block			
2	1	I3,G13.6	Format number,*** terminator data read consecutively into the data block spaced by the cycle length	Equals dimension of arrays in data block	2	Usually 2
	2-	2G13.6				
	last	2G13.6	Terminator indicates end of data for this data block			
3	1	I3,G13.6	Format number,*** terminator data read consecutively into the data block spaced by the cycle length	Equals dimension of arrays in data block	3	Usually 3
	2-	3G13.6				
	last	3G13.6	Terminator indicates end of data for this data block			

* Except for format A, the structure of the data block is a single variable (whose value will be set equal to the number of data values read in to the data block) followed by the data block arrays. This structure must be set up in the subroutines that define the atmospheric model in question.

** Format A implies the data will go into data block 1.

*** Format numbers 1 through 6 imply the data will go into data block 2. The maximum number of columns is now 6.

5.4.5 The Return Line

After the end-of-data number signifies the end of tabular input, you will usually put a line beginning with a 0 in column 3 to return to the W-array data format.

PART III: HOW THE PROGRAM WORKS

6. The Ray-Tracing Equations

6.1 Hamilton's Equations in Spherical Polar Coordinates

HARPA calculates raypaths by numerically integrating Hamilton's equations. Lighthill (1965, 1978) gives Hamilton's equations in four dimensions (three spatial and one temporal) for Cartesian coordinates. Haselgrove (1954) gives Hamilton's equations in three dimensions for spherical polar coordinates, a more useful coordinate system for geophysical media. Combining the two gives Hamilton's equations in four dimensions in which the three spatial coordinates are earth-centered spherical polar (see Table 6.1 for a definition of the symbols):

$$\frac{dr}{d\tau} = \frac{\partial H}{\partial k_r} , \tag{6.1}$$

$$\frac{d\theta}{d\tau} = \frac{1}{r} \frac{\partial H}{\partial k_\theta} , \tag{6.2}$$

$$\frac{d\phi}{d\tau} = \frac{1}{r \sin\theta} \frac{\partial H}{\partial k_\phi} , \tag{6.3}$$

$$\frac{dt}{d\tau} = - \frac{\partial H}{\partial \omega} , \tag{6.4}$$

$$\frac{dk_r}{d\tau} = - \frac{\partial H}{\partial r} + k_\theta \frac{d\theta}{d\tau} + k_\phi \sin\theta \frac{d\phi}{d\tau} , \tag{6.5}$$

$$\frac{dk_\theta}{d\tau} = \frac{1}{r} \left(- \frac{\partial H}{\partial \theta} - k_\theta \frac{dr}{d\tau} + k_\phi \, r \cos\theta \frac{d\phi}{d\tau} \right) , \tag{6.6}$$

$$\frac{dk_\phi}{d\tau} = \frac{1}{r \sin\theta} \left(- \frac{\partial H}{\partial \phi} - k_\phi \sin\theta \frac{dr}{d\tau} - k_\phi \, r \cos\theta \frac{d\theta}{d\tau} \right) , \tag{6.7}$$

$$\frac{d\omega}{d\tau} = \frac{\partial H}{\partial t} . \tag{6.8}$$

The variables r, θ, ϕ are the (Earth-centered) spherical polar coordinates of a point on the raypath; k_r, k_θ, and k_ϕ are the local Cartesian components of the propagation vector (a vector whose magnitude,

Table 6.1--The more important symbols and their definitions

A	In Section 6.1.2, absorption in dB
C	Sound speed
C_{ref}	A reference sound speed (= .344 km/s)
f	Wave frequency (in Hz)
Δf	Frequency shift of a wave due to a time-varying medium
H	Hamiltonian
k_r, k_θ, k_ϕ	Components of the propagation vector in the r, θ, ϕ directions--a vector normal to the wave front having a magnitude $2\pi/\lambda = \omega/v$
k_{disp}	Complex wave number determined by the dispersion relation
M	Mean molecular atmospheric weight (the average is over molecular constituents)
P	Phase path length, phase of the wave divided by the reference wave number ($2\pi/\lambda_o = \omega/C_{ref}$)
P'	Group path length = $C_{ref}t$
p	Atmospheric pressure
R	Gas constant = 8.31436×10^{-3} kg (kg mole)$^{-1}$ km^2 s^{-2} K^{-1}
r, θ, ϕ	Spherical polar coordinates of a raypath point
s	Geometric raypath length
T	Atmospheric temperature
t	Time of travel of a wave packet (in some cases, used to express the time dependence of the propagation medium)
V	Wind velocity
V_r, V_θ, V_ϕ	Components of the wind velocity in the r, θ, ϕ direction
v	Wave phase velocity
γ	= 1.4, the ratio of specific heat at constant pressure to that at constant density
θ	Colatitude in spherical polar coordinates
λ	Wavelength
$\lambda_o = (2\pi/\omega)C_{ref}$	Reference wavelength
ρ	Atmospheric density
τ	Independent variable in Hamilton's equations (no physical significance)
ϕ	Longitude in spherical polar coordinates
Ω	$= \omega - \vec{k}\cdot\vec{V}$, the intrinsic wave frequency, the wave frequency as seen by an observer moving with the medium
$\omega = 2\pi f$	Radian wave frequency
$\Delta\omega = 2\pi\Delta f$	Radian frequency shift

$$k = \sqrt{k_r^2 + k_\theta^2 + k_\phi^2} = 2\pi/\lambda \quad , \tag{6.9}$$

is the wave number, and that points in the wave normal direction) in the r, θ, and ϕ directions; t is time--in (6.4) it is the propagation time of a wave packet; in (6.8) it expresses the variation with time of a time-varying medium; τ is a parameter whose value depends on the choice of the Hamiltonian H. Section 6.4 explains how the Hamiltonian is defined.

For actual calculation, HARPA uses group path $P' = C_{ref}\, t$ (where C_{ref} is a standard reference speed) as the independent variable because the derivatives with respect to P' are independent of the choice of Hamiltonian, allowing the program to switch Hamiltonians in the middle of a path. This choice automatically causes the program to take smaller steps in real path length where the calculations are more critical, as when refractive index varies rapidly. These equations are obtained by dividing (6.1) through (6.8) by C_{ref} times (6.4):

$$\frac{dr}{dP'} = - \frac{1}{C_{ref}} \frac{\partial H/\partial k_r}{\partial H/\partial \omega} \quad , \tag{6.10}$$

$$\frac{d\theta}{dP'} = - \frac{1}{rC_{ref}} \frac{\partial H/\partial k_\theta}{\partial H/\partial \omega} \quad , \tag{6.11}$$

$$\frac{d\phi}{dP'} = - \frac{1}{rC_{ref}\, \sin\theta} \frac{\partial H/\partial k_\phi}{\partial H/\partial \omega} \quad , \tag{6.12}$$

$$\frac{dk_r}{dP'} = \frac{1}{C_{ref}} \frac{\partial H/\partial r}{\partial H/\partial \omega} + k_\theta \frac{d\theta}{dP'} + k_\phi \sin\theta \frac{d\phi}{dP'} \quad , \tag{6.13}$$

$$\frac{dk_\theta}{dP'} = \frac{1}{r} \left(\frac{1}{C_{ref}} \frac{\partial H/\partial \theta}{\partial H/\partial \omega} - k_\theta \frac{dr}{dP'} + k_\phi\, r \cos\theta \frac{d\phi}{dP'} \right) \quad , \tag{6.14}$$

$$\frac{dk_\phi}{dP'} = \frac{1}{r \sin\theta} \left(\frac{1}{C_{ref}} \frac{\partial H/\partial \phi}{\partial H/\partial \omega} - k_\phi \sin\theta \frac{dr}{kP'} - k_\phi\, r \cos\theta \frac{d\theta}{dP'} \right) \quad , \tag{6.15}$$

$$\frac{d(\Delta f)}{dP'} = \frac{1}{2\pi} \frac{d\Delta\omega}{dP'} = \frac{1}{2\pi} \frac{d\omega}{dP'} = - \frac{1}{2\pi} \frac{\partial H/\partial t}{\partial H/\partial \omega} \quad . \tag{6.16}$$

Equation (6.16) for the frequency shift of a wave propagating through a time-varying medium follows directly from Hamilton's equations (6.4) and (6.8). An alternative derivation is given by Bennett (1967). Large frequency shifts should be accumulated along the raypath and the shifted frequency used in calculations at each point on the raypath. Equations (6.1) through (6.8) imply that all eight dependent variables vary along the path, and that at each point on the path the instantaneous value of all parameters (including frequency) is used in further evaluations of the equations. However, the time variation of the atmosphere due to natural causes is so slow that the resulting frequency shifts have negligible effect on the propagation. For this reason, HARPA calculates frequency shift to compare with

frequency-shift measurements, but does not adjust the frequency of the wave used in the propagation calculations.

The first six differential equations, (6.10) through (6.15), are always integrated. By setting W(59), the user can choose whether to have the program integrate (6.16) to calculate the frequency shift.

6.1.1 Phase Path

Three other quantities can be calculated by integration along the ray-path. The phase path P (phase divided by the reference wave number $2\pi/\lambda_o = \omega/C_{ref}$) is calculated by integrating

$$\frac{dP}{dP'} = \frac{C_{ref}}{\omega}\left(k_r \frac{dr}{dP'} + k_\theta\, r \frac{d\theta}{dP'} + k_\phi\, r \sin\theta \frac{d\phi}{dP'}\right)$$

$$= -\frac{1}{\omega}\frac{k_r \frac{\partial H}{\partial k_r} + k_\theta \frac{\partial H}{\partial k_\theta} + k_\phi \frac{\partial H}{\partial k_\phi}}{\partial H/\partial\omega} \quad . \qquad (6.17)$$

6.1.2 Absorption

If the absorption per wavelength is small (as it must be for this type of ray tracing to be valid), then an approximate formula can be integrated to give the absorption in decibels:

$$\frac{dA}{dP'} = -\frac{10}{\log_e 10}\frac{\omega}{C_{ref}}\frac{\text{imag}\,(k^2_{disp})}{k_r^2 + k_\theta^2 + k_\phi^2}\frac{dP}{dP'}$$

$$= \frac{10}{\log_e 10}\frac{\text{imag}\,(k^2_{disp})}{k_r^2 + k_\theta^2 + k_\phi^2}\frac{k_r \frac{\partial H}{\partial k_r} + k_\theta \frac{\partial H}{\partial k_\theta} + k_\phi \frac{\partial H}{\partial k_\phi}}{C_{ref}\,\partial H/\partial\omega} \quad , \qquad (6.18)$$

where k_{disp} is the (complex) wave number determined by the dispersion relation. If you want to include the effects of absorption from some independent formula for absorption, then you can add that as a new equation to HAMLTN. The appropriate equation would be

$$dA/dP' = \omega/C_{ref}\ \alpha/k_{real}\ dP/dP' \quad , \qquad (6.19)$$

where α is an absorption in dB/km, and A will be the absorption in dB.

6.1.3 Path Length

The geometrical path length of the ray can be calculated by integrating

$$\frac{ds}{dP'} = \sqrt{\left(\frac{dr}{dP'}\right)^2 + r^2\left(\frac{d\theta}{dP'}\right)^2 + r^2 \sin^2\theta \left(\frac{d\phi}{dP'}\right)^2}$$

$$= \frac{\sqrt{\left(\frac{\partial H}{\partial k_r}\right)^2 + \left(\frac{\partial H}{\partial k_\theta}\right)^2 + \left(\frac{\partial H}{\partial k_\phi}\right)^2}}{C_{ref}\left|\partial H/\partial\omega\right|} \quad . \tag{6.20}$$

The user can choose to integrate and print frequency shift, phase time, absorption, or path length using Equations (6.16), (6.17), (6.18), or (6.20) by setting the appropriate values of W(59), W(57), W(58), W(60), respectively, in the Input Data File (Figure 2.19).

The user can add differential equations to the program by modifying HAMLTN, the subroutine that evaluates Hamilton's equations.

The Hamiltonian and its derivatives are calculated by one of the versions of dispersion-relation subroutine (with entry point DISPER), which also calculates k_{disp}^2.

6.2 Numerical Integration

Subroutines RKAM and RKAM1 integrate the differential equations numerically using an Adams-Moulton predictor-corrector method with a Runge-Kutta starter. RKAM1 was adapted from a program in the CDC CO-OP library called RKAMSUB, written by G. J. Lastman and dated March 1964. The program executes one integration step by one of four methods the user can specify using W(41). The subroutine is called once for each advance of the independent variable. The flow charts of Figures 6.1 through 6.5 show how the integration routine works.

Usually, RKAM1 is run in mode 3, that is, Adams-Moulton integration with relative-error checking. The user can trade execution time for accuracy by varying the single-step integration error, W(42). RKAM1 will increase or decrease the step length to maintain the specified error. Table 6.2 gives an

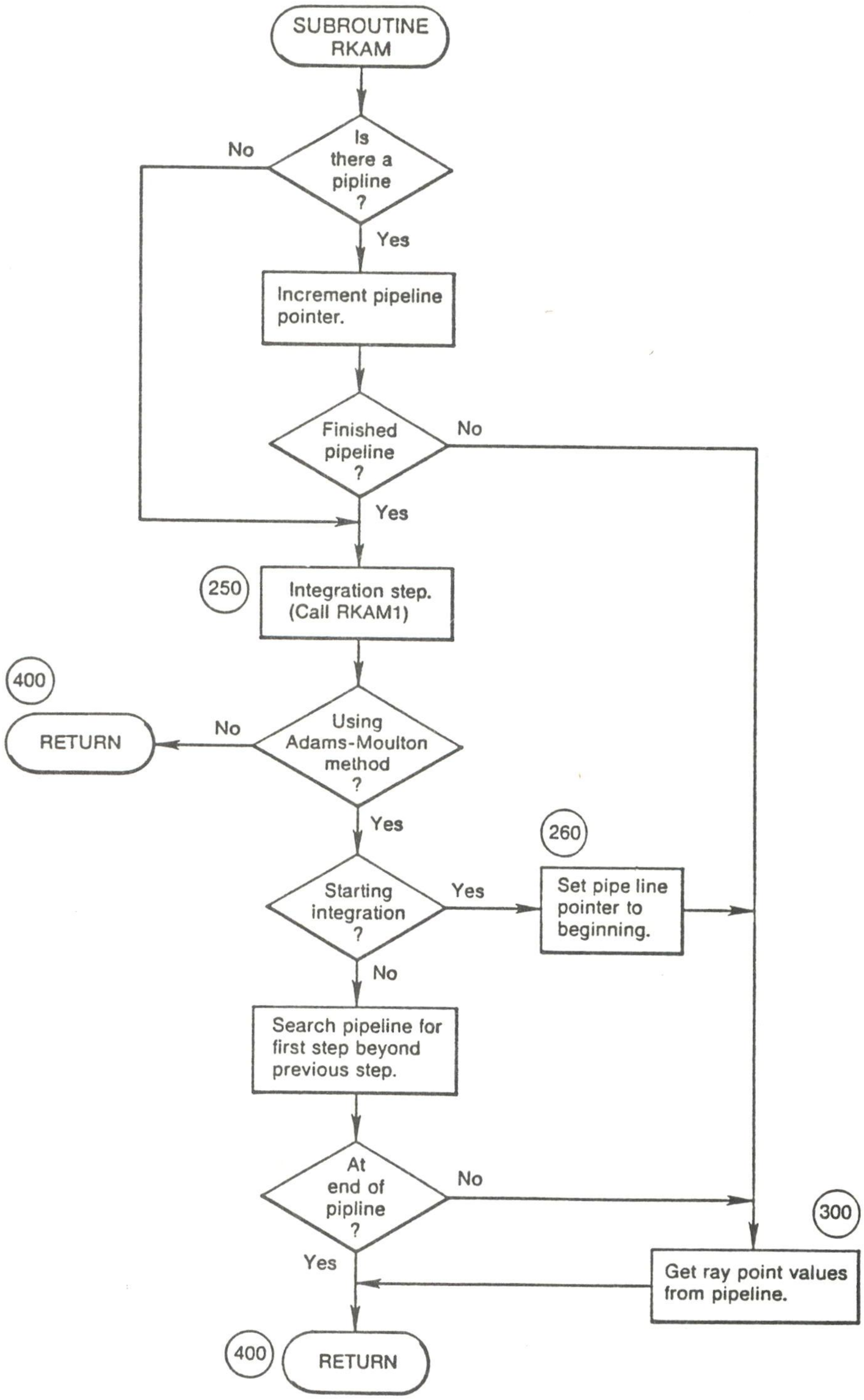


Figure 6.1. Flow chart for subroutine RKAM. The term "pipeline" refers to the sequence of four consecutive integration steps kept by the Adams-Moulton integration method.

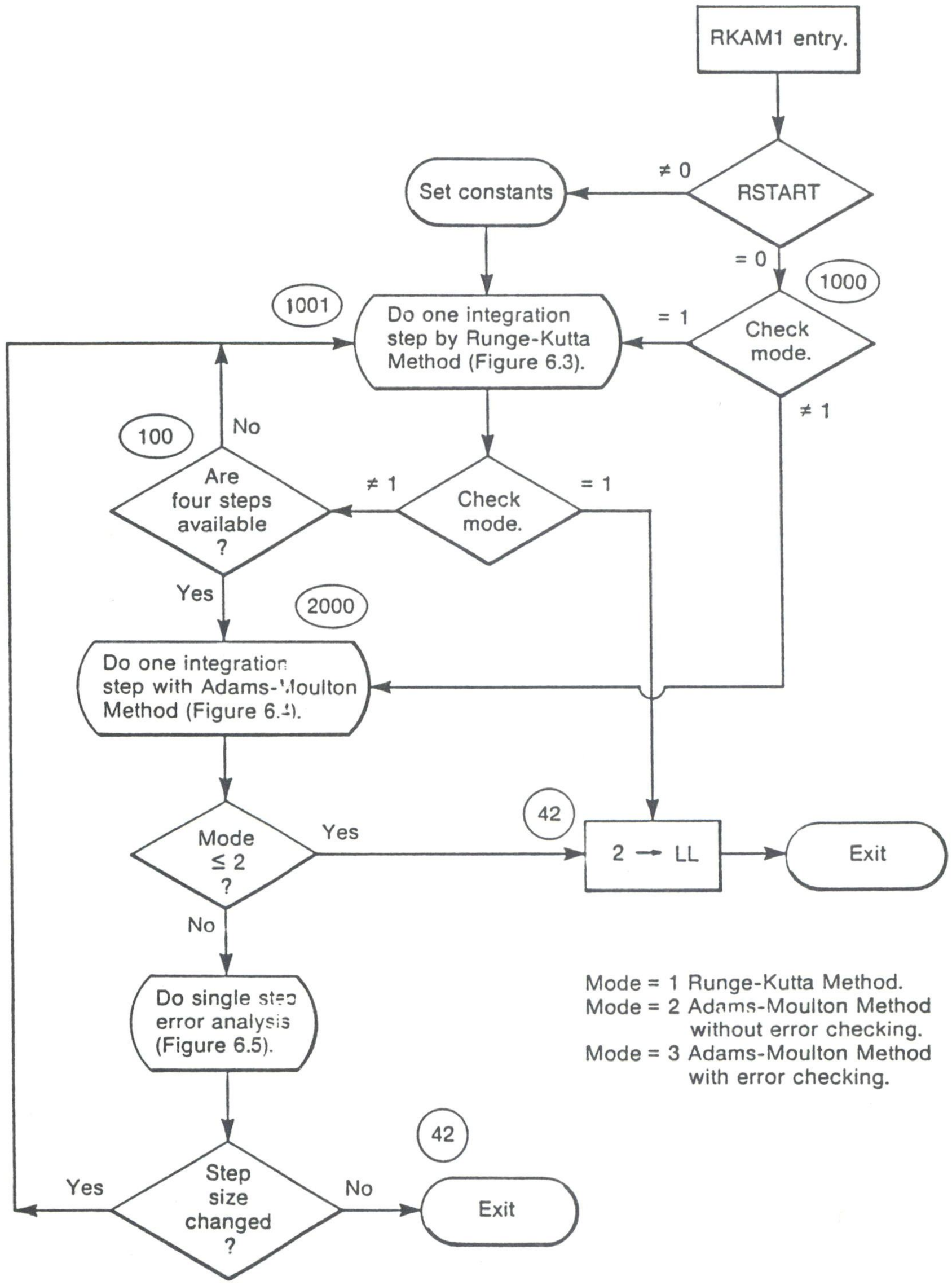


Figure 6.2. Flow chart for subroutine RKAM1.

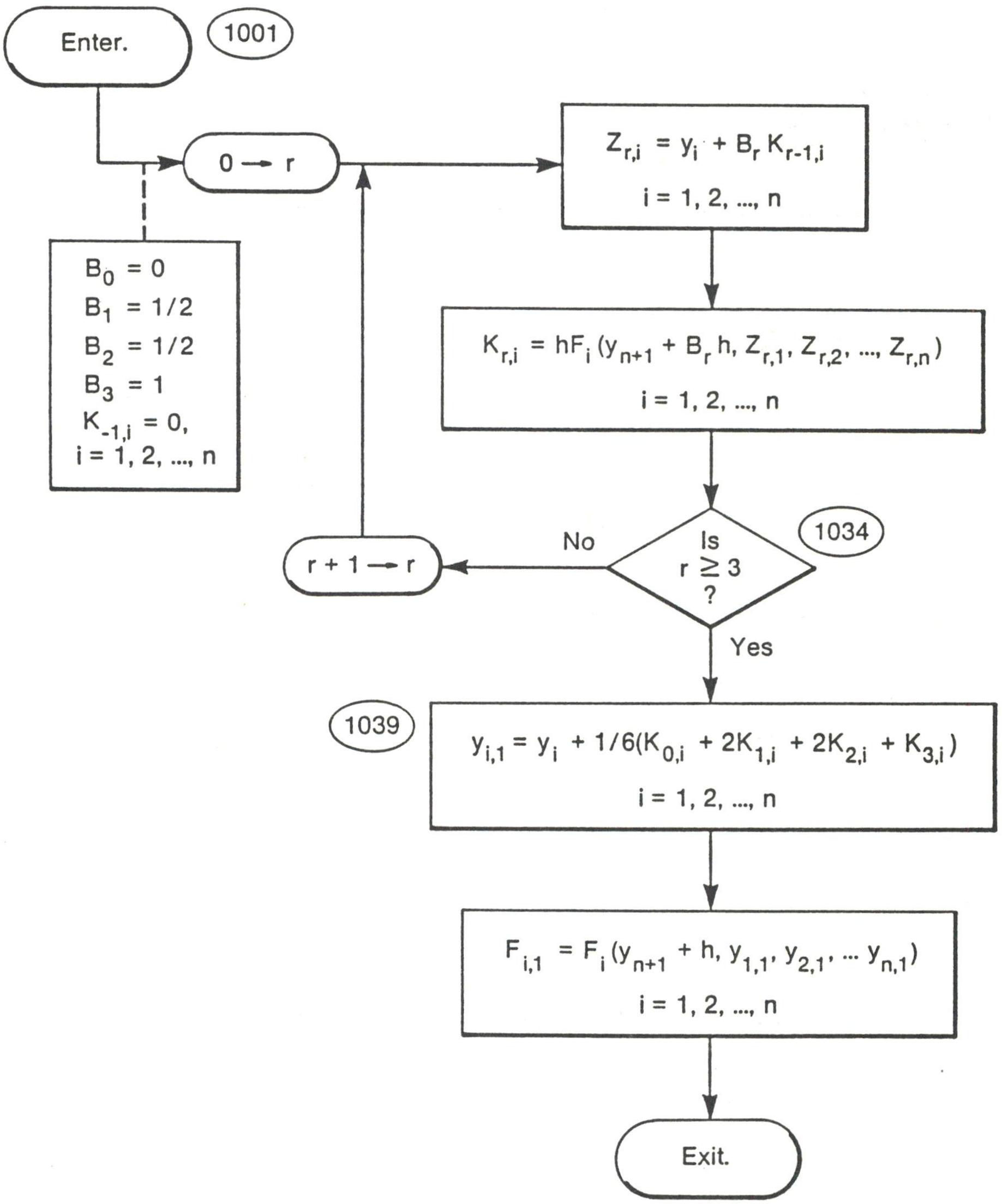


Figure 6.3. Flow chart for the Runge-Kutta procedure. The variables y_1, y_2, ... y_n are the dependent variables, n is the order of the system, and y_{n+1} is the independent variable.

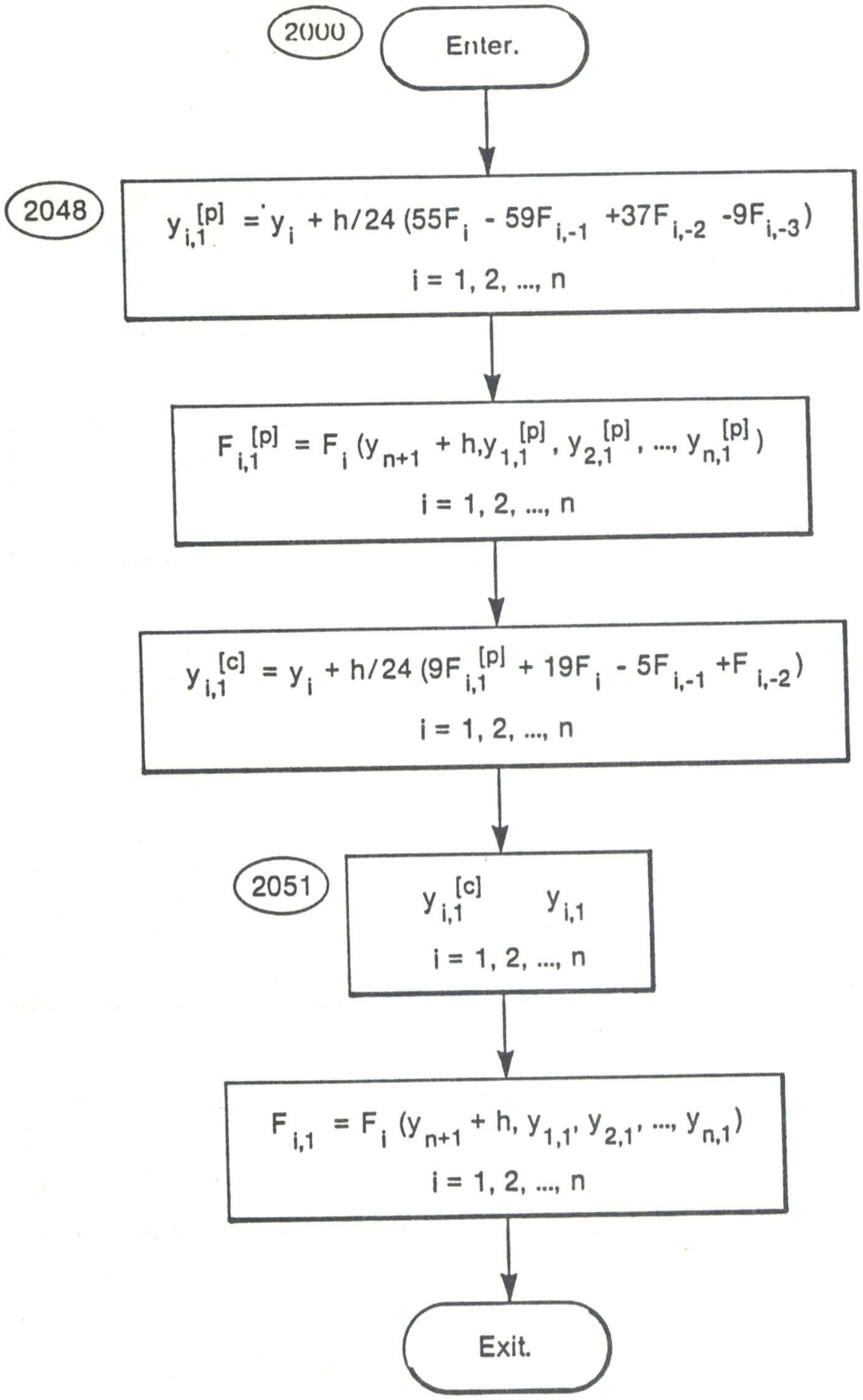
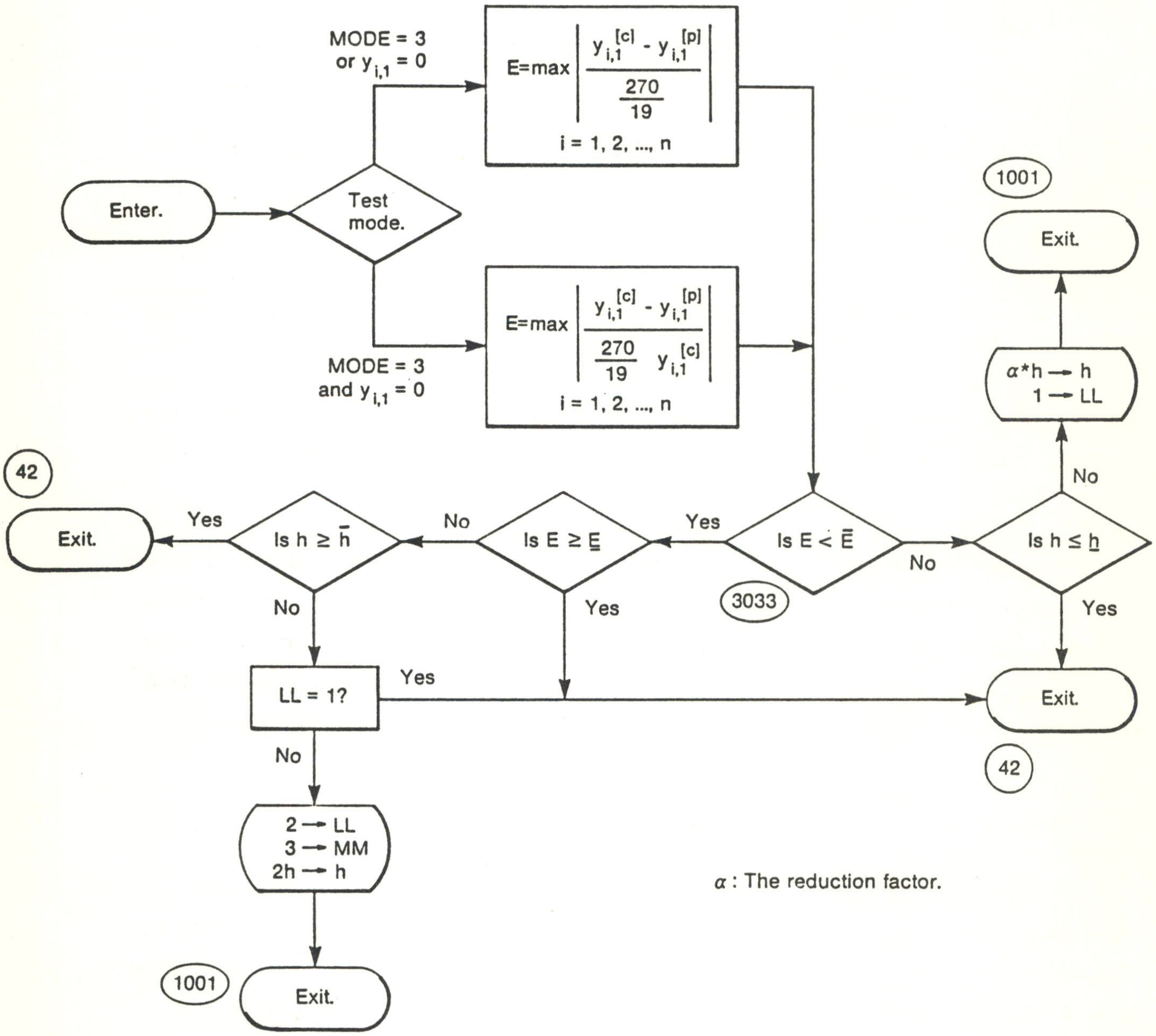


Figure 6.4. Flow chart for the Adams-Moulton integration method. The four starting values needed for this method are supplied by the Runge-Kutta method.



α : The reduction factor.

Figure 6.5. Flow chart for the single-step error analysis. The symbol E represents the maximum single-step error, and $\bar{E}$, $\underline{E}$, $\bar{h}$, and $\underline{h}$ represent the maximum and minimum acceptable single-step error and the maximum and minimum mesh size, respectively.

Table 6.2--Run time vs. accuracy

Maximum integration error, W(42)	Run time (s)	Range error
10^{-9}	9.9	$<10^{-7}$
10^{-8}	7.1	$<10^{-7}$
10^{-7}	4.5	1×10^{-7}
10^{-6}	3.3	1×10^{-6}
10^{-5}	2.3	6×10^{-6}
10^{-4}	1.7	1.7×10^{-4}
10^{-3}	1.2	5.7×10^{-3}

Note: Data obtained using model OT2; elevation angle = 4.46°; range = 1000 km; computer: CYBER 750.

idea of how the tradeoff works for a single ray calculation using the ocean version, HARPO and a model of the ocean sound channel described by Georges et al. (1986).

The user can vary other parameters, W(43) - W(47), that control the way RKAM1 adjusts its step length and controls errors (see Sec. 5.3.2), but the initial values assigned in the sample case have been found to work best for most cases met in practice. If the scale of the model differs greatly from the sample case, the initial step length, W(44), should be adjusted.

6.3 The Atmospheric Sound-Speed Model (Subroutine GAMRTDM)

Atmospheric sound-speed models can be specified either directly as $C(r,\theta,\phi,t)$, or they can call models of other atmospheric variables such as temperature $T(r,\theta,\phi,t)$ using a connecting definition of C(T). One choice we provide assumes that the atmosphere is a perfect gas with the equation of state

$$p = \frac{\rho RT}{M} , \tag{6.21}$$

where p is the pressure, ρ is the density,

$$R = 8.31436 \times 10^{-3} \text{ kg (kg mole)}^{-1} \text{ km}^2 \text{ s}^{-2} \text{ K}^{-1} \qquad (6.22)$$

is the universal gas constant, T is the absolute temperature in Kelvins, and

$$M = M(r,\theta,\phi) \qquad (6.23)$$

is the mean molecular weight of the atmosphere.

The square of the sound speed is

$$C^2 = \frac{\gamma RT}{M} , \qquad (6.24)$$

where

$$\gamma = 1.4 \qquad (6.25)$$

is the ratio of the specific heat at constant pressure to the specific heat at constant density. Subroutine GAMRTDM implements Equation (6.24) in HARPA.

The temperature and its gradients are provided as a function of t,r,θ,ϕ by one of the atmospheric temperature-model subroutines. The molecular weight and its gradients are provided as a function of t, r,θ,ϕ by the molecular weight model subroutine. The average molecular weight generally decreases with height because the relative constituency of the atmosphere varies with height. The main effect is from the increase in the fraction of mono-atomic molecules with height. Although the height variation of molecular weight varies with season and time of day as the atmosphere expands and contracts, it can be accurately modeled as a function of the atmospheric pressure (Jones and Georges, 1976). The only molecular weight model included in the present models treats it as a constant, however.

The gradients of the square of the sound speed are as follows.

$$\frac{\partial C^2}{\partial t} = C^2 \left(\frac{1}{T}\frac{\partial T}{\partial t} - \frac{1}{M}\frac{\partial M}{\partial t}\right) \qquad (6.26)$$

$$\frac{\partial C^2}{\partial r} = C^2 \left(\frac{1}{T}\frac{\partial T}{\partial r} - \frac{1}{M}\frac{\partial M}{\partial r}\right) \qquad (6.27)$$

$$\frac{\partial C^2}{\partial \theta} = C^2 \left(\frac{1}{T}\frac{\partial T}{\partial \theta} - \frac{1}{M}\frac{\partial M}{\partial \theta}\right) \qquad (6.28)$$

$$\frac{\partial C^2}{\partial \phi} = C^2 \left(\frac{1}{T}\frac{\partial T}{\partial \phi} - \frac{1}{M}\frac{\partial M}{\partial \phi}\right) . \qquad (6.29)$$

Table 7.11 shows how the output from the sound-speed model subroutine is organized in common block /CC/.

6.4 Acoustic Dispersion Relations

HARPA gains versatility without sacrificing speed by having several versions of some of the subroutines. For example, the four versions of the dispersion relation subroutine allow the user to decide in making up a run module (Section 3.3.2) whether to include or ignore winds and absorption. (If there are no winds (or absorption) in the calculation, it is much cheaper to leave them out of the equations than it is to make the calculations with zero wind, or zero absorption).

The input to the dispersion-relation subroutine is through blank common and common blocks /UU/, /CC/, /TT/, and /MM/. Output is through common block /RIN/. The dispersion-relation subroutine is called through the entry point DISPER. The subroutine names are used only for user identification.

HARPA has four versions of the dispersion-relation subroutine.

(1) ANWNL - Acoustic waves, No Winds, No Losses
(2) AWWNL - Acoustic waves, With Winds, No Losses
(3) ANWWL - Acoustic waves, No Winds, With Losses
(4) AWWWL - Acoustic Waves, With Winds, With Losses

All of these versions calculate a Hamiltonian and its derivatives and the square of the wave number that satisfies the dispersion relation. All of the above variables and some others are in the common block /RIN/ (described in Table 7.9), which has all of the output from the dispersion-relation subroutines.

6.4.1 ANWNL - Acoustic, No Winds, No Losses

The dispersion relation for pure acoustic waves is

$$k^2 = k_r^2 + k_\theta^2 + k_\phi^2 = \frac{\omega^2}{C^2} \quad , \tag{6.30}$$

where $C(t,r,\theta,\phi)$ is the speed of sound (provided by one of the sound-speed model subroutines).

At the beginning of the numerical integration, the magnitude of $\vec{k}$ is automatically set by the program so that the dispersion relation (4.1) is satisfied. During the numerical integration, the components of $\vec{k}$ are allowed to vary according to Hamilton's equations. Because of integration errors, there will be slight differences between k^2 and

$$k_{disp}^2 = \frac{\omega^2}{C^2} \quad , \tag{6.31}$$

the value it would have according to the dispersion relation. As a check on the accuracy of the numerical integration and on the consistency of the equations, the quantity

$$\text{ERROR} \equiv \frac{k^2}{k_{disp}^2} - 1 \tag{6.32}$$

is printed at each step of the raypath calculation. It is possible, however, for ERROR to exceed somewhat the maximum allowable single-step integration error (W42) because k does not vary monotonically along the raypath. ERROR serves mainly as a check that the integration is proceeding correctly and that there are no errors in computing derivatives in the model subroutines. If ERROR is generally smaller than W(42), then integrated quantities that vary monotonically (like travel time) will be computed with the accuracy given by W(42).

We use the following form of the dispersion relation for the Hamiltonian:

$$H(t,r,\theta,\phi,\omega,k_r,k_\theta,k_\phi) = \omega^2 - (k_r^2 + k_\theta^2 + k_\phi^2)\, C^2(t,r,\theta,\phi) \quad . \tag{6.33}$$

The partial derivatives of the Hamiltonian are

$$\frac{\partial H}{\partial t} = - k^2 \frac{\partial C^2}{\partial t} \tag{6.34}$$

$$\frac{\partial H}{\partial r} = - k^2 \frac{\partial C^2}{\partial r} \tag{6.35}$$

$$\frac{\partial}{\partial \theta} = - k^2 \frac{\partial C^2}{\partial \theta} \tag{6.36}$$

$$\frac{\partial H}{\partial \phi} = - k^2 \frac{\partial C^2}{\partial \phi} \tag{6.37}$$

$$\frac{\partial H}{\partial \omega} = 2\omega \tag{6.38}$$

$$\frac{\partial H}{\partial k} = - 2 C^2 k_r \tag{6.39}$$

$$\frac{\partial H}{\partial k_\theta} = - 2 C^2 k_\theta \tag{6.40}$$

$$\frac{\partial H}{\partial k_\phi} = - 2 C^2 k_\phi \tag{6.41}$$

$$k \cdot \frac{\partial H}{\partial k} = - 2 C^2 k^2 \quad . \tag{6.42}$$

6.4.2 AWWNL - Acoustic, With Winds, No Losses

The dispersion relation for pure acoustic waves in terms of the sound speed in the presence of winds is

$$\Omega^2 - C^2 k^2 = 0 \ , \tag{6.43}$$

where

$$k^2 = k_r^2 + k_\theta^2 + k_\phi^2 \tag{6.44}$$

and

$$\Omega = \omega - \vec{k} \cdot \vec{V} = \omega - k_r V_r - k_\theta V_\theta - k_\phi V_\phi \tag{6.45}$$

is the intrinsic frequency of the wave (the frequency seen by an observer moving with the wind). $\vec{V}(t,r,\theta,\phi)$ is the wind velocity (provided by a wind-velocity model subroutine).

At the beginning of the numerical integration, the magnitude of k is set by the program so that the dispersion relation (6.43) is satisfied. During the numerical integration, the components of $\vec{k}$ are allowed to vary according to Hamilton's equations. Because of integration errors, there will be slight differences between K^2 and

$$k^2_{disp} = \frac{\omega^2}{\left(C + \frac{\vec{k}\cdot\vec{V}}{k}\right)^2} \quad , \tag{6.46}$$

the value it would have according to the dispersion relation. Notice that

$$\frac{\vec{k}\cdot\vec{V}}{k} = \frac{k_r V_r + k_\theta V_\theta + k_\phi V_\phi}{\sqrt{k_r^2 + k_\theta^2 + k_\phi^2}} \tag{6.47}$$

is independent of the magnitude of $\vec{k}$, as it should be.

As a check on the accuracy of the numerical integration and on the consistency of the equations, the quantity in (6.32) is printed at each step of the raypath calculation.

We use the following form of the dispersion relation for the Hamiltonian:

$$H(t,r,\theta,\phi,\omega,k_r,k_\theta,k_\phi) =$$

$$\Omega^2(t,r,\theta,\phi,\omega,k_r,k_\theta,k_\phi) - (k_r^2+k_\theta^2+k_\phi^2)\, C^2(t,r,\theta,\phi), \tag{6.48}$$

where the intrinsic frequency Ω is given by (6.45)

The partial derivatives of the Hamiltonian are as follows.

$$\frac{\partial H}{\partial t} = 2\Omega \frac{\partial \Omega}{\partial t} - k^2 \frac{\partial C^2}{\partial t} \tag{6.49}$$

$$\frac{\partial H}{\partial r} = 2\Omega \frac{\partial \Omega}{\partial r} - k^2 \frac{\partial C^2}{\partial r} \tag{6.50}$$

$$\frac{\partial H}{\partial \theta} = 2\Omega \frac{\partial \Omega}{\partial \theta} - k^2 \frac{\partial C^2}{\partial \theta} \tag{6.51}$$

$$\frac{\partial H}{\partial \phi} = 2\Omega \frac{\partial \Omega}{\partial \phi} - k^2 \frac{\partial C^2}{\partial \phi} \tag{6.52}$$

$$\frac{\partial H}{\partial \omega} = 2\Omega \tag{6.53}$$

$$\frac{\partial H}{\partial k_r} = -\, 2(\Omega V_r + C^2\, k_r) \tag{6.54}$$

$$\frac{\partial H}{\partial k_\theta} = -\, 2(\Omega V_\theta + C^2\, k_\theta) \tag{6.55}$$

$$\frac{\partial H}{\partial k_\phi} = -\,2(\Omega V_\phi + C^2\, k_\phi) \tag{6.56}$$

$$k \cdot \frac{\partial H}{\partial k} = k_r \frac{\partial H}{\partial k_r} + k_\theta \frac{\partial H}{\partial k_\phi} + k_\phi \frac{\partial}{\partial k_\phi} = -\,2(\Omega \vec{k} \cdot \vec{V} + C^2\, k^2)\ , \tag{6.57}$$

where

$$\frac{\partial \Omega}{\partial t} = -\,k_r \frac{\partial V_r}{\partial t} - k_\theta \frac{\partial V_\theta}{\partial t} - k_\phi \frac{\partial V_\phi}{\partial t} \tag{6.58}$$

$$\frac{\partial \Omega}{\partial r} = -\,k_r \frac{\partial V_r}{\partial r} - k_\theta \frac{\partial V_\theta}{\partial r} - k_\phi \frac{\partial V_\phi}{\partial r} \tag{6.59}$$

$$\frac{\partial \Omega}{\partial \theta} = -\,k_r \frac{\partial V_r}{\partial \theta} - k_\theta \frac{\partial V_\theta}{\partial \theta} - k_\phi \frac{\partial V_\phi}{\partial \theta} \tag{6.60}$$

$$\frac{\partial \Omega}{\partial \phi} = -\,k_r \frac{\partial V_r}{\partial \phi} - k_\theta \frac{\partial V_\theta}{\partial \phi} - k_\phi \frac{\partial V_\phi}{\partial \phi}\ . \tag{6.61}$$

6.4.3 ANWWL - Acoustic, No Winds, With Losses and AWWWL - Acoustic, With Winds, With Losses

Propagation losses for acoustic waves in the atmosphere occur when viscosity and thermal conductivity are included in the Navier-Stokes equations that describe fluid dynamics. The acoustic wave dispersion relation that results gives a complex wave number. The imaginary part of that wave number leads to absorption as explained in Section 6.1.2.

If the imaginary part of the wave number is small ($k^2_{imag} << k^2_{real}$) (as it must be for ordinary ray tracing such as described here to be valid), then we can neglect the effect of viscosity and thermal conductivity on the real part of the wave number so that the raypaths will be unaffected by viscosity and thermal conductivity.

Within this assumption, we can approximate (the square of) the imaginary part of the acoustic wave number for propagation through a perfect gas as (Gossard and Hooke, 1975, pp. 230-233)

$$k^2_{imag} = -\,\Omega/(\gamma P)\ [4/3\mu + (\gamma-1)^2\, M/(\gamma R)\ \kappa]\ k^2_{real}\ , \tag{6.62}$$

where $\gamma = 1.4$ is the ratio of specific heat at constant pressure to that at constant density, P is the atmospheric pressure, μ is the viscosity, M is the

atmospheric mean molecular weight, R is the universal gas constant, and κ is the thermal conductivity.

Whenever you use a dispersion relation with losses (ANWWL or AWWWL), you have to supply models for P, μ, κ and M. We provide one model for μ and κ (MUARDC), one for P (PEXP), and one for M (MCONST).

6.5 Reflecting Rays From Irregular Terrain

This section describes the method HARPA uses to find the intersections of a ray with any terrain surface and to compute the correct reflected ray, even in an anisotropic medium (an atmosphere with winds). A more detailed discussion of terrain-reflection algorithms is given in the report by Jones (1982). Essentially the same methods are used to detect receiver-surface crossings.

6.5.1 Detecting Ray Intersections With the Terrain

Detecting that the ray has crossed the terrain surface is straightforward for the simple case shown in Figure 6.6. Figure 6.7 shows a more difficult example in which the ray crosses the terrain surface twice. It is difficult to distinguish such a raypath from the example in Figure 6.8, knowing only the raypath coordinates and ray directions between the integration steps (shown by dots in Figures 6.7 and 6.8). A further difficulty is that iteration of the numerical integration in Figure 6.7 might lead to finding the wrong intersection with the surface of discontinuity, a problem shared by the example in Figure 6.9.

Although infrequent, the difficulties illustrated in Figures 6.7, 6.8 and 6.9 occur often enough that any useful algorithm must be able to handle them. These difficult cases obviously occur more often when large integration steps are used. This section derives algorithms that can handle these difficult cases in addition to the straightforward cases. Figure 6.10 illustrates cases that HARPA's intersection algorithm will not correctly handle unless step length is decreased or the terrain model is made smoother.

HARPA accepts only terrain models whose surface is smooth and whose slope and curvature are continuous. Thus, wedge-shaped surfaces, for example, are

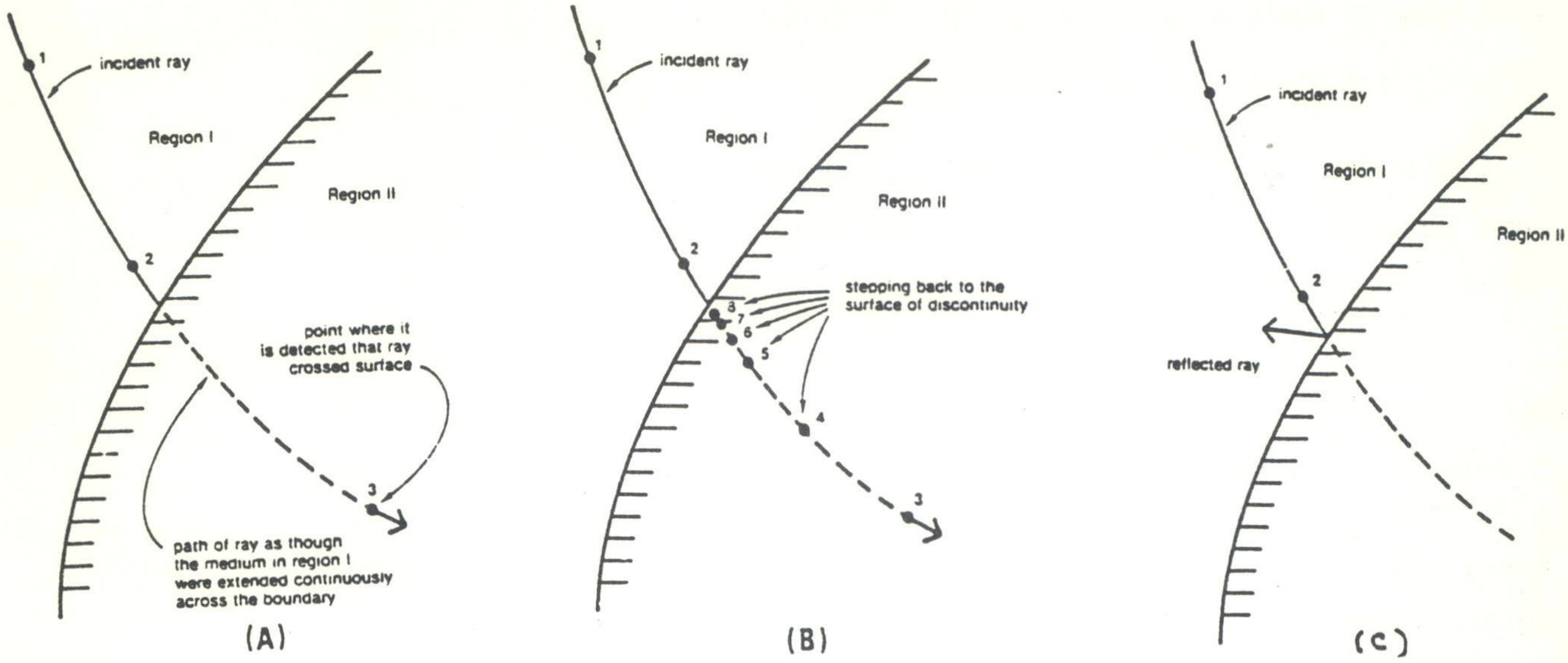


Figure 6.6. Three steps in calculating the intersection and reflection of a ray at a terrain surface: (a) recognition that the ray has crossed the terrain surface (numbers indicate successive positions of the ray after each integration step; the raypath is curved because the atmosphere is inhomogeneous); (b) iteration by numerical integration to find the intersection of the ray with the terrain surface; and (c) computation of the reflected ray ready to start numerical integration in a new direction in the atmosphere. The same algorithm could be used to compute ray refraction at discontinuities of refractive index.

not allowed. Not only are diffraction effects important at such edges, but some of the algorithms developed in this report may not work properly for surfaces with edges. In addition, the algorithms used by HARPA may not always properly handle surfaces that contain caves or tunnels.

At each integration step in the raypath calculation, we assume that the following information is available:

(1) The position of the ray point (r, θ, ϕ) in spherical polar (Earth-centered) coordinates,

(2) The local Cartesian components (k_r, k_θ, k_ϕ) of the wave vector (a vector pointing in the wave-normal direction and normalized so that the magnitude equals the wave number),

(3) The accumulated group time delay, t, of the ray, (which is also the independent variable for the numerical integration), and

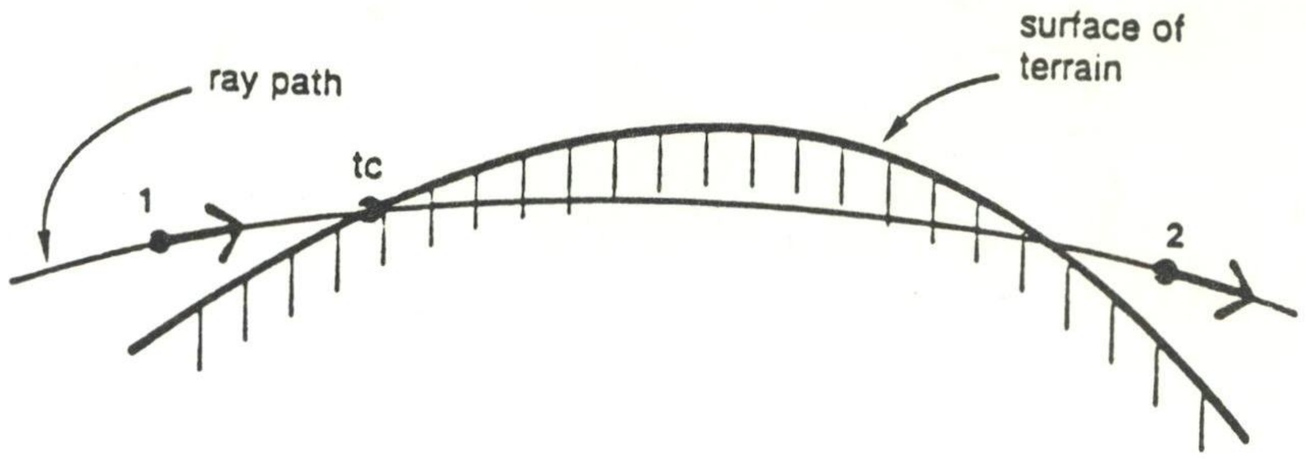


Figure 6.7. A ray crossing a terrain or receiver surface and crossing back again between integration steps. An algorithm that checked only to see if the ray at point 2 was in a different medium than point 1 would miss the intersections.

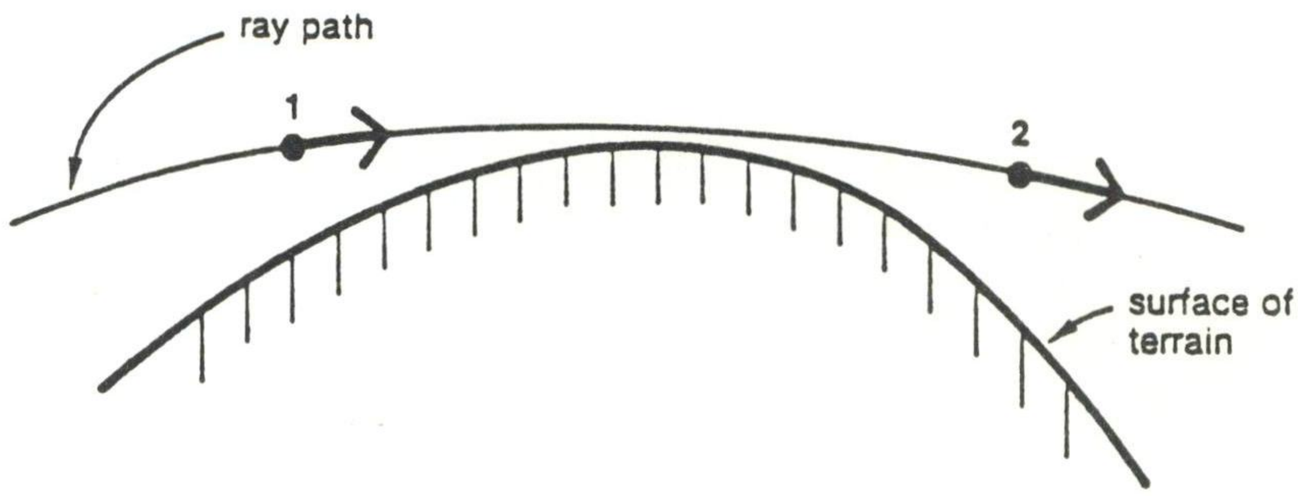


Figure 6.8. A ray that nearly intersects a terrain or receiver surfce. A useful intersection algorithm must be able to distinguish this case from the one depicted in figure 6.7.

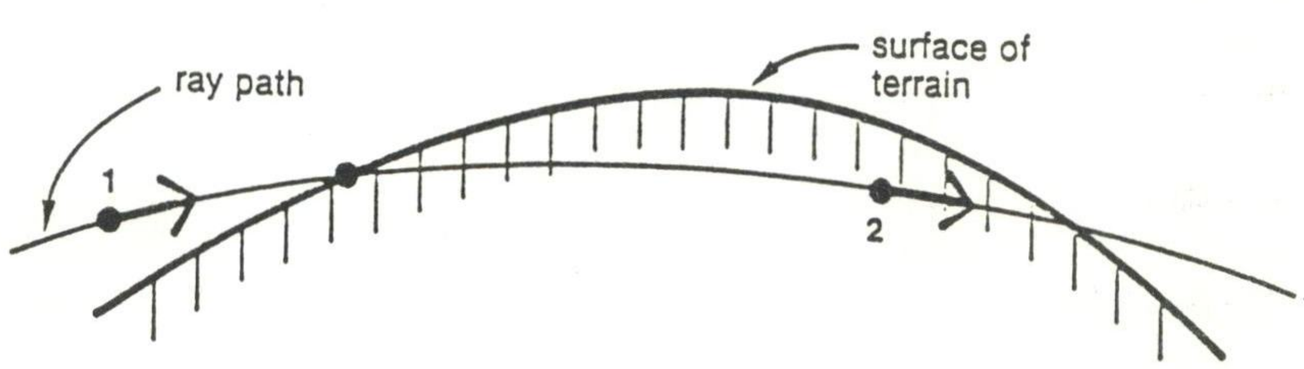


Figure 6.9. A ray crossing a terrain or receiver surface and ending closer to a second intersection. A useful algorithm must step backward and find the first intersection. HARPA will correctly handle the three cases on this page.

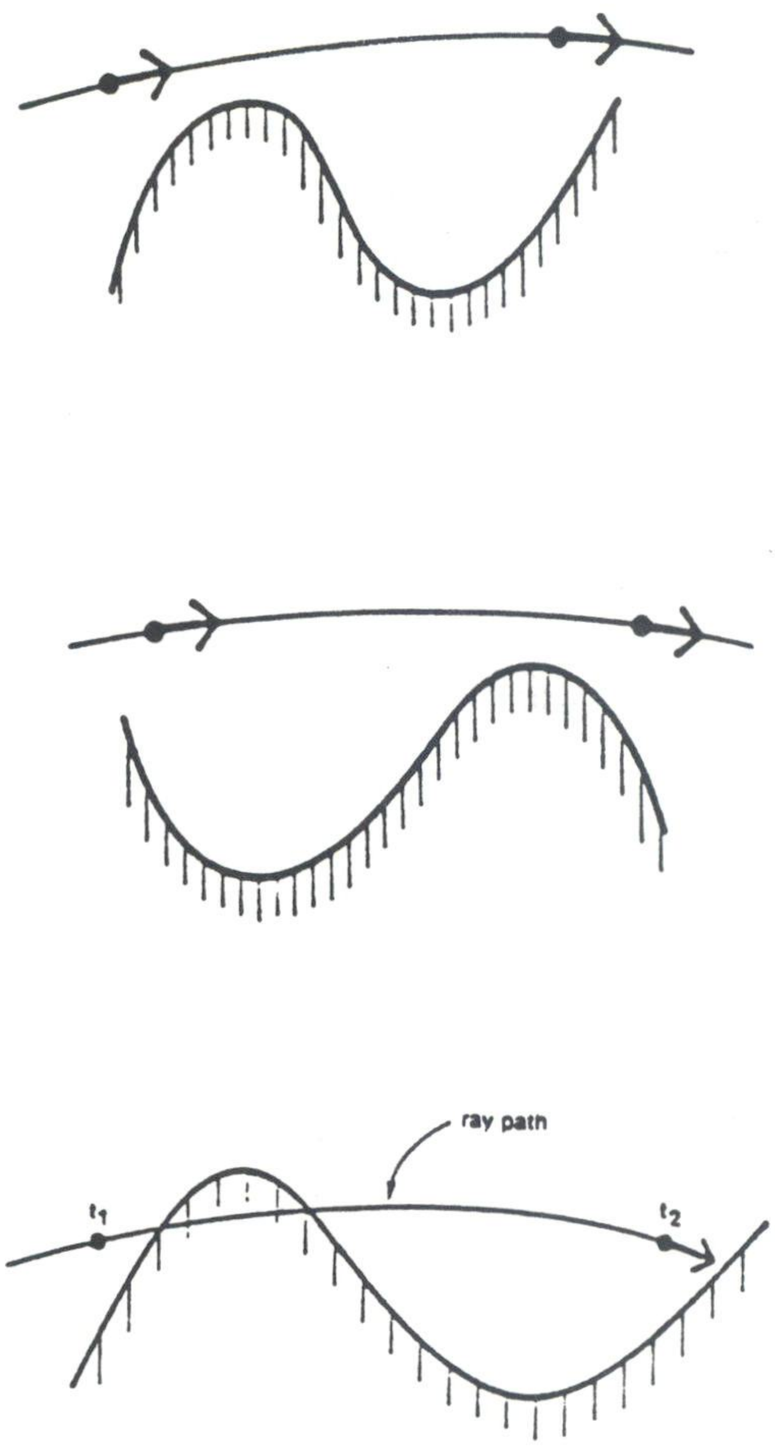


Figure 6.10. Examples of terrain (or receiver-surface) encounters that HARPA's intersection algorithm will not correctly handle. Step length must be decreased, or the terrain model must be smoothed.

(4) The derivatives

$$\dot{r} \equiv dr/dt \tag{6.63}$$

$$\dot{\theta} \equiv d\theta/dt \tag{6.64}$$

$$\dot{\phi} \equiv d\phi/dt \tag{6.65}$$

$$\dot{k}_r \equiv dk_r/dt \tag{6.66}$$

$$\dot{k}_\theta \equiv dk_\theta/dt \tag{6.67}$$

$$\dot{k}_\phi \equiv dk_\phi/dt \ . \tag{6.68}$$

We assume also that the values of any of these variables can be saved from one step to the next for comparison. In particular, we make the following approximations,

$$\ddot{r} \approx (\dot{r}(t_2) - \dot{r}(t_1))/t_2 - t_1) \tag{6.69}$$

$$\ddot{\theta} \approx (\dot{\theta}(t_2) - \dot{\theta}(t_1))/(t_2 - t_1) \tag{6.70}$$

$$\ddot{\phi} \approx (\dot{\phi}(t_2) - \dot{\phi}(t_1))/(t_2 - t_1) \ , \tag{6.71}$$

which allow us to estimate the curvature of ray. In using these algorithms, it would probably be useful to incorporate a test of the validity of the above approximations by evaluating both sides of (6.69) - (6.71), but HARPA does not do that.

The simplest method for predicting whether an extension of the raypath from a point will intersect the terrain surface (or the receiver surface) is to extend the ray in a straight line and see if it meets the terrain when the surface is extended as a plane by using the local slope. However, whenever the curvature of the ray and the terrain are small enough for that approximation to be useful, the ray would probably eventually go below the terrain on one of the integration steps, and the prediction from the simplest algorithm would not be needed.

Because we want an algorithm sophisticated enough to estimate the time of nearest intersection (if one occurs) in cases like those in Figures 6.7 or 6.8, we should include at least the local curvature in any approximations. Also, because it would be difficult to deal with a higher order approximation, a quadratic approximation to both the ray and the terrain seems to be the best compromise.

In addition, when searching for an intersection with the terrain (or receiver) surface, the intersection must be in the correct direction. In the case of the terrain, the intersection will always be into the ground. In the case of the receiver surface, the correct direction of crossing will alternate from one crossing to the next, but for each crossing, the direction will be known. For the purposes of the present development, it is useful to define a parameter S that is equal to +1 if the wanted crossing is upward and -1 if the wanted crossing is downward. Thus, the value of S will always be -1 for a terrain crossing.

6.5.2 The Surface Model

HARPA expresses an arbitrary model of a terrain or receiver surface in the form

$$f(r, \theta, \phi) = 0 \ . \tag{6.72}$$

Because f is zero only on the surface, it always has one sign on one side of the surface and the opposite sign on the other side. Let us call the side of the surface that is underground the inside and the other side the outside. Then we can arbitrarily require that f be positive outside of the surface and negative inside the surface. We can similarly designate an inside and an outside for the receiver surface and make the same requirement on f.

Thus, we have

$$f(r, \theta, \phi) > 0 \tag{6.73}$$

outside the surface and

$$f(r, \theta, \phi) < 0 \tag{6.74}$$

inside the surface. The time derivative of f (which indicates the rate that the ray is moving away from the surface) is

$$\dot{f} = f_r \dot{r} + f_\theta \dot{\theta} + f_\phi \dot{\phi} \tag{6.75}$$

where a subscript indicates a partial derivative with respect to the subscript. The time derivative of (6.75) is

$$\ddot{f} = f_r \ddot{r} + f_\theta \ddot{\theta} + f_\phi \ddot{\phi} + f_{rr} \dot{r}^2 + f_{\theta\theta} \dot{\theta}^2 + f_{\phi\phi}\dot{\phi}^2 + 2f_{r\theta} \dot{r}\dot{\theta} + 2f_{r\phi} \dot{r}\dot{\phi} + 2f_{\theta\phi} \dot{\theta}\dot{\phi}. \tag{6.76}$$

Assuming that (6.76) is nearly constant locally, we have

$$f = f_1 + \dot{f}_1(t - t_1) + \frac{1}{2} \ddot{f}_1(t - t_1)^2 \ , \tag{6.77}$$

where the subscript 1 refers to the values at the time t_1. We want to find the value of t for which the ray intersects the surface, that is, where f = 0. Let t_c be the value for which f = 0. Then

$$0 = f_1 + \dot{f}_1(t_c - t_1) + \frac{1}{2}\ddot{f}_1(t_c - t_1)^2 \quad . \tag{6.78}$$

For simplicity, let us drop the subscript 1 in (6.78), but remember that f and t without subscripts refer to the integration step on the raypath where we are trying to estimate the time t_c where the ray will intersect the surface. Then (6.78) becomes

$$0 = f + \dot{f}(t_c - t) + \frac{1}{2}\ddot{f}(t_c - t)^2 \quad . \tag{6.79}$$

The solution of (6.79), for which the ray is crossing from inside to outside when S = +1 and crossing from outside to inside when S = -1, is

$$t_c - t = \frac{-\dot{f} + S\sqrt{\dot{f}^2 - 2f\ddot{f}}}{\ddot{f}} \quad . \tag{6.80}$$

Within the approximation made here, the ray will intersect the surface if

$$\dot{f}^2 - 2f\ddot{f} > 0 \tag{6.81}$$

but will make a closest approach to the surface if

$$\dot{f}^2 - 2f\ddot{f} < 0 \quad . \tag{6.82}$$

In the latter case, we can estimate the time t_p at which f is a minimum.

$$t_p - t = -\frac{\dot{f}}{\ddot{f}} \quad . \tag{6.83}$$

This is close to the time when the ray makes a closest approach to the surface. If the second derivative in (6.76) is very small, then the formula in (6.80) may be impractical. In that case, the solution

$$t_c - t = \frac{-2f}{\dot{f} + S\sqrt{\dot{f}^2 - 2f\ddot{f}}} \tag{6.84}$$

is more useful. The advantage of (6.84) is that it is uniformly valid as $\ddot{f}$ approaches zero.

In HARPA, different formulas are used in different circumstances: statement 501 in TRACE uses (6.84) to estimate t_c. Subroutine BACKUP uses

$$t_c = t - f/\dot{f} \tag{6.85}$$

when it is stepping to an intersection. Subroutine BACKUP uses (6.83) to step to a closest approach. When BACKUP has tried to step to a closest approach and fails after 10 tries, it tries to find an intersection. In that case, it uses (6.80) to give a first estimate for t_c, then uses (6.85) for iterating. Statement 30 in TRACE uses (6.83) to estimate the time of closest approach. See Section 7.3 for flow charts of these functions.

6.5.3 Reflecting the Ray From the Terrain Surface

Once the intersection with the terrain has been found, the ray must be properly reflected. For an isotropic medium, this is straightforward. The algorithm must first project the wave vector into two components parallel to the surface and the component perpendicular to the surface. It then changes sign on the component perpendicular to the surface.

An anisotropic medium (such as an atmosphere with wind) is more difficult. The two components parallel to the surface remain unchanged, as before, but the component perpendicular to the surface must be changed so that the dispersion relation is satisfied. Although this principle is the same for all media, the solution depends on the dispersion relation. At this point, we must specialize to the particular medium of interest, namely, acoustic waves in the presence of winds.

We need to first separate the wave vector $\vec{k}$ into components perpendicular and parallel to the surface. Let $\vec{n}$ be a unit vector pointing out of the surface. Then the component of $\vec{k}$ normal to the surface is

$$k_\perp = \vec{k} \cdot \vec{n} \tag{6.86}$$

$$\vec{k}_\perp = (\vec{k} \cdot \vec{n})\ \vec{n} \tag{6.87}$$

and the part parallel to the surface is

$$\vec{k}_\parallel = \vec{k} - (\vec{k} \cdot \vec{n})\ \vec{n}\ . \tag{6.88}$$

The dispersion relation for acoustic waves in the presence of winds is

$$-\Omega^2 + c^2 k^2 = 0\ , \tag{6.89}$$

where $$\Omega \equiv \omega - \vec{k}\cdot\vec{v} \tag{6.90}$$

is the intrinsic frequency, ω is the wave frequency, and $\vec{v}$ is the wind velocity.

With the help of (6.90), we can separate (6.89) as follows:

$$-(\omega - \vec{k}_\perp\cdot\vec{v} - \vec{k}_\parallel\cdot\vec{v})^2 + c^2 k_\perp^2 + c^2 k_\parallel^2 = 0 \ . \tag{6.91}$$

We want to solve (6.91) for $k_\perp$, assuming $\vec{k}_\parallel$ to be known. We can rewrite (6.89) as

$$(c^2 - v_\perp^2) k_\perp^2 + 2 \Omega_\parallel v_\perp k_\perp - \Omega_\parallel^2 + c^2 k_\parallel^2 = 0 \ , \tag{6.92}$$

where

$$\Omega_\parallel \equiv \omega - \vec{k}_\parallel\cdot\vec{v} \tag{6.93}$$

and

$$\vec{v}_\perp \equiv (\vec{v}\cdot\vec{n})\ \vec{n} \quad , \quad v_\perp \equiv \vec{v}\cdot\vec{n} \tag{6.94}$$

is the component of wind normal to the surface. The quadratic formula gives the solution to (6.92) as

$$k_\perp = \frac{-\Omega_\parallel v_\perp \pm c\sqrt{\Omega_\parallel^2 - k_\parallel^2 (c^2 - v_\perp^2)}}{c^2 - v_\perp^2} \ . \tag{6.95}$$

One solution of (6.95) should be the normal component of $\vec{k}$ for the incident wave, the other the normal component of $\vec{k}$ for the reflected wave. To convert from the incident wave to the reflected wave, it is necessary simply to change the sign of

$$k_\perp + \frac{\Omega_\parallel v_\perp}{c^2 - v_\perp^2} \ . \tag{6.96}$$

To do this, we can use (6.87) and (6.88) to write

$$\vec{k} = \vec{k} - (\vec{k}\cdot\vec{n})\vec{n} + (\vec{k}\cdot\vec{n})\vec{n} \ . \tag{6.97}$$

This is equivalent to

$$\vec{k} = \vec{k} - (\vec{k}\cdot\vec{n})\vec{n} - \frac{\Omega_{\parallel} v_{\perp}}{c^2 - v_{\perp}^2}\vec{n} + (\vec{k}\cdot\vec{n})\vec{n} + \frac{\Omega_{\parallel} v_{\perp} \vec{n}}{c^2 - v_{\perp}^2} . \qquad (6.98)$$

Let us assume that (6.98) applies to the incident wave, that is,

$$\vec{k}_{inc} = \vec{k}_{inc} - (\vec{k}_{inc}\cdot\vec{n})\vec{n} - \frac{\Omega_{\parallel} v_{\perp}}{c^2 - v_{\perp}^2}\vec{n} + (\vec{k}_{inc}\cdot\vec{n})\vec{n} + \frac{\Omega_{\parallel} v_{\perp} \vec{n}}{c^2 - v_{\perp}^2} , \qquad (6.99)$$

where the subscript inc signifies the incident wave. To get the wave vector for the reflected wave, we need only reverse the sign of the last two terms in (6.99), that is,

$$\vec{k}_{ref} = \vec{k}_{inc} - 2(\vec{k}_{inc}\cdot\vec{n})\vec{n} - 2\frac{\Omega_{\parallel} v_{\perp} \vec{n}}{c^2 - v_{\perp}^2} , \qquad (6.100)$$

where the subscript ref signifies the reflected wave.

To be more explicit, we can write (6.100) in terms of components. We assume an earth-centered spherical polar-coordinate system (r, θ, ϕ). We then consider Cartesian components of $\vec{k}$, (k_r, k_θ, k_ϕ) in the r, θ, and ϕ directions. We also consider components of n, (n_r, n_θ, n_ϕ) in the r, θ, and ϕ directions. Then (6.100) is equivalent to

$$k_{r\ ref} = k_{r\ inc} - 2(\vec{k}_{inc}\cdot\vec{n})n_r - \frac{2\Omega_{\parallel} v_{\perp} n_r}{c^2 - v_{\perp}^2} \qquad (6.101a)$$

$$k_{\theta\ ref} = k_{\theta\ inc} - 2(\vec{k}_{inc}\cdot\vec{n})n_\theta - \frac{2\Omega_{\parallel} v_{\perp}}{c^2 - v_{\perp}^2} n_\theta \qquad (6.101b)$$

$$k_{\phi\ ref} = k_{\phi\ inc} - 2(\vec{k}_{inc}\cdot\vec{n})n_\phi - \frac{2\Omega_{\parallel} v_{\perp}}{c^2 - v_{\perp}^2} n_\phi . \qquad (6.101c)$$

One might wonder whether it is realistic to allow a component of the wind normal (or even parallel) to the surface of the terrain. Rather than debate this point here, we simply point out that HARPA does not check wind models to see if they satisfy continuity or physical boundary conditions (in fact, many of our models don't). This is the responsibility of those who design wind models, if such conditions are important in their applications. The last term

in (6.101) guarantees that the dispersion relation will be satisfied for the reflected wave, even if the wind does not vanish at the surface.

6.5.4 Unit-Normal Directions From the Surface

The previous section requires unit normal directions to the surface. Because f is a constant along the surface, the gradient of f is in the same direction as the unit normal. That is

$$\vec{\nabla} f = f_r \hat{i}_r + \frac{f_\theta}{r} \hat{i}_\theta + \frac{f_\phi}{r \sin\theta} \hat{i}_\theta \propto \vec{n} \ . \qquad (6.102)$$

Taking the ratio of components gives

$$n_\theta = \frac{f_\theta}{r\, f_r} n_r \qquad (6.103)$$

and

$$n_\phi = \frac{f_\phi}{f_r\, r \sin\theta} n_r \ . \qquad (6.104)$$

The solution of (6.103), and (6.104), while requiring $n_r^2 + n_\theta^2 + n_\phi^2 = 1$, is

$$n_r = \frac{f_r}{\sqrt{f_r^{\,2} + \frac{f_\theta^{\,2}}{r^2} + \frac{f_\phi^{\,2}}{r^2 \sin^2\theta}}} \ , \qquad (6.105)$$

$$n_\theta = \frac{f_\theta}{r\sqrt{f_r^{\,2} + \frac{f_\theta^{\,2}}{r^2} + \frac{f_\phi^{\,2}}{r^2 \sin^2\theta}}} \ , \qquad (6.106)$$

$$n_\phi = \frac{f_\phi}{r \sin\theta \sqrt{f_r^{\,2} + \frac{f_\theta^{\,2}}{r^2} + \frac{f_\phi^{\,2}}{r^2 \sin^2\theta}}} \ . \qquad (6.107)$$

6.6 Coordinate Systems

HARPA uses two different earth-centered spherical polar-coordinate systems, one geographic and one computational, because it is easier to express some models in a different coordinate system. Input data for the coordinates of the transmitter, W(4) and W(5), and input data for the coordinates of the north pole of the computational coordinate system, W(24) and W(25), are entered in geographic coordinates. Putting W(25) equal to 0° and W(24) equal to 90° would superimpose the two north poles and equate the two coordinate systems.

When the two coordinate systems do not coincide, the atmospheric models calculate wind, sound speed, temperature, and molecular weight in terms of the computational coordinate system. Dudziak (1961) describes the transformations between these coordinate systems.

7. Structure of the Program

This chapter explains how the parts of HARPA work together, including a brief description of each program subroutine and detailed flow charts of the central ray-tracing parts. Also included are hierarchical or organization diagrams that show the calling sequences of the principal ray-tracing operations and details of the common-block structure and usage.

7.1 Description of the Subroutines

Following is a list of all the programs, subroutines, and functions that constitute HARPA, that is, the functions inside the dashed lines of Figure 1.1. They are listed in the order they appear in Files 3, 4, and 5 of the distribution tape and in the source-code listings of Appendix D. The routines are divided into a RAY-TRACING "CORE," the set of programs that is always required to do ray tracing, DISPERSION-RELATION ROUTINES, from which you must select one, and ATMOSPHERIC MODEL SUBROUTINES, from which you select the routines that correspond to the atmospheric models you want to use. A more detailed description of the distribution-tape structure is given in Sec. 3.3.1.

7.1.1 Ray-Tracing Core

PROGRAM RAYTRC -- The main program; sets the initial conditions for each ray and calls TRACE.

SUBROUTINE DFSYS -- Contains system-dependent functions such as date, time (user must modify).

SUBROUTINE DFCNST -- Defines machine-dependent constants (user must modify).

SUBROUTINE READW1 -- Reads variable-length tabular data from input data table.

SUBROUTINE GTUNIT -- Interprets units line in tabular input data.

SUBROUTINE SREAD1 -- Handles unassigned labeled-common blocks.

FUNCTION READW -- Reads input data table into W array, converting units.

SUBROUTINE CLEAR -- Sets n elements of an array to zero.

FUNCTION ND2B -- Converts decimal digits to positionally equivalent binary numbers when reading W(29).

FUNCTION UCON -- Provides keyword units conversion for input data.

SUBROUTINE TRACE -- Calculates a raypath for the requested number of hops.

FUNCTION PCROSS -- Tests whether ray crosses a surface.

SUBROUTINE RCROSS -- Estimates point where ray crosses a surface.

SUBROUTINE HAMLTN -- Calculates Hamilton's equations for ray tracing and other quantities to be integrated.

SUBROUTINE RKAM -- Keeps track of integration steps performed by RKAM1 and makes them available to calling subroutines.

SUBROUTINE RKAM1 -- Numerically integrates Hamilton's equations.

SUBROUTINE BACKUP -- Moves the ray point to the last intersection with receiver or terrain surface.

FUNCTION REFLECT -- Computes normal and parallel components of K vector at ground reflections.

SUBROUTINE FIT -- Computes 3 types of parabolic fit to raypath relative to terrain.

FUNCTION GET -- Gets the value of the terrain function and its derivatives; calls the terrain model subroutine if necessary.

FUNCTION GET1 -- Second version of GET to avoid self-calls.

FUNCTION ITEST -- Passes integer values through for variables typed real.

SUBROUTINE CONBLK -- Data-initialization and file-opening service routine.

FUNCTION WCHANGE -- Determines equivalence of two W arrays for producing raysets.

FUNCTION RENORM -- Normalizes a vector to a specified magnitude.

SUBROUTINE SET2 -- Sets n components of vector to a specified single value.

SUBROUTINE PRINTR -- Prints details of the raypath calculation at specified intervals and produces computer-readable output (raysets).

SUBROUTINE ATMOSHD -- Includes page headings in printout.

SUBROUTINE PUTDES -- Prints model information on printout header.

FUNCTION NUMSTG -- Converts a numeric value to a string.

SUBROUTINE SFILL -- Fills a string with n specified characters.

FUNCTION STRIM -- Determines position of last nonblank character of a string.

FUNCTION RERR -- Computes for subroutine PRINTR the largest relative integration error.

SUBROUTINE RERROR -- Reports error conditions and stops program.

SUBROUTINE STOPIT -- Prints error condition and stops program.

SUBROUTINE PUTKST -- Multiple ENTRY points to produce line-printer output while accounting for line count, new page, etc.

SUBROUTINE OPNREP -- Increases portability among FORTRAN 77 systems for opening files with replacement.

SUBROUTINE OVERRD -- Tests for "zero-override" condition in input data (Sec. 5.3.1).

SUBROUTINE SFILTR -- Filters extraneous characters from plot annotations.

FUNCTION ALCOSH -- Compute log[cosh(x)] and use large-argument approx.

SUBROUTINE GAUSEL -- Calculates coefficients of functions to fit points in TTABLE.

[PLOTTING ROUTINES]

SUBROUTINE RAYPLT -- Main plotting program; initializes, reads input, plots projections of rays on a vertical or horizontal plane.

SUBROUTINE PLOT -- XY plotting routine, called by RAYPLT.

SUBROUTINE LABPLT -- Labels rayplots.

[TICK/ANNOTATION ROUTINES]

SUBROUTINE PLTHLB -- Plots horizontal ticks and annotation for rayplot.

SUBROUTINE PLTANH -- Generic horizontal tick annotation.

SUBROUTINE SETXY -- Plot initialization; sets projection parameters.

SUBROUTINE TIKLINE -- Draws straight line with ticks at intervals.

SUBROUTINE PLTANOT -- Puts general annotations on plots.

SUBROUTINE DRAWTKS -- Draws plot boundary, ticks, and labels for horizontal ray projection.

SUBROUTINE PLTLB -- Puts vertical tick annotations on rayplots.

SUBROUTINE ARCTIC -- Draws curved range axis for rayplot.

BLOCK DATA PLOTBL -- Initializes plot range variables.

[GRAPHICS WRITE ROUTINES]

SUBROUTINE DDINIT -- Initializes plotting process (writes header line to TAPE5).

SUBROUTINE DDBP -- Sets a vector origin (writes IX,IY to TAPE5).

SUBROUTINE DDVC -- Plots a vector (writes IX,IY for vector end point to TAPE5).

SUBROUTINE DDTEXT -- Writes an array (character string) to TAPE 5 in tabular text mode.

SUBROUTINE DDTAB -- Sends instruction to TAPE5 that initializes tabular (text) plotting.

SUBROUTINE DDFR -- Sends instruction to TAPE5 to advance a microfilm frame.

SUBROUTINE DDEND -- Empties plot buffer and releases plotting command file to microfilm plot queue.

SUBROUTINE DASH -- Sets dashed-line mode; that is, all plotted curves will be dashed instead of solid after a call to subroutine DASH.

SUBROUTINE RESET('DASH') -- Sets solid-line mode; that is, all plotted curves will be solid lines after this call.

SUBROUTINE HEIGHT -- If you do not have the DISSPLA* plotting package, load SUBROUTINE SMPANN instead of SUBROUTINE FULANN, and you can ignore this routine.

SUBROUTINE MX1ALF -- If you do not have the DISSPLA* plotting package, load SUBROUTINE SMPANN instad of SUBROUTINE FULANN, and you can ignore this routine.

SUBROUTINE MX2ALF -- If you do not have the DISSPLA* plotting package, load SUBROUTINE SMPANN instead of SUBROUTINE FULANN, and you can ignore this routine.

SUBROUTINE SCMPLX -- If you do not have the DISSPLA* plotting package, load SUBROUTINE SMPANN instead of SUBROUTINE FULANN, and you can ignore this routine.

7.1.2 Dispersion Relation Routines

SUBROUTINE ANWNL -- Acoustic wave, no winds, no losses.

SUBROUTINE AWWNL -- Acoustic wave, with wind, no losses.

SUBROUTINE ANWWL -- Acoustic wave, no wind, with losses.

SUBROUTINE AWWWL -- Acoustic wave, with wind, with losses.

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* DISSPLA is the proprietary product of ISSCO, Inc.

7.1.3 Atmospheric Model Subroutines

SUBROUTINE WLINEAR -- Constant upward or northward background wind; linear eastward wind profile.

SUBROUTINE WTIDE -- Eastward and northward background wind profiles that are sinusoidal in height and time and are in time quadrature.

SUBROUTINE ULOGZ2 -- Logarithmic atmospheric boundary-layer profile; eastward background wind only.

SUBROUTINE VVORTX3 -- Vertical vortex wind perturbation with viscous core and Gaussian height profile.

SUBROUTINE WGAUSS2 -- Eastward perturbation wind that decays in three dimensions (jet).

SUBROUTINE NPWIND -- Do-nothing wind perturbation model.

SUBROUTINE GAMRTDM -- Sound-speed model: $C^2 = \gamma RT/M$.

SUBROUTINE CSTANH -- Background sound-speed profile with linear segments joined smoothly.

SUBROUTINE NPSPEED -- Do-nothing sound-speed-perturbation model.

SUBROUTINE CBLOB2 -- Sound-speed perturbation with Gaussian decay in three dimensions.

SUBROUTINE TLINEAR -- Background linear temperature profile.

SUBROUTINE TTANH5 -- Background height profile of temperature with linear segments joined smoothly.

SUBROUTINE TTABLE -- Background tabular temperature profiles with cubic interpolation between points.

SUBROUTINE NTEMP -- Do-nothing background temperature model.

SUBROUTINE TBLOB2 -- Temperature perturbation with Gaussian decay in three dimensions.

SUBROUTINE NPTEMP -- Do-nothing temperature perturbation model.

SUBROUTINE MCONST -- Constant molecular weight model.

[TERRAIN MODELS]

SUBROUTINE GHORIZ -- Terrain model at fixed height above sea level.

SUBROUTINE GLORENZ -- Lorentzian-ridge terrain model.

SUBROUTINE GTANH -- 2-D terrain model with a series of linear segments joined smoothly.

[ABSORPTION MODELS]

SUBROUTINE NPTERR -- Do-nothing terrain-perturbation model.

SUBROUTINE MUARDC -- ARDC background absorption formula.

SUBROUTINE NPABSR -- Do-nothing absorption-perturbation model.

SUBROUTINE PEXP -- Exponential background pressure profile.

SUBROUTINE NPPRES -- Do-nothing pressure-perturbation model.

[RECEIVER-SURFACE MODELS]

SUBROUTINE RHORIZ -- Horizontal receiver-surface model.

SUBROUTINE RTERR -- Receiver-surface model at fixed height above terrain.

SUBROUTINE RVERT -- Vertical (conical) receiver surface at a fixed radius from a specified origin.

[ANNOTATION MODELS]

SUBROUTINE SMPANN -- Initializes plot in draft mode (must be used if you don't have DISSPLA).

SUBROUTINE FULANN -- Initializes plot in publication-quality mode (requires DISSPLA).

7.2 HARPA Organization Diagrams

This section contains hierarchical diagrams, Figures 7.1 through 7.4, that show how the principal subroutines are interrelated by calling sequences. These diagrams are not flow charts; they show how control passes among the program modules. Not all subroutines are shown, only the major ones that perform the ray-tracing function.

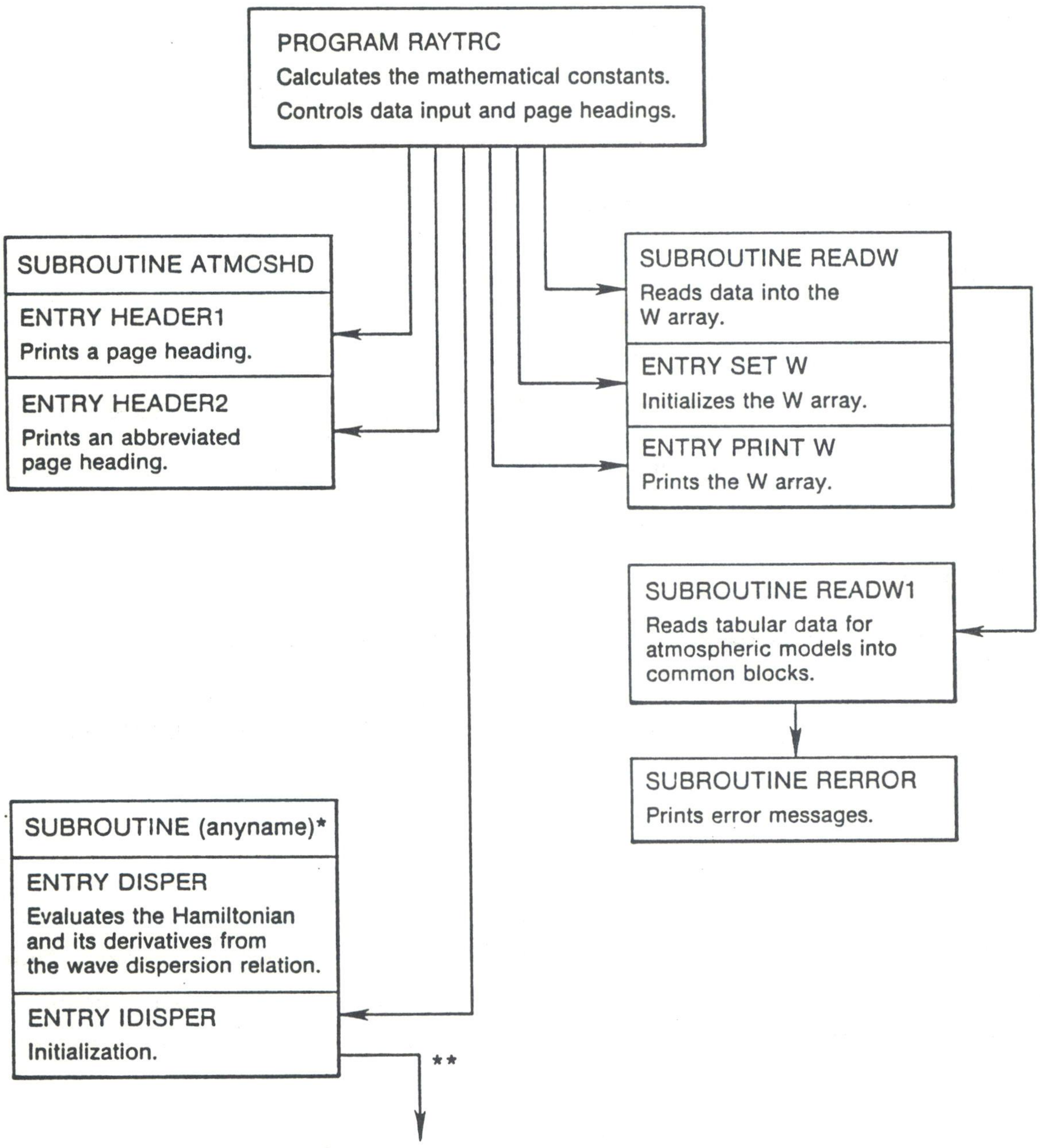


Figure 7.1. Block diagram (not a flow chart) of the ray-tracing program showing the relation (hierarchy, what calls what) of the main program to other subroutines during the initialization stage (immediately after new input data are read in).

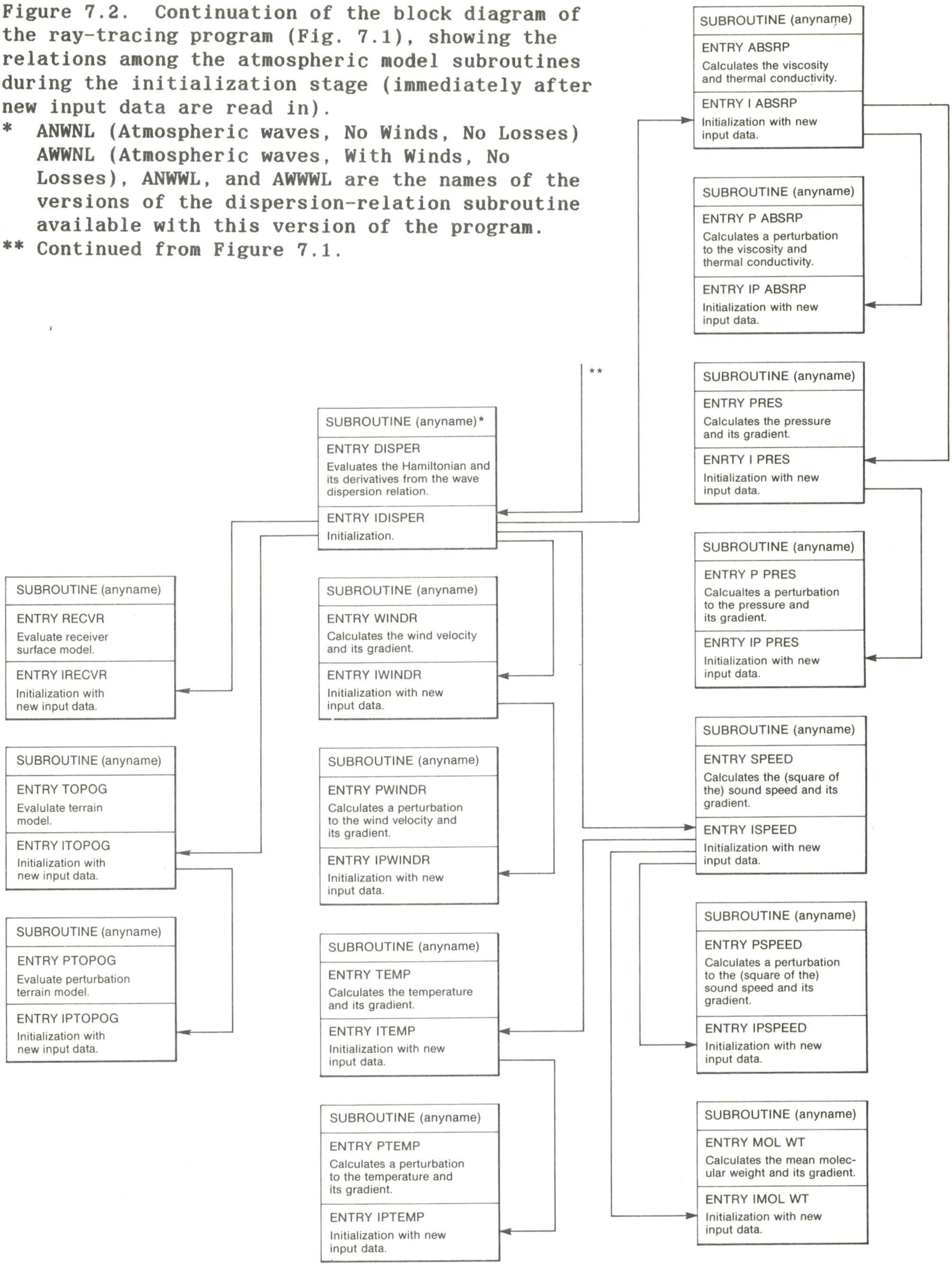
* ANWNL (Acoustic, No Winds, No Losses), AWWNL, With Winds, No Losses), ANWWL, and AWWWL are the names of the versions of the dispersion-relation subroutine available.

** Figure 7.2 shows the continuation of this block diagram.

Figure 7.2. Continuation of the block diagram of the ray-tracing program (Fig. 7.1), showing the relations among the atmospheric model subroutines during the initialization stage (immediately after new input data are read in).

* ANWNL (Atmospheric waves, No Winds, No Losses) AWWNL (Atmospheric waves, With Winds, No Losses), ANWWL, and AWWWL are the names of the versions of the dispersion-relation subroutine available with this version of the program.

** Continued from Figure 7.1.



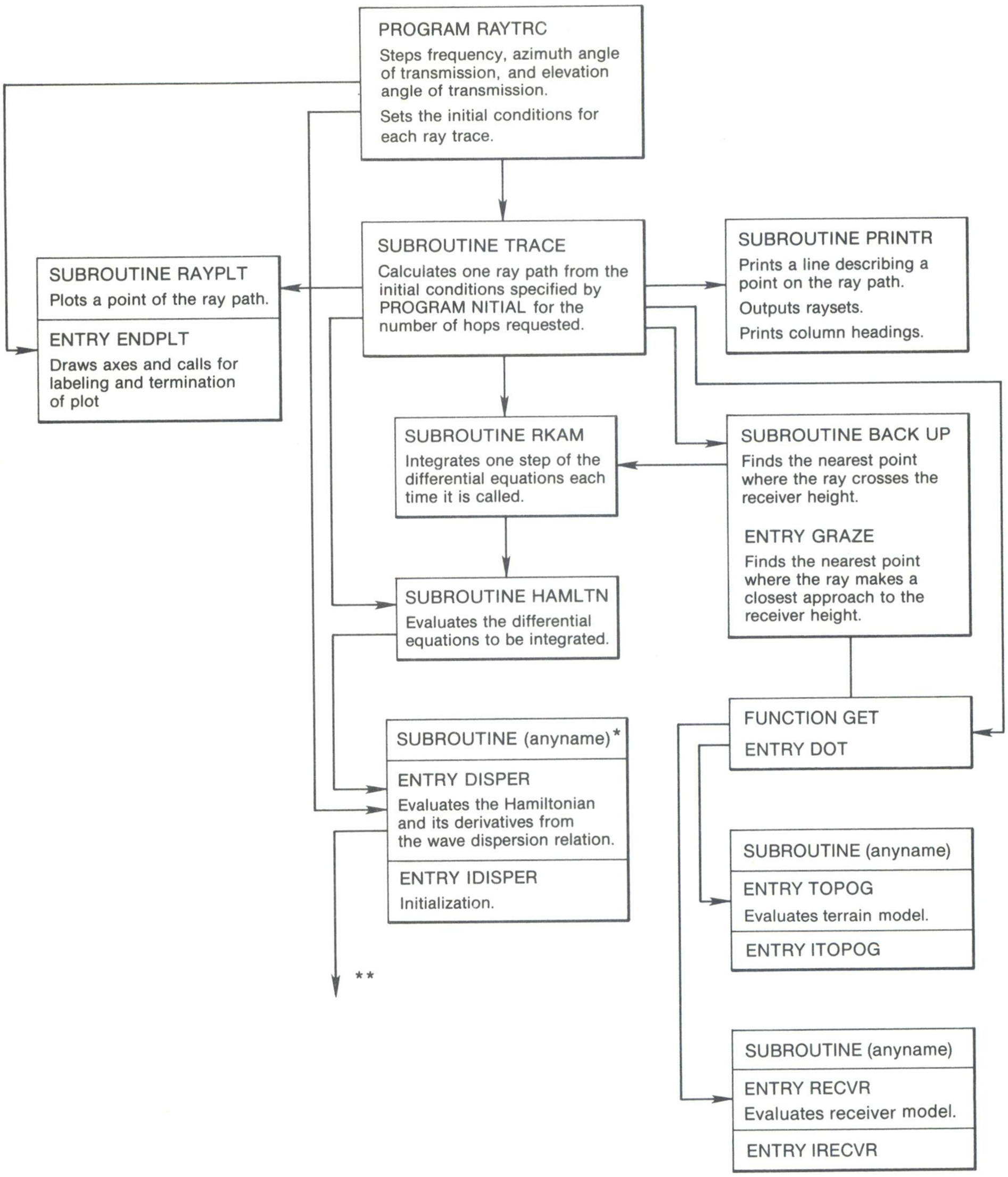


Figure 7.3. Block diagram (not a flow chart) of the ray-tracing program showing the relations (hierarchy, what calls what) among the main program and the subroutines during the raypath calculation stage (after the initialization stage).

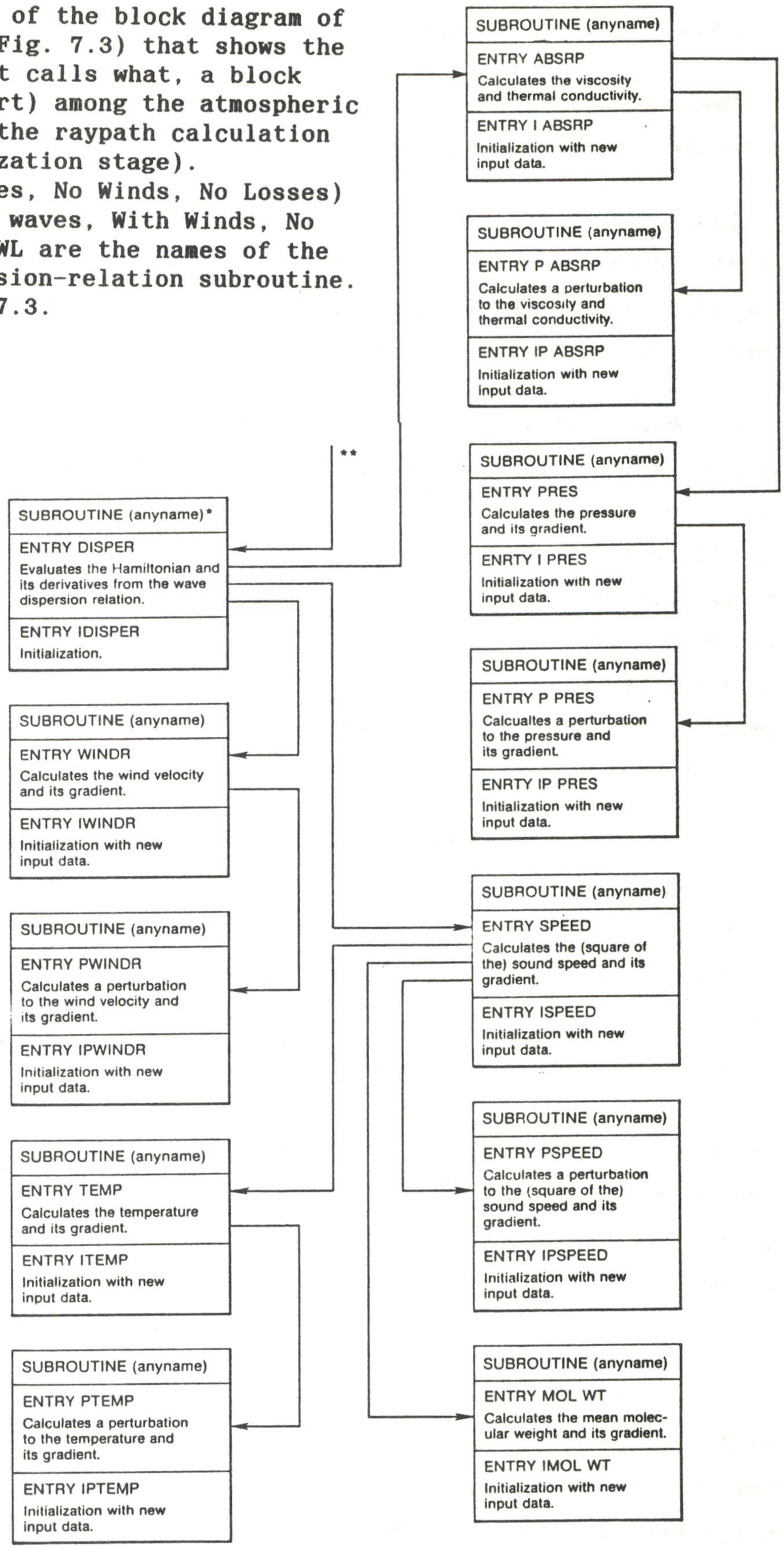
* ANWWL (Acoustic, No Winds, No Losses) and AWWNL (Acoustic, With Winds, No Losses), AWWWL and ANWWL are the names of the versions of the dispersion-relation subroutine.

** Figure 7.4 shows the continuation of the block diagram that shows the relations among the atmospheric model subroutines.

Figure 7.4. Continuation of the block diagram of the ray-tracing program (Fig. 7.3) that shows the relations (hierarchy, what calls what, a block diagram is not a flow chart) among the atmospheric model subroutines during the raypath calculation stage (after the initialization stage).

* ANWNL (Atmospheric waves, No Winds, No Losses) and AWWNL (Atmospheric waves, With Winds, No Losses), AWWWL and ANWWL are the names of the versions of the dispersion-relation subroutine.

** Continued from Figure 7.3.



7.3 Flow Charts for Program RAYTRC and Subroutines TRACE and BACKUP

These three routines contain the central logic of the raypath calculations and so are described in detail in flow-chart form.

This ray-tracing program consists of various subroutines that perform specific tasks in calculating raypaths. The division of labor makes it easier to modify the program to solve specific problems. Often it may be necessary to change only one or two subroutines to convert the program to a different use.

The main program (RAYTRC) sets up the initial conditions (transmitter location, wave frequency, and direction of transmission) for each ray trace. In setting up the initial conditions for each ray trace, the main program (RAYTRC) steps frequency, azimuth angle of transmission, and elevation angle of transmission (see Figs. 7.5 and 7.6). Then subroutine TRACE calculates one raypath for the requested number of crossings of the specified receiver height. Subroutine TRACE is the heart of the ray-tracing prograr. It is the most complicated subroutine included, but also the most important to understand. The flow charts in Figures 7.6 and 7.7 explain how TRACE works.

Subroutine RKAM integrates the differential equations numerically using an Adams-Moulton predictor-corrector method with a Runge-Kutta starter. Subroutine HAMLTN evaluates the differential equations to be integrated. Subroutine DISPER calculates the Hamiltonian and its derivatives, the wave number from the dispersion relation, and the wave polarization. (Four versions of subroutine DISPER are included.) Subroutines WIND, SPEED, TEMP, MOLWT, RECUR, TOPOG, ABSRP, and PRES calculate the atmospheric wind speed, sound speed, temperature, mean molecular weight, receiver surface, terrain, viscosity/thermal conductivity, and pressure. Several versions of these eight subroutines are included, and it is easy to add more. Subroutine BACKUP finds an intersection of the ray with the receiver surface or with the terrain. The flow charts in Figures 7.8 through 7.10 and Section 6.5 explain how BACKUP works.

Subroutine PRINTR prints information describing the raypath and outputs the results in computer-readable form (raysets). Subroutine RAYPLT plots the raypath. The block diagrams in Figures 7.1 through 7.4 show the relationships among these (and other) subroutines.

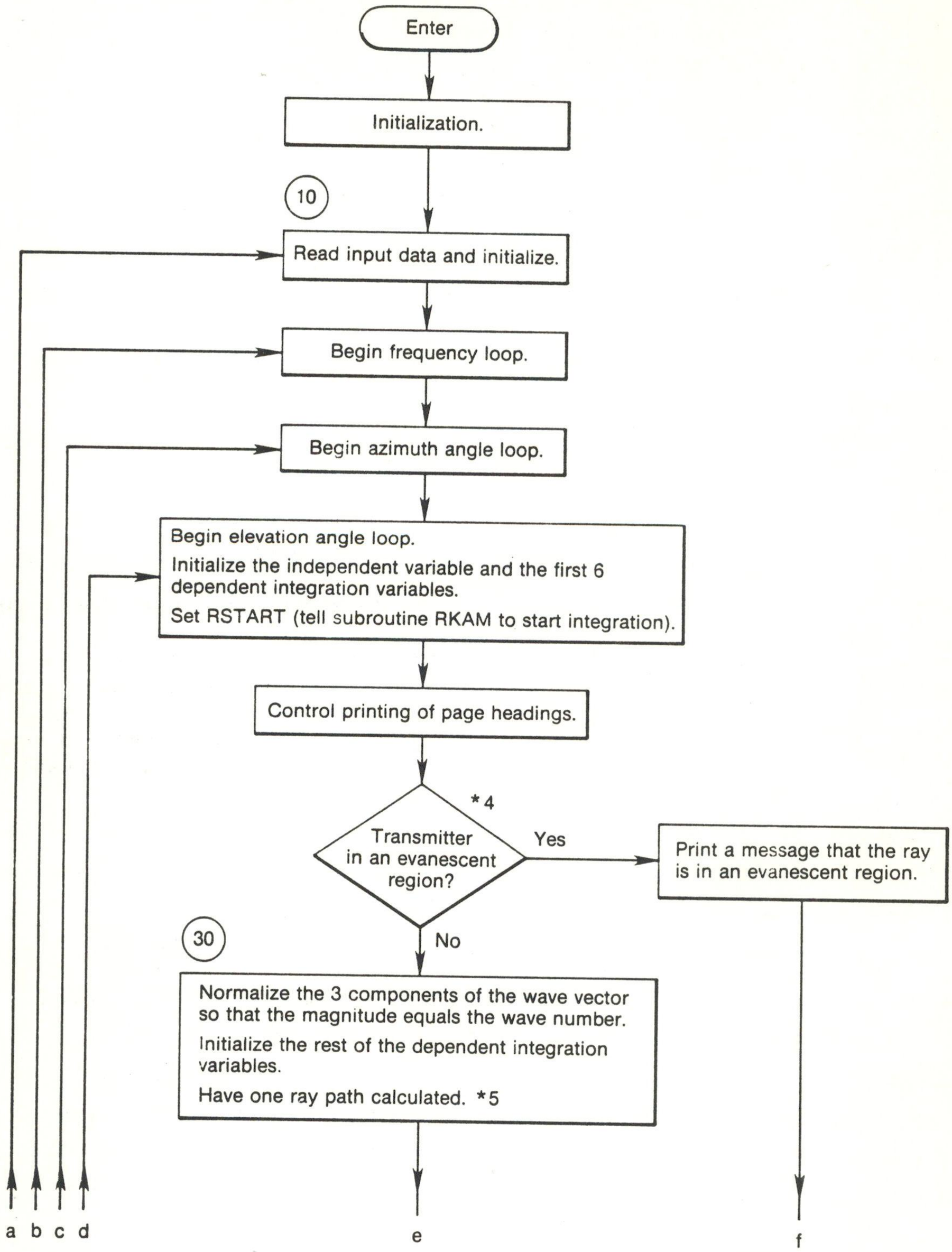


Figure 7.5. Flow chart for program RAYTRC. Circled block numbers correspond to program statement numbers.
*4 There are no evanescent regions for pure acoustic waves (with no cutoff frequency).
*5 Subroutine TRACE calculates one raypath.

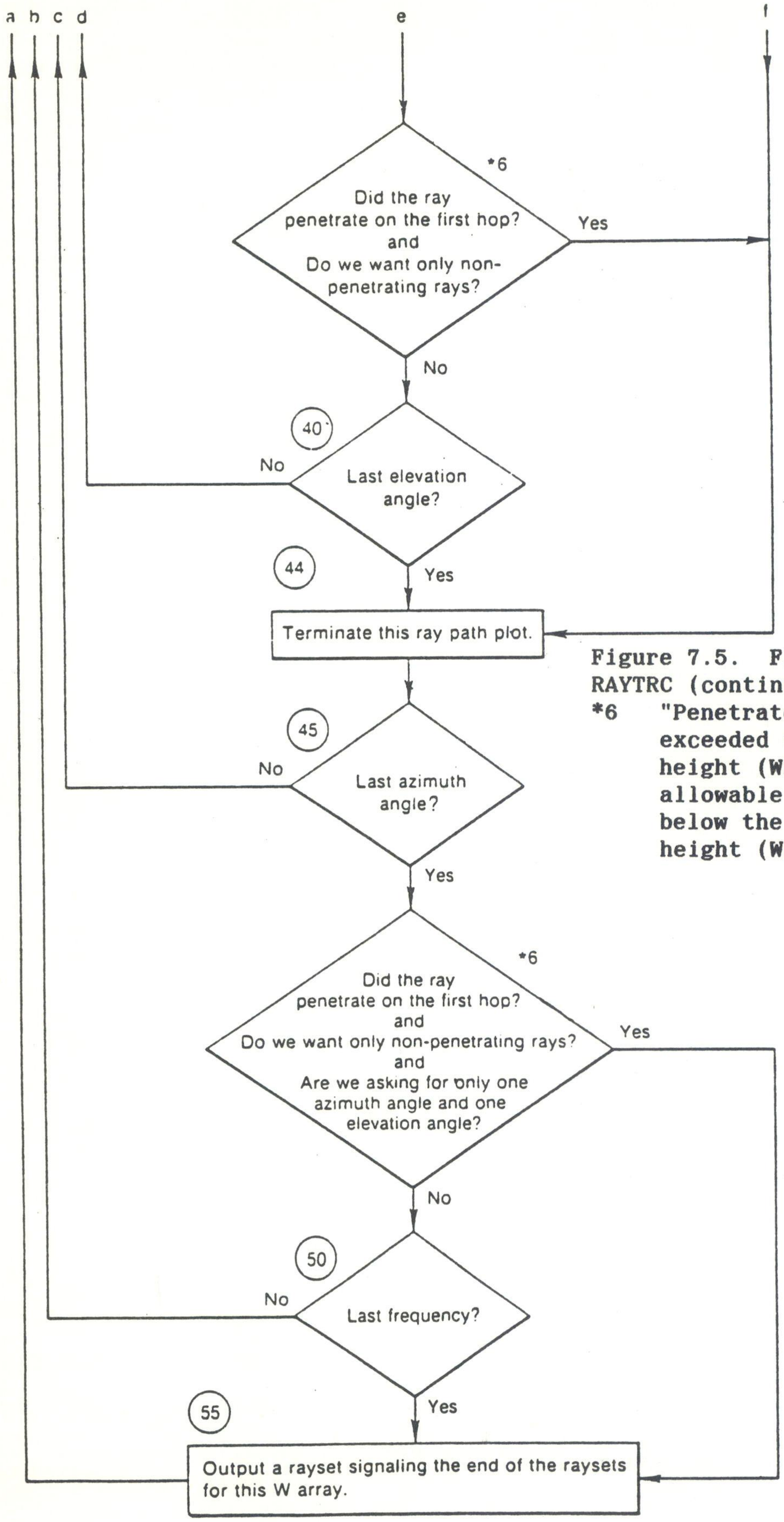


Figure 7.5. Flow chart for program RAYTRC (continued).

***6 "Penetrate" means the ray exceeded the maximum allowable height (W26) or the maximum allowable range (W28) or went below the minimum allowable height (W27).**

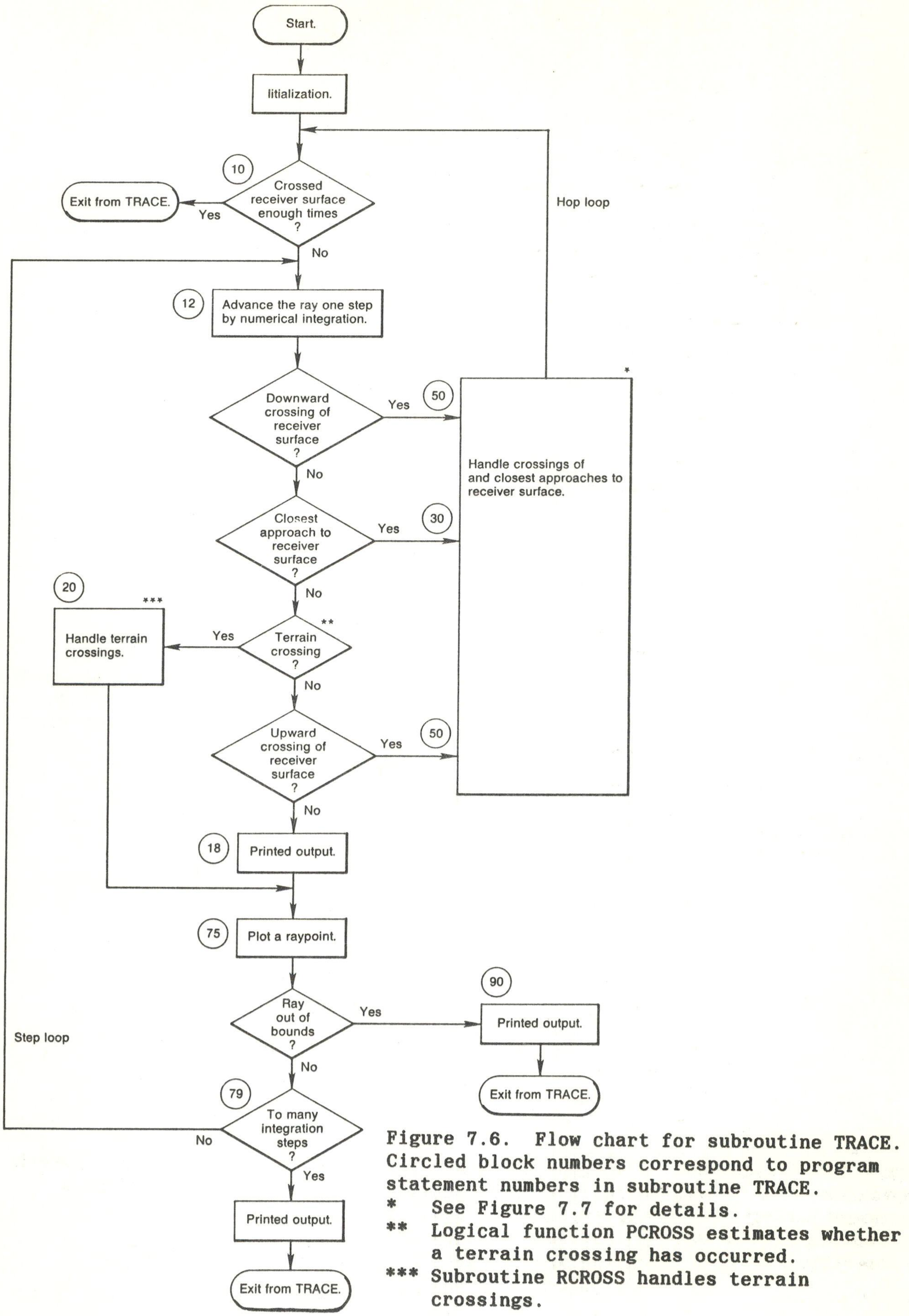


Figure 7.6. Flow chart for subroutine TRACE. Circled block numbers correspond to program statement numbers in subroutine TRACE.

* See Figure 7.7 for details.

** Logical function PCROSS estimates whether a terrain crossing has occurred.

*** Subroutine RCROSS handles terrain crossings.

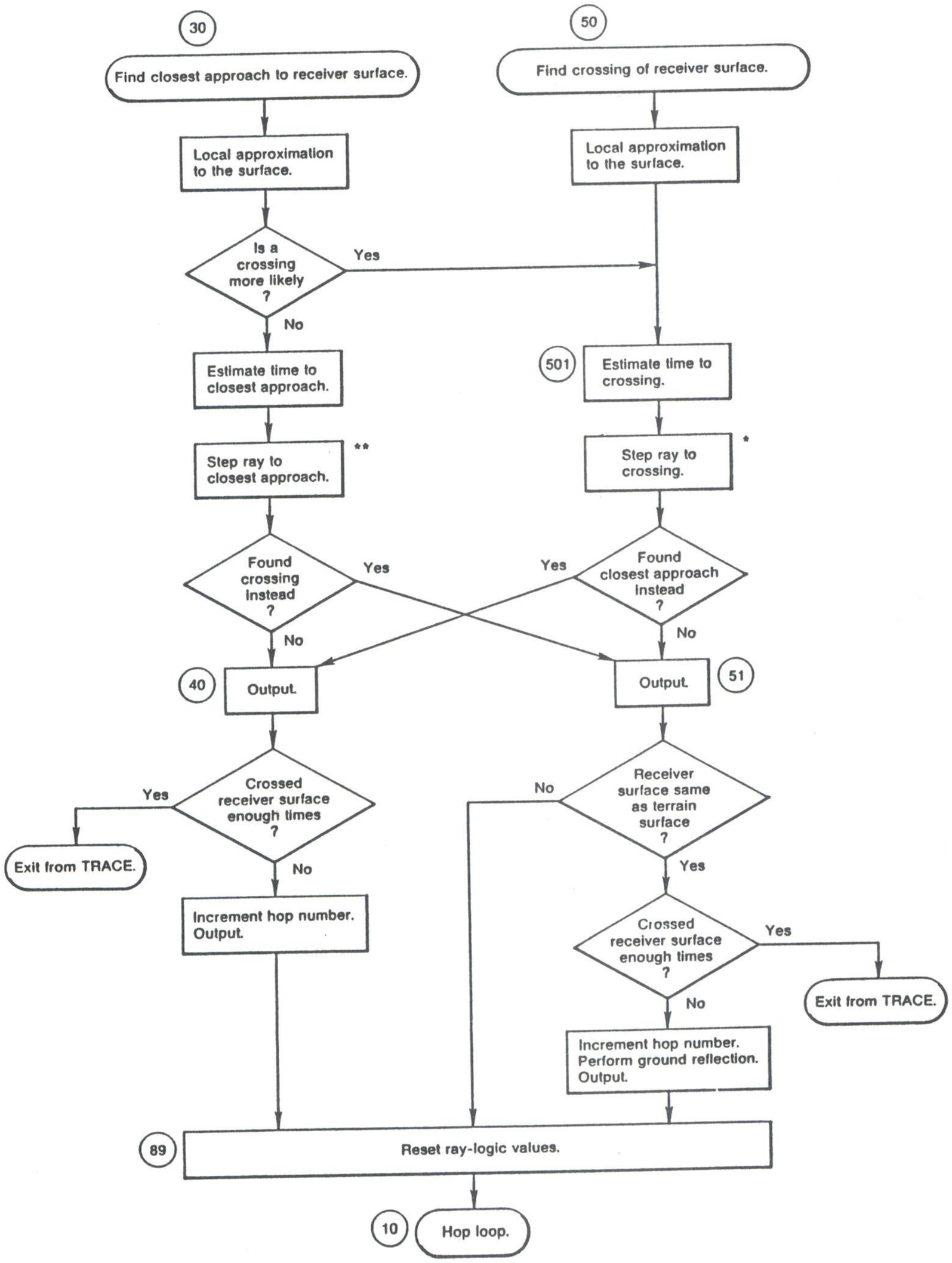


Figure 7.7. Flow chart showing some details of finding crossings of and closest approaches to receiver surface. Circled block numbers correspond to program statement numbers in subroutine TRACE.
* See Figure 7.8 for details (subroutine BACKUP).
** See Figure 7.8 for details (entry point GRAZE in subroutine BACKUP).

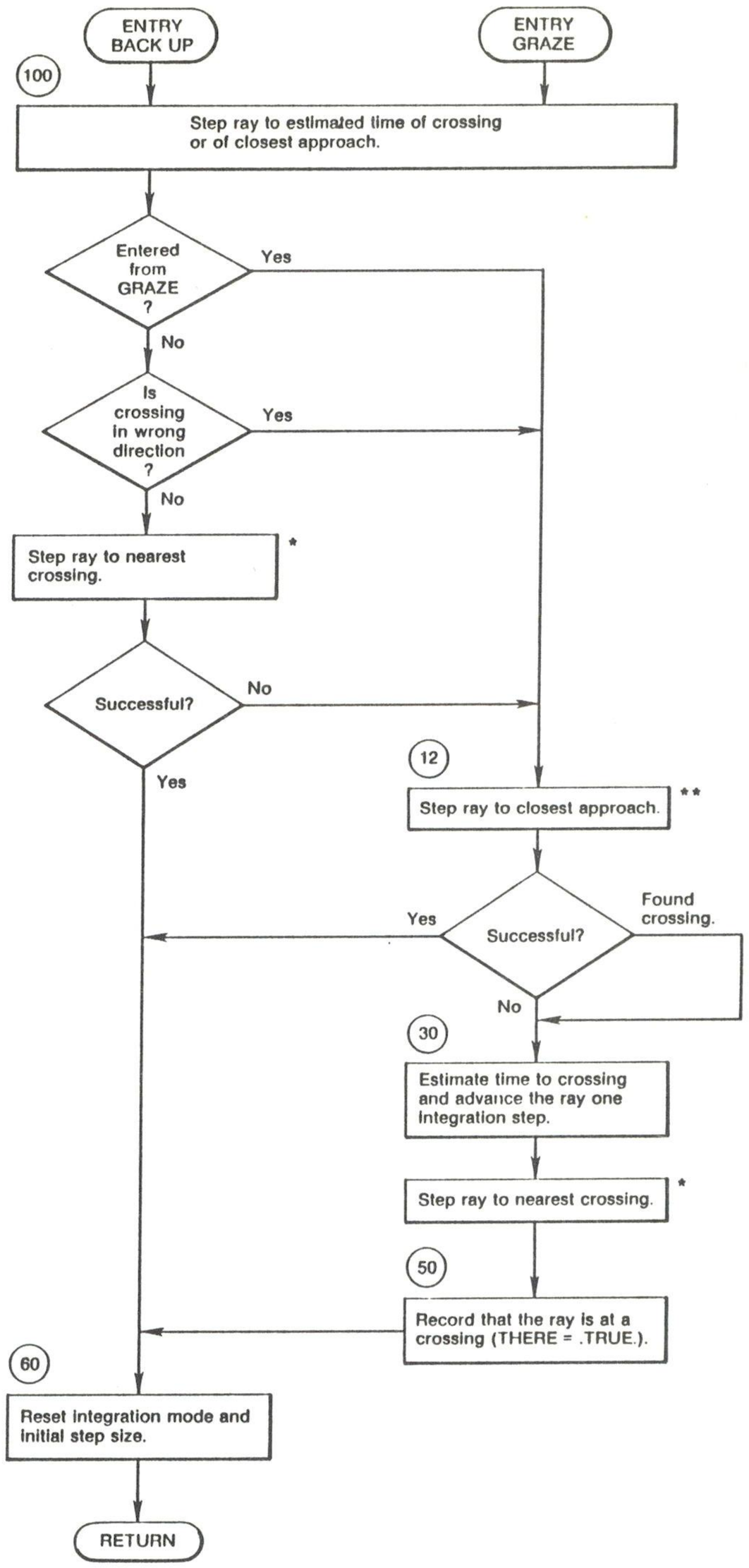


Figure 7.8. Flow chart for subroutine BACKUP. Circled block numbers correspond to program statement numbers. Entry BACKUP steps the ray to a crossing with a specified height. Entry GRAZE steps the ray to a point of closest approach to the specified height. The calling routine (subroutine TRACE) specifies the height with which the ray is to intersect, the direction of crossing (up or down), and estimates the time of crossing (group time delay). Asterisks identify supplementary procedures.

* See Figure 7.9 for details of the algorithm that steps the ray by numerical integration to the nearest crossing of a specified height.

** See Figure 7.10 for details of the algorithm that steps the ray by numerical integration to a closest approach to a specified height.

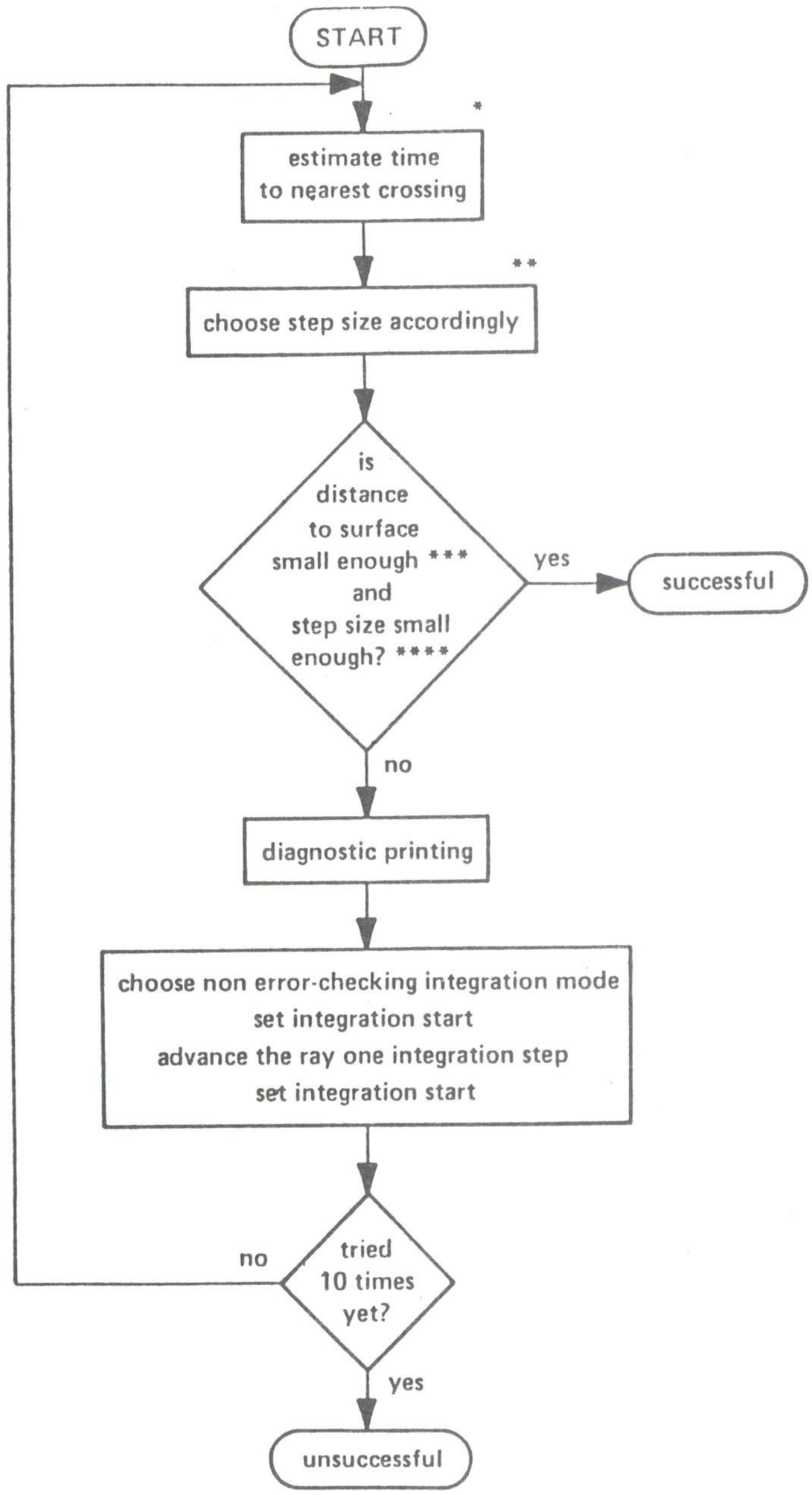


Figure 7.9. Flow chart for the algorithm that steps the ray by numerical integration to a crossing of a specified height. Circled block numbers correspond to program statement numbers.

* See Equation (6.85) to estimate the time of the nearest crossing of the specified height.

** The step size should be no larger than that being used by the numerical integration routine to maintain accuracy in the error-checking mode.

*** 0.5×10^{-4} km.

**** Small enough to ensure the required accuracy and smaller than the smallest allowable step size.

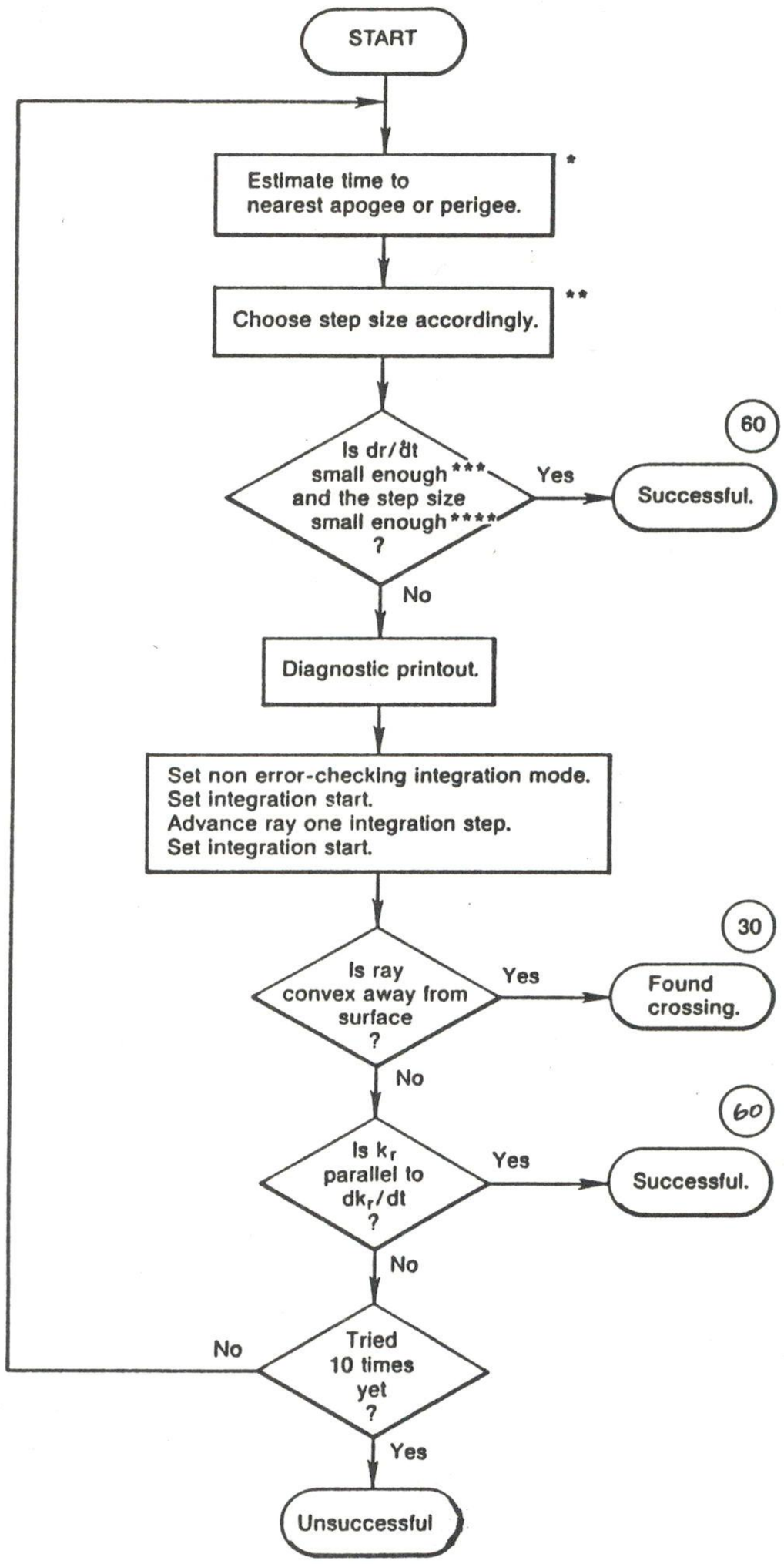


Figure 7.10. Flow chart for the algorithm that steps the ray by numerical integration to a point of closest approach to a specified height. Circled block numbers correspond to program statement numbers.

* See Equation (6.91) to estimate the time of the nearest crossing of the specified height.

** The step size should be no larger than that being used by the numerical integration routine to maintain accuracy in the error-checking mode.

*** 10^{-6} km/km.

**** Small enough to ensure the required accuracy and smaller than the smallest allowable step size.

The listings of most of the subroutines have comments that should help in understanding how they work. In addition, Tables 7.1 through 7.40 define the variables in the common blocks.

Table 7.1--Definitions of the parameters in blank common

Position in common	Variable name	Definition
1-20	R	The dependent variables in the differential equations being integrated--the definitions of the first six are fixed, but the others may be varied by the program user
1	R(1) or R	r
2	R(2) or TH	θ
3	R(3) or PH	ϕ
4	R(4) or KR	k_r
5	R(5) or KTH	k_θ
6	R(6) or KPH	k_ϕ
7-12	R(7)-R(12) or RKVARS(1)-RKVARS(6)	Those variables the user has chosen to integrate, taken in the following order: P -phase path in kilometers A -absorption in decibels Δf -Doppler shift in hertz s -geometrical path length in kilometers
13-20	R(13)-R(20)	Reserved for future expansion
21	TPULSE	Group path length in kilometers (the independent variable in the differential equations)
22	CSTEP	Step length in group path
23-42	DRDT	The derivatives of the dependent variables with respect to the independent variable TPULSE

R and TPULSE are initialized in program RAYTRC and changed in subroutines TRACE, RKAM, and BACK UP.

CSTEP is calculated in subroutine RKAM.

DRDT is calculated in subroutine HAMLTN and used in subroutine RKAM.

7.4 Common-Block Structure and Usage

We use common blocks instead of calling sequences to pass information between subroutines and functions because it is faster. This section describes how those common blocks are organized and which blocks link which program modules, and defines the variables in each block.

Table 7.1 defines the variables in blank common. These are mostly the dependent variables in the numerical integration and their derivatives. Nearly all of the subprograms use this common block.

Table 7.2 describes the common block /MCONST/, which contains mathematical constants. Table 7.3 describes the common block /PCONST/, which contains physical constants.

Many common blocks are used to communicate among the various routines in the program. Table 7.4 lists those common blocks and shows which routines use those common blocks. Blank common, common blocks /MCONST/, /PCONST/, /WW/, and the common blocks listed in Tables 4.2 and 4.3 are not included in Table 7.4. Table 7.5 lists the variable names in these common blocks that are used for input and output by each routine. Tables 7.6 through 7.32 list all of the variables in these common blocks and give the meanings of those variables.

Table 7.17 describes common block /RIN/, which contains parameters output by all of the versions of the dispersion relation subroutines (all of which have the entry point name DISPER). Tables 7.33 through 7.40 describe the common blocks /UU/, /CC/, /TT/, /MM/, /RR/, /GG/, /AA/, and /PP/, which contain the parameters output by the various atmospheric models.

Table 7.2--Definitions of the parameters in common block /MCONST/*

Position in common	Variable name	Definition
1	PI	π
2	PIT2	2π
3	PID2	$\pi/2$
4	DEGS	$180.0/\pi$
5	RAD	$\pi/180.0$
6	ALN10	$\log_e 10$

* These parameters are set in program RAYTRC.

Table 7.3--Definitions of the parameters in common block /PCONST/

Position in common	Variable name	Definition
1	CREF	A reference sound speed (0.344 km/s), the reference sound speed in air at 20°C, Handbook of Chemistry and Physics (1954, page 2312), used to convert group delay time in seconds to an equivalent group path length in kilometers, and to convert a phase time in seconds to an equivalent phase-path length in kilometers
2	RGAS	The gas constant, = 8.31436×10^{-3} kg (kg mole)$^{-1}$ km^2 s^{-2} K^{-1} (this value of the gas constant gives a sound speed in km/s)
3	GAMMA	γ, the ratio of specific heat at constant pressure to that at constant density, = 1.4

Table 7.4.--Common block usage by the core routines

Routine \ Common block	PROCFL	HDR	UCONC	UCONV	RKAMS	CGET	CRMACH	CRKTIME	TRLOCAL	RK	TRAC	FNDER	RIN	ERR	RAYDEV	FLGP	RINPL	FLG	HDRC	FILEC	PLT	RAYCON	ANNCTC	ANNCTL	LABCLT	DD	KNKN	DDLIM
RAYTRC		O								I/O			I	I	I	O		I/O	O	O								
CONBLK	O	O	O	O				O					O		I/O				O			O						
WCHANGE																												
RENORM																												
SET2																												
ITEST																												
PUTDES																												
NUMSTG																												
SFILL																												
STRIM																												
RERR																												
RERROR																												
STOPIT																												
PUTKST																												
OPENREP																												
OVERRD																												
CLEAR																												
ND2B																												
DFSYS																												
DFCNST							O																					
UCON	I	I/O																										
HAMLTN													I															
RKAM			I/O					I/O		I/O																		
RKAM1			O							I/O																		
TRACE								I/O	I/O	I/O	I/O								O									
PCROSS											I																	
RCROSS									O	O	I/O								O									
BACKUP										I/O	I/O																	
REFLECT											I/O	I																
FIT											I/O	I																
GET					O	I	I					O																
GET1					O	I	I																					
READW1															I													
READW															I	I		I										
PRINTR										I			I	O				I/O										
ATMOSHD													I			I	I	I/O	I									
RAYPLT																		I/O		I	O							
PLOT																					I/O							O
LABPLT													I						I									O
PLTHLB																												
PLTANH																						I						
SETXY																									I	I		O
TIKLINE																									O			
PLTANOT																							I	I	I	I		
DRAWTKS																												
PLTLB																									I	I		
ARCTIC																												
PLOTBL																												
DDINIT																										O		O
DDBP																												
DDVC																										I	I/O	I/O
DDTEXT																										I	I/O	I/O
DDTAB																										I	I/O	
DDFR																												
DDEND																												
DASH																												
RESET																												
HEIGHT																												
MX1ALF																												
MX2ALF																												
SCMPLX																												

Notes:

1. "I" signifies that the routine uses information from the common block.

2. "O" signifies that the routine puts information into the common block.

3. Blank common, common blocks /MCONST/, /PCONST/, /WW/, and the common blocks listed in Tables 4.2 and 4.3 are not included in this table.

Table 7.5--Input and output variables to routines in common blocks other than blank common and labeled common blocks /MCONST/, /PCONST/, and /WW/ and other than the common blocks listed in Tables 4.2 and 4.3

Routine	Input parameters		Output parameters	
	common block	parameter name	common block	parameter name
RAYTRC	/FLG/	IHOP	/HDRC/	DAT
	/RIN/	KAY2	/HDRC/	INITID
	/FLG/	LINES	/FLG/	LINES
	/RK/	NEQS	/FLG/	NEWWP
	/ERR/	NERG	/FLG/	NEWWR
	/ERR/	NERP	/FILEC/	NPLTDP
	/ERR/	NERR	/FLGP/	NSET
	/ERR/	NERT	/HDR/	SEC
	/RAYDEV/	NRYIND	/HDRC/	TOD
	/RIN/	OMEGMAX	/RK/	RSTART
	/RIN/	OMEGMIN		
	/FLG/	PENET		
	/RIN/	SGN		
DFCNST			/CRMACH/	RMACH
READW1	/RAYDEV/	NDEVTMP		
	/RAYDEV/	NRYIND		
READW	/B1/→/B20/		/B1/→/B20/	
	/FLG/	LINES		
	/RAYDEV/	NDEVTMP		
	/RAYDEV/	NFRMAT		
	/RAYDEV/	NRYIND		
	/FLGP/	NSET		
UCON	/UCONC/	CNVC	/UCONV/	CNVV
	/UCONV/	CNVV		
	/UCONC/	PCV		
TRACE	/TRAC/	D2Z	/TRAC/	DROLD
	/TRAC/	GROUND	/RK/	E1MAX
	/CRKTIME/	IRKTIME	/RK/	E1MIN
	/TRAC/	RAD	/RK/	E2MAX
	/TRAC/	RAD1	/RK/	E2MIN
	/TRAC/	THERE	/RK/	FACT
	/TRAC/	ZDOT	/TRLOCAL/	FDOT
	/TRLOCAL/	RSIGN	/TRLOCAL/	GDOLD
	/TRLOCAL/	HOME	/TRLOCAL/	GDOT
	/TRLOCAL/	FDOT	/TRLOCAL/	GOLD
			/TRAC/	GROUND
			/TRAC/	HOME
			/FLG/	HPUNCH
			/FLG/	IHOP

Table 7.5--(continued)

Routine	Input parameters		Output parameters	
	common block	parameter name	common block	parameter name
TRACE (continued)			/CRKTIME/	IRKTIME
			/RK/	MODE
			/TRAC/	NEWRAY
			/FLG/	NEWTRC
			/FLG/	PENET
			/TRAC/	ROLD
			/TRLOCAL/	RSIGN
			/RK/	RSTART
			/RK/	STEP
			/TRAC/	THERE
			/TRAC/	TOLD
PCROSS	/TRAC/	OSMT		
	/TRAC/	SMT		
RCROSS	/TRAC/	RAD1	/TRLOCAL/	FDOT
	/TRAC/	ZDOT	/TRLOCAL/	HOME
			/FLG/	HPUNCH
			/TRLOCAL/	RSIGN
			/RK/	RSTART
HAMLTN	/RIN/			
RKAM	/RKAMS/	ALPHA	/RK/	E1MAX
	/RK/	E1MAX	/CRKTIME/	IRKTIME
	/RKAMS/	FV	/RKAMS/	MM
	/CRKTIME/	IRKTIME	/RK/	MODE
	/RKAMS/	MM	/RK/	NEQS
	/RK/	MODE	/RKAMS/	XV
	/RK/	NEQS		
	/RK/	RSTART		
	/RK/	STEP		
	/RKAMS/	XV		
	/RKAMS/	YU		
RKAM1	/RK/	E1MAX	/RKAMS/	ALPHA
	/RK/	E1MIN	/RKAMS/	EPM
	/RK/	E2MAX	/RK/	E1MIN
	/RK/	E2MIN	/RK/	FACT
	/RK/	FACT	/RKAMS/	FV
	/RK/	MODE	/RKAMS/	MM
	/RK/	NN	/RK/	RSTART
	/RK/	RSTART	/RKAMS/	XV
	/RK/	SPACE	/RKAMS/	YU

Table 7.5--(continued)

Routine	Input parameters		Output parameters	
	common block	parameter name	common block	parameter name
BACKUP	/TRAC/	DROLD	/RK/	MODE
	/TRAC/	D2Z	/RK/	RSTART
	/RK/	E1MAX	/RK/	STEP
	/RK/	E2MIN	/TRAC/	THERE
	/RK/	FACT	/TRAC/	TOLD
	/RK/	MODE	/TRAC/	ZDOT
	/TRAC/	RAD1		
REFLECT	/FNDER/	NPZPH		
	/FNDER/	NPZR		
	/FNDER/	NPZTH		
FIT	/TRAC/	DROLD	/TRAC/	D2Z
	/FNDER/	NPZPH	/TRAC/	OSMT
	/FNDER/	NPZPHPH	/TRAC/	RAD
	/FNDER/	NPZR	/TRAC/	RAD1
	/FNDER/	NPZRPH	/TRAC/	SMT
	/FNDER/	NPZRR	/TRAC/	ZDOT
	/FNDER/	NPZRTH		
	/FNDER/	NPZTH		
	/FNDER/	NPZTHPH		
	/FNDER/	NPZTHTH		
	/FNDER/	NZ		
	/TRAC/	TOLD		
GET	/CRKTIME/	IRKTIME	/FNDER/	NPZPH
	/CRKTIME/	RKTIME	/FNDER/	NPZPHPH
	/CRMACH/	RMACH	/FNDER/	NPZR
			/FNDER/	NPZRPH
			/FNDER/	NPZRR
			/FNDER/	NPZRTH
			/FNDER/	NPZTH
			/FNDER/	NPZTHPH
			/FNDER/	NPZTHTH
			/FNDER/	NSELECT
			/FNDER/	NTIME
			/FNDER/	NZ
			/CGET/	ZERO
GET1	/CRKTIME/	IRKTIME	/CGET/	ZERO
	/CRKTIME/	RKTIME		
	/CRMACH/	RMACH		
CONBLK	/RAYDEV/	NRYIND	/UCONC/	CNVC
			/UCONV/	CNVV
			/CRKTIME/	IRKTIME
			/RIN/	KVECT

Table 7.5--(continued)

Routine	Input parameters common block	Input parameters parameter name	Output parameters common block	Output parameters parameter name
CONBLK (continued)			/RIN/	LPOLAR
			/RAYCON/	MCONP
			/RAYDEV/	NDEVTMP
			/RAYDEV/	NFRMAT
			/RAYDEV/	NRYIND
			/RIN/	OMEGMAX
			/RIN/	OMEGMIN
			/UCONC/	PCV
			/RIN/	POLAR
			/RIN/	RAYNAME
			/HDRC/	DAT
			/HDRC/	INITID
			/PROCFL/	LIST
			/PROCFL/	PITBL
			/PROCFL/	PNTBL
			/HDR/	SEC
			/HDRC/	TOD
PRINTR	/FLG/	HPUNCH	/FLG/	LINES
	/FLG/	IHOP	/ERR/	NERG
	/RIN/	KAY2	/ERR/	NERP
	/FLG/	LINES	/ERR/	NERR
	/RK/	NEQS	/ERR/	NERT
	/FLG/	NTYP	/FLG/	NEWWP
	/RIN/	POLAR		
	/RIN/	TYPE		
ATMOSHD	/HDRC/	DAT	/FLG/	LINES
	/RINPL/	DISPM	/FLG/	NTYP
	/FLG/	LINES		
	/RIN/	MODRIN		
	/FLGP/	NSET		
	/RIN/	RAYNAME		
	/HDRC/	TOD		
PUTKST	/FLG/	LINES	/FLG/	LINES
RAYPLT	/FLG/	NEWTRC	/PLT/	ALPHA
	/FLG/	NEWWR	/PLT/	APLT
	/FILEC/	NPLTDP	/FLG/	NEWTRC
			/FLG/	NEWWR
			/PLT/	PRESET
			/PLT/	RMAX
			/PLT/	RMIN
			/PLT/	XL
			/PLT/	XR
			/PLT/	YB
			/PLT/	YT

Table 7.5--(continued)

Routine	Input parameters		Output parameters	
	common block	parameter name	common block	parameter name
PLOT	/PLT/	ALPHA	/DD/	IX
	/PLT/	APLT	/DD/	IY
	/PLT/	RESET	/PLT/	RESET
	/PLT/	RMAX		
	/PLT/	RMIN		
	/PLT/	XMAXO		
	/PLT/	XMINO		
	/PLT/	YMAXO		
	/PLT/	YMINO		
LABPLT	/HDRC/	DAT	/DD/	IOR
	/RIN/	MODRIN	/DD/	IS
			/DD/	IT
			/DD/	IX
			/DD/	IY
PLTANH	/RAYCON/	MCONP	/DD/	IOR
	/LABCLT/	PROJCT	/DD/	IX
	/LABCLT/	RMAX	/DD/	IY
	/LABCLT/	RMIN		
	/LABCLT/	THMAX		
	/LABCLT/	THMIN		
SETXY			/LABCLT/	PROJCT
			/LABCLT/	RMAX
			/LABCLT/	RMIN
			/LABCLT/	THMAX
			/LABCLT/	THMIN
PLOTANOT	/ANNCTC/	ANOTES	/DD/	IOR
	/ANNCTC/	HNOTES	/DD/	IX
	/DD/	IX	/DD/	IY
	/DD/	IY		
	/ANNCTL/	LENA		
	/ANNCTL/	LENHA		
	/LABCLT/	THMAX		
	/LABCLT/	THMIN		
PLTLB	/DD/	IX	/DD/	IOR
	/DD/	IY	/DD/	IX
	/LABCLT/	PROJCT		
	/LABCLT/	RMAX		
	/LABCLT/	RMIN		

Table 7.5--(continued)

Routine	Input parameters		Output parameters	
	common block	parameter name	common block	parameter name
PLOTBL			/KNKN/	
			/DDLIM/	
DDBP	/DD/	IX	/KNKN/	KNBP
	/DD/	IY	/DDLIM/	MNIX
	/KNKN/	KNBP	/DDLIM/	MNIY
	/DDLIM/	MNIX	/DDLIM/	MXIX
	/DDLIM/	MNIY	/DDLIM/	MXIY
	/DDLIM/	MXIX		
	/DDLIM/	MXIY		
DDVC	/DD/	IX	/KNKN/	KNVC
	/DD/	IY	/DDLIM/	MNIX
	/KNKN/	KNVC	/DDLIM/	MNIY
	/DDLIM/	MNIX	/DDLIM/	MXIX
	/DDLIM/	MNIY	/DDLIM/	MXIY
	/DDLIM/	MXIX		
	/DDLIM/	MXIY		
DDTEXT	/DD/	IOR	/KNKN/	KNDT
	/DD/	IX		
	/DD/	IY		
	/KNKN/	KNDT		

Table 7.6--Definitions of the parameters in common block /HDR/

Position in common	Variable name	Definition
1	SEC	Total elapsed computer calculation time at end of calculating previous raypath

Table 7.7--Definitions of the parameters in common block /UCONC/

Position in common	Variable name	Definition
1-4	PCV	List of valid unit types for units conversion: blank (no conversion), AN (angle), LN (length), FQ (frequency
5-20	CNVC	An array of lists of valid physical units for each unit type for units conversion: blank (no conversion), M (meters), KM (kilometers), DG (degrees), etc

Table 7.8--Definitions of the parameters in common block /UCONV/

Position in common	Variable name	Definition
1-16	CNVV	An array of units conversion factors corresponding to the array CNVC in common block /UCONC/

Table 7.9--Definitions of the parameters in common block /RKAMS/

Position in common	Variable name	Definition
1-5	XV	Values of independent variable for 5 integration steps
6-85	FV	Values of the derivatives of the 20 dependent variables for 4 integration steps
86-285	YU	Values of the 20 dependent variables for 5 integration steps (in double precision)
286	EPM	The amount by which the independent variable changed during the previous call to SUBROUTINE RKAM1
287	ALPHA	Value of the independent variable at the beginning of the latest integration step
288	MM	Relative integration step number (varies from 1 to 4)

Table 7.10--Definitions of the parameters in common block /CGET/

Position in common	Variable name	Definition
1	ZERO	A great circle distance at sea level corresponding to a central earth angle that is twice the smallest floating point variable that can be stored in one single precision word in the computer being used

Table 7.11--Definitions of the parameters in common block /CRMACH/

Position in common	Variable name	Definition
1	RMACH(1)	Smallest positive magnitude = B**(EMIN-1)
2	RMACH(2)	Largest magnitude = B**EMAX*(1-B**(-T))
3	RMACH(3)	Smallest relative spacing = B**(-T)
4	RMACH(4)	Largest relative spacing = B**(1-T)
5	RMACH(5)	$Log_{10}B = Log_{10}2$

Notes: 1. B = the number base used by the computer (= 2 for most computers)
2. T = the number of bits in the mantissa of a floating point number
3. EMIN = the most negative allowable exponent
4. EMAX = the largest allowable positive exponent

Table 7.12--Definitions of the parameters in common block /CRKTIME/

Position in common	Variable name	Definition
1	IRKTIME	The number of times that SUBROUTINE RKAM has been called (used to compare FTIME or GTIME with to know whether F or G need to be updated)
1	RKTIME	Floating point name of IRKTIME

Table 7.13--Definitions of the parameters in common block /TRLOCAL/

Position in common	Variable name	Definition
1	RSIGN	+1 if next receiver-surface crossing is going up; -1 if going down
2	HOME	.TRUE. if ray is going away from receiver surface; .FALSE. otherwise
3	FDOT	Rate of change of distance of ray above the receiver surface
4	GDOT	Rate of change of distance of ray above the terrain
5	GOLD	Value of G at previous integration step (= distance of ray above terrain)
6	GDOLD	Value of GDOT at previous integration step

Table 7.14--Definitions of the parameters in common block /RK/*

Position in common	Variable name	Definition
1	N	The number of equations being integrated
2	STEP	The initial step in group path in kilometers
3	MODE	Defines type of integration used (same as W41), see Section 5.3.2
4	E1MAX	Maximum allowable single step error (same as W42)
5	E1MIN	Minimum allowable single step error (= W42/W43)
6	E2MAX	Maximum step length (same as W45)
7	E2MIN	Minimum step length (same as W46)
8	FACT	Factor to use to decrease step length (same as W47)
9	RSTART	Nonzero to initialize numerical integration, zero to continue integration

* These parameters are calculated in subroutine READW (some are temporarily reset in subroutine BACKUP) and are used in subroutine RKAM.

Table 7.15--Definitions of the parameters in common block /TRAC/*

Position in common	Variable name	Definition
1	GROUND	.TRUE. if the ray is on the surface of the Earth
2	PERIGE	.TRUE. if the ray has just made a perigee
3	THERE	.TRUE. if the ray is at the receiver height
4	MINDIS	.TRUE. if the ray has just made a closest approach to the receiver height
5	NEWRAY	Not used in this version of the program
6	SMT	An estimation of the vertical distance to an apogee or perigee of the ray
7	OSMT	Value of SMT at previous integration step
8-27	ROLD	Value of R(1) (=r in r,θ,ϕ earth-centered spherical polar coordinate system) at previous integration step
28-47	DROLD	Value of dr/dt at previous integration step
48	TOLD	Value of t (= independent variable for numerical integration) at previous integration step
49	ZDOT	dZ/dt (= dF/dt or dG/dt, depending on the situation)
50	D2Z	d^2Z/dt^2 (= d^2F/dt^2 or d^2G/dt^2, depending on the situation)
51	RAD	$(dZ/dt)^2 - 2\ Z\ d^2Z/dt^2$
52	RAD1	$\sqrt{RAD}$

* These parameters are used for communication between subroutines TRACE and BACKUP.

Table 7.16--Definitions of the parameters in common block /FNDER/

Position in common	Variable name	Definition	Value
1	NZ	Relative position of F in common block /RR/ (or G in common block /GG/)	1
2	NPZR	Relative position of PFR in common block /RR/ (or PGR in common block /GG/)	2
3	NPZRR	Relative position of PFRR in common block /RR/ (or PGRR in common block /GG/)	3
4	NPZRTH	Relative position of PFRTH in common block /RR/ (or PGRTH in common block /GG/)	4
5	NPZRPH	Relative position of PFRPH in common block /RR/ (or PGRPH in common block /GG/)	5
6	NPZTH	Relative position of PFTH in common block /RR/ (or PGTH in common block /GG/)	6
7	NPZPH	Relative position of PFPH in common block /RR/ (or PGPH in common block /GG/)	7
8	NPZTHTH	Relative position of PFTHTH in common block /RR/ (or PGTHTH in common block /GG/)	8
9	NPZPHPH	Relative position of PFPHPH in common block /RR/ (or PGPHPH in common block /GG/)	9
10	NPZTHPH	Relative position of PFTHPH in common block /RR/ (or PGTHPH in common block /GG/)	10
11	NSELECT	Relative position of FSELECT in common block /RR/ (or GSELECT in common block /GG/)	11
12	NTIME	Relative position of FTIME in common block /RR/ (or GTIME in common block /GG/)	12

Table 7.17--Definition of the parameters in common block /RIN/*

Position in common	Variable name	Definition
1-8	MODRIN	Description of version of DISPER in BCD
9-14	RAYNAME	Hollerith names of the characteristic rays in a birefringent medium (= blank for this version of the program)
15-17	TYPE	= Hollerith 1 or 3 if this version of DISPER includes wind, = Hollerith 2 or 3 if this version of DISPER includes losses
18	SPACE	TRUE, if the ray is in a homogeneous non-dissipative medium (Unconditionally set to FALSE in this version of the program)
19	OMEGMIN	Minimum frequency for nonevanescent propagation (= 0 for this version of the program)
20	OMEGMAX	Maximum frequency for nonevanescent propagation (not applicable for this version of the program, set to 0)
21,22	KAY2	k^2, square of the complex wave number
23,24	H	Hamiltonian (complex)
25,26	PHPT	$\partial H/\partial t$ (complex)
27,28	PHPR	$\partial H/\partial r$ (complex)
29,30	PHPTH	$\partial H/\partial \theta$ (complex)
31,32	PHPPH	$\partial H/\partial \phi$ (complex)
33,34	PHPOM	$\partial H/\partial \omega$ (complex)
35,36	PHPKR	$\partial H/\partial k_r$ (complex)
37,38	PHPKTH	$\partial H/\partial k_\theta$ (complex)
39,40	PHPKPH	$\partial H/\partial k_\phi$ (complex)
41,42	KPHPK	$\vec{k} \cdot \partial H/\partial \vec{k}$ (complex) $= k_r \partial H/\partial k_r + k_\theta \partial H/\partial k_\theta + k_\phi \partial H/\partial k_\phi$
43,44	POLAR	Characteristic transverse polarization of the wave (complex) (= 0 for this version of the program)
45,46	LPOLAR	Characteristic longitudinal polarization of the wave (complex) (= 1 for this version of the program)
47	SGN	= +1 or -1; used for ray tracing in complex space

* These parameters are calculated in subroutine DISPER and used in subroutine HAMLTN.

Note: In some subroutines, the real and imaginary parts of the complex variables have separate names.

Table 7.18--Definitions of the parameters in common block /ERR/

Position in common	Variable name	Definition
1	NERG	Index number for the dependent variable for the integration that gives G
2	NERR	Index number for the dependent variable for the integration that gives $\partial G/\partial r$
3	NERT	Index number for the dependent variable for the integration that gives $\partial G/\partial \theta$
4	NERP	Index number for the dependent variable for the integration that gives $\partial G/\partial \phi$

Table 7.19--Definitions of the parameters in common block /RAYDEV/

Position in common	Variable name	Definition
1	NRYIND	Device unit number for input data
2	NDEVTMP	Device unit number for temporary output and input
3	NFRMAT	Device unit number for secondary input file (not used by ray tracing program)
4		Device unit number for graphics output
5		Device unit number for binary raypath coordinate output

Table 7.20--Definitions of the parameters in common block /FLGP/

Position in common	Variable name	Definition
1	NSET	Runset number

Table 7.21--Definitions of the parameters in common block /RINPL/

Position in common	Variable name	Definition
1	DISPM	Character string identifier for the dispersion relation model

Table 7.22--Definitions of the parameters in common block /FLG/*

Position in common	Variable	Definition
1	NTYP	Wave polarization indicator (not used in this version of program)
2	NEWWR	Set equal to .TRUE. to tell subroutine RAYPLT there is a new W array
3	NEWWP	Set equal to .TRUE. to tell subroutine PRINTR there is a new W array
4	PENET	Set equal to .TRUE. if the ray left the allowed region of the atmosphere
5	LINES	Number of lines printed on the current page
6	IHOP	Hop number (at the beginning of each ray, subroutine TRACE sets this parameter to zero so that subroutine RAYPLT will begin a new line in plotting the raypath, and subroutine PRINTR will print column headings and punch a transmitter rayset)
7	HPUNCH	The height to be output on the raysets

* The parameters are used to communicate between various subroutines.

Table 7.23--Definitions of the parameters in common block /RINPL/

Position in common	Variable name	Definition
1	DISPM	Character string identifier for the dispersion relation model

Table 7.24--Definitions of the parameters in common block /FILEC/

Position in common	Variable name	Definition
1	NPLTDP	Set equal to the device unit number for binary raypath coordinate output (variable in position 5 of common block /RAYDEV/) if binary raypath coordinate output has been requested, set to zero otherwise

Table 7.25--Definitions of the parameters in common block /PLT/*

Position in common	Variable name	Definition
1	XMINO,XL	The x-coordinate of the left side of the plotting area in kilometers
2	XMAXO,XR	The x-coordinate of the right side of the plotting area in kilometers
3	XMINO,YB	The y-coordinate of the bottom of the plotting area in kilometers
4	XMAXO,YT	The y-coordinate of the top of the plotting area in kilometers
5	RESET	Set equal to one whenever the plotting area is changed

* These parameters are used for communication between subroutine RAYPLT and subroutine PLOT.

Table 7.26--Definitions of the parameters in common block /RAYCON/

Position in common	Variable name	Definition
1	MCONP	Set to zero for the raytracing program to indicate that the abscissa in raypath plots is a central-earth angle in radians, set non-zero for the contouring program to indicate that the abscissa in contour plots is a great-circle distance in kilometers

Table 7.27--Definitions of the parameters in common block /ANNCTC/

Position in common	Variable name	Definition
1-8	ANOTES	Character strings to label the ordinate of raypath plots
9-20	HNOTES	Character strings to label the abscissa of raypath plots

Table 7.28--Definitions of the parameters in common block /ANNCTL/

Position in common	Variable name	Definition
1-4	LENA	Lengths of the character strings that label the ordinate of raypath plots
5-7	LENHA	Lengths of the character strings that label the abscissa of raypath plots

Table 7.29--Definitions of the parameters in common block /LABCLT/

Position in common	Variable name	Definition
1	PROJCT	Number that indicates which type of projection is being used for raypath plots
2	THMIN	θ_{min}, minimum value of the abscissa of a raypath plot
3	THMAX	θ_{max}, maximum value of the abscissa of a raypath plot
4	RMIN	r_{min}, minimum value of the ordinate of a raypath plot
5	RMAX	r_{max}, maximum value of the ordinate of a raypath plot

Table 7.30--Definitions of the parameters in common block /DD/

Position in common	Variable name	Definition
1	IN	Intensity IN = 0 specifies normal intensity IN = 1 specifies high intensity
2	IOR	Orientation IOR = 0 specifies upright orientation IOR = 1 specifies rotated orientation (90° counterclockwise)
3	IT	Italics (Font) IT= 0 specifies non-italic (Roman) symbols IT = 1 specifies italic symbols
4	IS	Symbol size IS = 0 specifies miniature size IS = 1 specifies small size IS = 2 specifies medium size IS = 3 specifies large size
5	IC	Symbol case IC = 0 specifies uppercase IC = 1 specifies lowercase
6	ICC	Character code, 0-63 (R1 format) ICC and IC together specify the symbol plotted
7	IX	X-coordinate, 0-1023
8	IY	Y-coordinate, 0-1023

Table 7.31--Definitions of the parameters in common block /KNKN/

Position in common	Variable name	Definition
1	KNBP	Number of times SUBROUTINE DDBP was called
2	KNVC	Number of times SUBROUTINE DDVC was called
3	KNDT	Number of times SUBROUTINE DDTEXT was called

Table 7.32--Definitions of the parameters in common block /DDLIM/

Position in common	Variable name	Definition
1	MXIX	Maximum value of IX
2	MXIY	Maximum value of IY
3	MNIX	Minimum value of IX
4	MNIY	Minimum value of IY

Table 7.33--Definitions of the parameters in common block /UU/

Position in common	Variable name	Definition
1-4	MODU	Wind-velocity model and parameter identification
1	MODU(1)	Name of wind-velocity subroutine
2	MODU(2)	Wind-velocity parameter identification number
3	MODU(3)	Name of wind-velocity perturbation subroutine
4	MODU(4)	Wind-velocity perturbation parameter identification number
5	V	$\|V\|$, wind speed in km/s
6	PVT	$\partial\|V\|/\partial t$
7	PVR	$\partial\|V\|/\partial r$
8	PVTH	$\partial\|V\|/\partial\theta$
9	PVPH	$\partial\|V\|/\partial\phi$
10	VR	V_r, upward component of wind velocity
11	PVRT	$\partial V_r/\partial t$
12	PVRR	$\partial V_r/\partial r$
13	PVRRTH	$\partial V_r/\partial\theta$
14	PVRPH	$\partial V_r/\partial\phi$
15	VTH	V_θ, southward component of wind velocity
16	PVTHT	$\partial V_\theta/\partial t$
17	PVTHR	$\partial V_\theta/\partial r$
18	PVTHTH	$\partial V_\theta/\partial\theta$
19	PVTHPH	$\partial V_\theta/\partial\phi$
20	VPH	V_ϕ, eastward component of wind velocity
21	PVPHT	$\partial V_\phi/\partial t$
22	PVPHR	$\partial V_\phi/\partial r$
23	PVPHTH	$\partial V_\phi/\partial\theta$
24	PVPHPH	$\partial V_\phi/\partial\phi$

Table 7.34--Definitions of the parameters in common block /CC/

Position in	Variable	Definition common name
1-4	MODC	Sound-speed model and parameter identification
1	MODC(1)	Name of sound-speed subroutine
2	MODC(2)	Sound-speed parameter identification number
3	MODC(3)	Name of sound-speed perturbation subroutine
4	MODC(4)	Sound-speed perturbation parameter identification number
5	CS	C^2, square of sound speed in km^2/s^2
6	PCST	$\partial C^2/\partial t$
7	PCSR	$\partial C^2/\partial r$
8	PCSTH	$\partial C^2/\partial \theta$
9	PCSPH	$\partial C^2/\partial \phi$

Table 7.35--Definitions of the parameters in common block /TT/

Position in common	Variable name	Definition
1-4	MODT	Temperature model and parameter identification
1	MODT(1)	Name of temperature subroutine
2	MODT(2)	Temperature parameter identification number
3	MODT(3)	Name of temperature-perturbation subroutine
4	MODT(4)	Temperature-perturbation-parameter identification number
5	T	T, temperature in kelvins
6	PTT	$\partial T/\partial t$
7	PTR	$\partial T/\partial r$
8	PTTH	$\partial T/\partial \theta$
9	PTPH	$\partial T/\partial \phi$

Table 7.36--Definitions of the parameters in common block /MM/

Position in common	Variable name	Definition
1-4	MODM	Molecular weight model and parameter identification
	MODM(1)	Name of molecular weight subroutine
2	MODM(2)	Parameter identification number for molecular weight model
3	MODM(3)	Unused now
4	MODM(4)	Unused now
5	M	M, mean molecular weight
6	PMT	$\partial M/\partial t$
7	PMR	$\partial M/\partial r$
8	PMTH	$\partial M/\partial \theta$
9	PMPH	$\partial M/\partial \phi$

Table 7.37--Definitions of the parameters in common block /RR/

Position in common	Variable name	Definition
1-4	MODREC	Receiver-surface model and parameter identification
1	MODREC(1)	Name of receiver-surface subroutine
2	MODREC(2)	Parameter identification number for receiver-surface model
3	MODREC(3)	Unused now
4	MODREC(4)	Unused now
5	F	$f(r,\theta,\phi)$ defined in (6.72)-(6.74)
6	PFR	$\partial f/\partial r$
7	PFRR	$\partial^2 f/\partial r^2$
8	PFRTH	$\partial^2 f/\partial r \partial \theta$
9	PFRPH	$\partial^2 f/\partial r \partial \phi$
10	PFTH	$\partial f/\partial \theta$
11	PFPH	$\partial f/\partial \phi$
12	PFTHTH	$\partial^2 f/\partial \theta^2$
13	PFPHPH	$\partial^2 f/\partial \phi^2$
14	PFTHPH	$\partial^2 f/\partial \theta \partial \phi$
15	FSELECT	= "RECEIVER"
16	FTIME	An integer that is initialized to equal -1 at the beginning of each raypath calculation and is incremented by 1 at each integration step so that it is possible to determine whether the variables in this common block are current

Table 7.38--Definitions of the parameters in common block /GG/

Position in common	Variable name	Definition
1-4	MODG	Terrain model and parameter identification
1	MODG(1)	Name of terrain subroutine
2	MODG(2)	Terrain-parameter identification number
3	MODG(3)	Name of terrain-perturbation subroutine
4	MODG(4)	Terrain-perturbation parameter identification number
5	G	$g(r,\theta,\phi)$ defined in the same way as $f(r,\theta,\phi)$ in (6.72)-(6.74)
6	PGR	$\partial g/\partial r$
7	PGRR	$\partial^2 g/\partial r^2$
8	PGRTH	$\partial^2 g/\partial r \partial \theta$
9	PGRKPH	$\partial^2 g/\partial r \partial \phi$
10	PGTH	$\partial g/\partial \theta$
11	PGPH	$\partial g/\partial \theta$
12	PGTHTH	$\partial^2 g/\partial \theta^2$
13	PGPHPH	$\partial^2 g/\partial \phi^2$
14	PGTHPH	$\partial^2 g/\partial \theta \partial \phi$
15	GSELECT	= "TERRAIN"
16	GTIME	An integer that is initialized to equal -1 at the beginning of each raypath calculation and is incremented by 1 at each integration step so that it is possible to determine whether the variables in this common block are current

Table 7.39--Definitions of the parameters in common block /AA/

Position in common	Variable name	Definition
1-4	MODA	Viscosity/thermal conductivity model and parameter identification
1	MODA(1)	Name of viscosity/thermal conductivity subroutine
2	MODA(2)	Viscosity/thermal conductivity parameter identification number
3	MODA(3)	Name of viscosity/thermal conductivity perturbation subroutine
4	MODA(4)	Viscosity/thermal conductivity perturbation parameter identification number
5	MU	μ, viscosity
6	MUPT	$\partial\mu/\partial t$
7	MUPR	$\partial\mu/\partial r$
8	MUPTH	$\partial\mu/\partial\theta$
9	MUPPH	$\partial\mu/\partial\phi$
10	KAPPA	κ, thermal conductivity
11	KAPPT	$\partial\kappa/\partial t$
12	KAPPR	$\partial\kappa/\partial r$
13	KAPPTH	$\partial\kappa/\partial\theta$
14	KAPPPH	$\partial\kappa/\partial\phi$

Table 7.40--Definitions of the parameters in common block /PP/

Position in common	Variable name	Definition
1-4	MODP	Pressure model and parameter identification
1	MODP(1)	Name of pressure subroutine
2	MODP(2)	Pressure-parameter identification number
3	MODP(3)	Name of pressure-perturbation subroutine
4	MODP(4)	Pressure-perturbation parameter identification number
5	P	P, pressure
6	PPT	$\partial p/\partial t$
7	PPR	$\partial p/\partial r$
8	PPTH	$\partial p/\partial \theta$
9	PPPH	$\partial p/\partial \phi$

REFERENCES

Bennett, J. A. (1967): The calculation of Doppler shifts due to a changing ionosphere. J. Atmos. Terr. Phys., 29, 887-891.

Budden, K. G. (1961): Radio Waves in the Ionosphere. University Press, Cambridge, England.

Budden, K. G. (1972): The theory of coupling of characteristic radio waves in the ionosphere. J. Atmos. Terr. Phys., 34, 1909-1921.

Croft, T. A., and L. Gregory (1963): A fast, versatile ray-tracing program for IBM 7090 digital computers. Rept. SEL-63-107 (TR 82), Contract No. 225(64), Stanford Electronics Laboratories, Stanford, Calif.

Cornyn, J. J. (1973): GRASS: A digital computer ray-tracing and transmission-loss-prediction system. Vol. 1, NRL Report 7621, Naval Research Laboratory, Washington, D.C.

Courant, R., and D. Hilbert (1962): Methods of Mathematical Physics, vol. II, Partial Differential Equations. Interscience Publishers, John Wiley and Sons, New York.

Dudziak, W. F. (1961): Three-dimensional ray trace computer program for electromagnetic wave propagation studies. RM 61 TMP-32, DASA 1232, G. E. TEMPO, Santa Barbara, Calif.

Felsen, L. B., and N. Marcuvitz (1973): Radiation and Scattering of Waves. Prentice-Hall, Englewood Cliffs, N.J.

Feynman, R. P., and A. R. Hibbs (1965): Quantum Mechanics and Path Integrals. McGraw-Hill, New York.

Garabedian, P. R. (1964): Partial Differential Equations. John Wiley and Sons, New York.

Georges, T. M. (1967): Ionospheric effects of atmospheric waves. ESSA Tech. Rept. IER 57-ITSA-54, ESSA Institute for Telecommunication Sciences, Boulder, Colo.

Georges, T. M., and J. J. Stephenson (1968): HF radar signatures of traveling ionospheric irregularities: 3D ray-tracing simulation. Radio Sci., 4, 679-696.

Georges, T. M. (1970): Amplification of ionospheric heating and triggering of 'spread-F' by natural irregularities. J. Geophys. Res., 75, 6436-6438.

Georges, T. M. (1971): A program for calculating three-dimensional acoustic-gravity ray paths in the atmosphere. NOAA Tech. Rep. ERL 212-WPL 16, NOAA Environmental Research Laboratories, Boulder, Colo.

Georges, T. M. (1972): Acoustic ray paths through a model vortex with a viscous core. J. Acoust. Soc. Am., 51, 206-209.

Georges, T. M., and W. H. Beasley (1977): Refraction of infrasound by upper atmospheric winds. J. Acoust. Soc. Am., 61, 28-34.

Georges, T. M., R. M. Jones, and J. P. Riley (1986): Simulating ocean acoustic tomography measurements with Hamiltonian ray tracing. IEEE J. Oceanic Engr., OE11, 58-71.

Gossard, E. E., and W. H. Hooke (1975): Waves in the Atmosphere. Elsevier, New York.

Haselgrove, J. (1954): Ray theory and a new method for ray tracing. Report of Conference on the Physics of the Ionosphere (London Physical Society), 355-364.

Jones, R. M. (1966): A three-dimensional ray tracing computer program. ESSA Tech. Rep., IER 17-ITSA 17, ESSA Institute for Telecommunication Sciences, Boulder, Colo.

Jones, R. M. (1968): Modifications to the three-dimensional ray tracing program described in IER 17-ITSA 17. ESSA Tech. Memo. ERLTM-ITS 134, ESSA Institute for Telecommunication Sciences, Boulder, Colo.

Jones, R. M. (1970): Ray theory for lossy media. Radio Sci., 6, 793-801.

Jones, R. M., and J. J. Stephenson (1975): A versatile three-dimensional ray tracing computer program for radio waves in the ionosphere. OT Rep.

75-76, U.S. Department of Commerce/Office of Telecommunications, Boulder, Colo.

Jones, R. M., and T. M. Georges (1976): Infrasound from convective storms. III. Propagation to the ionosphere. J. Acoust. Soc. Am., 59, 765-779.

Jones, R. M. (1981a): Bending of a ray in a random inhomogeneous medium. NOAA Tech. Memo. ERL WPL-77, NOAA Environmental Research Laboratories, Boulder, Colo.

Jones, R. M. (1981b): The frequency shift of a pulse by a time-independent dispersive, lossy medium. NOAA Tech. Memo. ERL WPL-80, NOAA Environmental Research Laboratories, Boulder, Colo.

Jones, R. M. (1982): Algorithms for reflecting rays from general topographic surfaces in a ray-tracing program. NOAA Tech. Memo. ERL WPL-98, NOAA Environmental Research Laboratories, Boulder, Colo., 58 pp.

Jones, R. M., J. P. Riley, and T. M. Georges (1982): A versatile three-dimensional Hamiltonian ray-tracing computer program for acoustic waves in the atmosphere. NOAA Tech. Memo. ERL WPL-103, NOAA Environmental Research Laboratories, Boulder, Colo., 242 pp.

Jones, R. M. (1983): A survey of underwater-acoustic ray-tracing techniques. NOAA Tech. Memo. ERL WPL-111, NOAA Environmental Research Laboratories, Boulder, Colo.

Jones, R. M., T. M. Georges, and J. P. Riley (1984): Modeling acoustic remote sensing in the Florida Straits with ray tracing. IEEE Trans. Geosci. Remote Sens., GE-22, 633-640.

Jones, R. M., J. P. Riley, and T. M. Georges (1986): HARPO--A versatile three-dimensional Hamiltonian ray-tracing program for acoustic waves in an ocean with arbitrary bottom. NOAA Special Rep., NOAA Environmental Research Laboratories, Boulder, Colo.

Keller, J. B. (1962): Geometrical theory of diffraction. J. Opt. Soc. Am., 52, 116-130.

Lighthill, M. J. (1965): Group velocity. J. Inst. Math. Appl., 1, 1-28.

Lighthill, M. J. (1978): Waves in Fluids. Cambridge Univ. Press, Cambridge, England, Sec. 4.5.

Ludwig, D. (1966): Uniform asymptotic expansions at a caustic. Commun. Pure Appl. Math., 19, 215-250.

NOAA, NASA, and USAF, "U.S. Standard Atmosphere, 1976". U.S. Government Printing Office, Washington, D.C. October 1976, p. 19.

Pedersen, M. A. (1961): Acoustic intensity anomalies introduced by constant velocity gradients. J. Acoust. Soc. Am., 33, 465-474.

Pierce, A. D. (1965): Extension of the method of normal modes to sound propagation in an almost-stratified medium. J. Acoust. Soc. Am., 37, 19-27.

Raspet, R., S. W. Lee, E. Kuester, D. C. Chang, W. F. Richards, R. Gilbert, and N. Bong (1985): Fast-field program for sound propagation in a layered atmosphere above an impedance ground. J. Acoust. Soc. Am., 77, 345-352.

Roberts, B. G., Jr. (1974): Horizontal-gradient acoustical ray-trace program TRIMAIN. NRL Report 7827, Naval Research Laboratory, Washington, D.C.

Sears, F. W. (1956): An Introduction to Thermodynamics, the Kinetic Theory of Gases, and Statistical Mechanics. Second Edition, Addison-Wesley, Reading, Massachusetts.

Stephenson, J. J., and T. M. Georges (1969): Computer routines for synthesizing ground-backscatter from three-dimensional raysets. ESSA Tech. Rep. ERL 120-ITS84, NOAA Environmental Research Laboratories, Boulder, Colo.

Tappert, F. D. (1977): The parabolic approximation method. In Wave Propagation in Underwater Acoustics, edited by J. B. Keller and J. S. Papadakis, Springer-Verlag, New York.

Tolstoy, I., and C. S. Clay (1966): Ocean Acoustics, Theory and Experiment in Underwater Sound. McGraw-Hill, New York.

Valley, S. L. (1965): Handbook of Geophysics and Space Environments. McGraw-Hill, New York.

White, D., and M. Pedersen (1981): Evaluation of shadow-zone fields by uniform asymptotics and complex rays. J. Acoust. Soc. Am., 69, 1029-1059.

APPENDIX A: PRINTOUT AND RAYSET LISTING FOR THE SAMPLE CASE

This appendix contains an abbreviated printout and rayset listing for the sample case. To save space, we have listed the printout for an elevation-angle increment of 20° instead of 5°, the increment used to produce the ray plots and raysets. Users should compare their sample-case output with this printout to be sure they are identical. The meanings of the printed quantities are explained in Sections 2.5.1 and 2.5.2, and the meanings of rayset quantities are listed in Figures 2.9 and 2.10.

***** H A R P A *****
HAMILTONIAN ACOUSTIC RAY-TRACING PROGRAM FOR THE ATMOSPHERE

BY
R. M. JONES, J. P. RILEY AND T. M. GEORGES
WAVE PROPAGATION LABORATORY
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
BOULDER, COLORADO 80303

RUN SET NUMBER 1

ATMOSPHERIC MODEL ID — S03

ATMOSPHERIC MODEL DESCRIPTION — SAMPLE CASE FOR HARPA DOCUMENTATION REV. 2-10-86

MODEL TYPE	SUBROUTINE NAME	DATA SET ID	DESCRIPTION
DISPERSION RELATION	AWWWL		ACOUSTIC WAVE *** WITH WIND ****** WITH LOSSES
BACKGROUND WIND VELOCITY	ULOGZ2	3.00	LOGARITHMIC EASTWARD WIND PROFILE, U*=.5 M/S, Z0=1 KM
WIND VELOCITY PERTURBATION	NPWIND	.00	NO WIND PERTURBATION
BACKGROUND SOUND SPEED	GAMRTDM	.00	SOUND SPEED IN TERMS OF TEMPERATURE MODEL
SOUND SPEED PERTURBATION	CBLOB2	2.00	50% INCREASE IN SQ. SOUND SPEED AT 125KM HT, 335KM N, 125KM E
BACKGROUND TEMPERATURE	TTANH5	1.00	U.S. STANDARD ATMOSPHERE 1962 TEMPERATURE PROFILE
TEMPERATURE PERTURBATION	TBLOB2	2.00	50% CYLINDRICAL INCREASE IN TEMPERATURE AT 105KM N., 105 KM W
MOLECULAR WEIGHT	MCONST	29.00	MOLECULAR WEIGHT = 29
BACKGROUND TERRAIN	GLORENZ	2.00	RIDGE 2-KM HIGH, 30-KM WIDE ALONG EQUATOR
TERRAIN PERTURBATION	NPTERR	.00	NO TERRAIN PERTURBATION
BACKGROUND VISCOSITY/ THERMAL CONDUCTIVITY	MUARDC	1.00	ARDC VISCOSITY AND THERMAL CONDUCTIVITY MODEL
VISCOSITY/THERMAL CONDUCTIVITY PERTURBATION	NPABSR	.00	NO VISCOSITY/CONDUCTIVITY PERTURBATION
BACKGROUND PRESSURE	PEXP	1.00	EXPONENTIAL PRESSURE MODEL, SCALE HEIGHT = 8.5 KM
PRESSURE PERTURBATION	NPPRES	.00	NO PRESSURE PERTURBATION
RECEIVER SURFACE	RTERR	.00	RECEIVER SURFACE 5 KM ABOVE TERRAIN

INPUT DATA FILE FOR RUN SET NUMBER 1

```
S03-1    SAMPLE CASE FOR HARPA DOCUMENTATION       REV. 2-10-86
  1     6370.           EARTH RADIUS, KM (6370.)
  3       13.          TTRANSMITTER HEIGHT, KM (T=ABOVE TERRAIN)
  4      200.    AN KM  N. TRANSMITTER LATITUDE, KM
  5        0.    AN KM  E. TRANSMITTER LONGITUDE, KM
  7      .05     FQ HZ  INITIAL FREQUENCY, HZ
 11       45.    AN DG  INITIAL AZIMUTH ANGLE, DEG
 15      -20.    AN DG  INITIAL ELEVATION ANGLE, DEG
 16      140.    AN DG  FINAL   ELEVATION ANGLE, DEG
 17       20.    AN DG  STEP IN ELEVATION ANGLE, DEG
 20        5.            RECEIVER HEIGHT, KM
 22        3.            MAXIMUM NUMBER OF HOPS (1.0)
 23     1000.            MAXIMUM NUMBER OF STEPS PER HOP (1000.)
 26      500.            MAXIMUM RAY HEIGHT, KM (500.)
 27       -1.            MINIMUM RAY HEIGHT, KM
 28     1000.            MAXIMUM RANGE, KM
 29  0000100.            DO: EIGRAY/RNG-TIM/RNG-ELV/NEW-PROJ/RAYTRC/CONT/PROF
 33   999.999            MAXIMUM ABSORPTION, DB (999.999)
 42      1.0E-6          SINGLE-STEP INTEGRATION ERROR (1.0E-4)
 44        .1            INITIAL INTEGRATION STEP SIZE, KM (1.0)
 57        2.            PHASE PATH (0=NO; 1=INTEGRATE; 2=INTEGRATE/PRINT)
 58        2.            ABSORPTION (0=NO; 1=INTEGRATE; 2=INTEGRATE/PRINT)
 60        2.            PATH LENGTH (0=NO; 1=INTEGRATE; 2=INTEGRATE/PRINT)
 71       50.            NUMBER OF INTEGRATION STEPS PER PRINT [1.E31]
 72        1.            OUTPUT RAYSETS (1=YES; 0=NO)
 73        0.            DIAGNOSTIC PRINTOUT (1=YES; 0=NO)
 74        0.            PRINT RAY STEPS (0=YES; 1=NO)
 75       .15            FULANN LETTER HEIGHT [0.15 IN]
 76        0.            BINARY RAY OUTPUT (1=YES; 0=NO)
 77       57.            LINES PER PAGE IN PRINTOUT (57.)
 81        1.            RAYPLOT PROJECTION (1=VERT; 2=HORIZ) PLANE
 82        1.            PLOT-EXPANSION FACTOR [1.0]
 83     -100.    AN KM  N. LATITUDE  OF LEFT PLOT EDGE, KM
 84     -300.    AN KM  E. LONGITUDE OF LEFT PLOT EDGE, KM
 85      500.    AN KM  N. LATITUDE  OF RIGHT PLOT EDGE, KM
 86      300.    AN KM  E. LONGITUDE OF RIGHT PLOT EDGE, KM
 87      100.    AN KM  DISTANCE BETWEEN TIC MARKS, KM
 88        0.           HEIGHT ABOVE SEA LEVEL OF BOTTOM OF GRAPH, KM
 89      300.           HEIGHT ABOVE SEA LEVEL OF TOP OF GRAPH, KM
 96      100.           DISTANCE BETWEEN VERTICAL TIC MARKS, KM
100        6.           ULOGZ2 WIND MODEL CHECK NUMBER
102        3.            BACKGROUND WIND DATA SET ID
103        5.    LN  M   REFERENCE WIND SPEED, M/S
104       .35            VON KARMAN'S CONSTANT
105        1.            ROUGHNESS HEIGHT, KM
150        1.           GAMRTDM SOUND SPEED MODEL CHECK NUMBER
175        2.           CBLOB2 MODEL CHECK NUMBER
177        2.            SOUND SPEED PERTURBATION DATA SET ID
178       .5             FRACTIONAL INCREASE OF SQUARED SOUND SPEED
179      125.            HEIGHT OF MAXIMUM INCREASE, KM
```

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180      335.    AN KM   N. LATITUDE OF MAXIMUM INCREASE, KM
181      125.    AN KM   E. LONGITUDE OF MAXIMUM INCREASE, KM
182       25.            GAUSSIAN WIDTH IN HEIGHT OF INCREASE, KM
183       50.    AN KM   N-S WIDTH OF THE INCREASE, KM
184       25.    AN KM   E-W WIDTH OF THE INCREASE, KM
200        7.           TTANH5 TEMPERATURE MODEL CHECK NUMBER
202        1.            BACKGROUND TEMPERATURE DATA SET ID
225        2.           TBLOB2 MODEL CHECK NUMBER
227        2.            TEMPERATURE PERTURBATION DATA SET ID
228        .5            FRACTIONAL TEMPERATURE INCREASE
229        0.            HEIGHT OF MAXIMUM INCREASE, KM
230      105.    AN KM   N. LATITUDE OF MAXIMUM INCREASE, KM
231     -105.    AN KM   E. LONGITUDE OF MAXIMUM INCREASE, KM
232        0.            GAUSSIAN WIDTH IN HEIGHT OF INCREASE, KM
233       50.    AN KM   N-S WIDTH OF THE INCREASE, KM
234       25.    AN KM   E-W WIDTH OF THE INCREASE, KM
250        1.           MCONST MOLECULAR WEIGHT MODEL CHECK NUMBER
252       29.            MOLECULAR WEIGHT DATA SET ID
253       29.            MOLECULAR WEIGHT
275        2.           RTERR RECEIVER MODEL CHECK NUMBER
300        4.           GLORENZ TERRAIN MODEL CHECK NUMBER
302        2.            TERRAIN MODEL DATA SET ID
303        2.            HEIGHT OF THE RIDGE, KM
304        0.            N. LATITUDE OF THE RIDGE CENTER
305       30.    AN KM   HALF-WIDTH OF THE RIDGE, KM
325        0.           NPTERR NO TERRAIN PERTURBATION
500        1.           MUARDC VISC/COND MODEL CHECK NUMBER
502        1.            VISC/COND MODEL DATA SET ID
503     1.458E-06        VISCOSITY COEFFICIENT BETA
504     110.4            SUTHERLAND'S CONSTANT, KELVINS
505      1.91            PRANDTL NUMBER
525        0.           NPABS NO VISC/COND PERTURBATION
550        1.           PEXP PRESSURE MODEL CHECK NUMBER
552        1.            BACKGROUND PRESSURE MODEL DATA SET ID
553   101328.            PRESSURE AT SEA LEVEL, N/SQ.M.
554      8.5             PRESSURE SCALE HEIGHT, KM
575        0.           NPPRES   NO PRESSURE PERTURBATION
 -1                     DATA SUBSET FOR BACKGROUND WIND MODEL
  A  LOGARITHMIC EASTWARD WIND PROFILE, U*=.5 M/S, Z0=1 KM
  0      RETURN TO W ARRAY DATA SET
 -2                     DATA SUBSET FOR WIND PERTURBATION MODEL
  A  NO WIND PERTURBATION
  0      RETURN TO W ARRAY DATA SET
 -3                     DATA SUBSET FOR BACKGROUND SOUND-SPEED MODEL
  A  SOUND SPEED IN TERMS OF TEMPERATURE MODEL
  0      RETURN TO W ARRAY DATA SET
 -4                     DATA SUBSET FOR SOUND-SPEED PERTURBATION MODEL
  A  50% INCREASE IN SQ. SOUND SPEED AT 125KM HT, 335KM N, 125KM E
  0      RETURN TO W ARRAY DATA SET
 -5                     DATA SUBSET FOR TEMPERATURE MODEL
  A  U.S. STANDARD ATMOSPHERE 1962 TEMPERATURE PROFILE
  3     999.0           TEMPERATURE PROFILE FOR 1962 STD ATMOSPHERE
   0.          288.000        0.
  15.0000      190.500       10.0000
  52.0000      320.000        7.50000
```

```
 95.0000      191.000      10.0000
165.0000     1451.000      50.0000
300.0000     1586.000       0.
999.0000
  0      RETURN TO W ARRAY DATA SET
 -6                     DATA SUBSET FOR TEMPERATURE PERTURBATION MODEL
  A  50% CYLINDRICAL INCREASE IN TEMPERATURE AT 105KM N., 105 KM W
  0      RETURN TO W ARRAY DATA SET
 -7                     DATA SUBSET FOR MOLECULAR WEIGHT MODEL
  A  MOLECULAR WEIGHT = 29
  0      RETURN TO W ARRAY DATA SET
 -8                     DATA SUBSET FOR RECEIVER SURFACE MODEL
  A  RECEIVER SURFACE 5 KM ABOVE TERRAIN
  0      RETURN TO W ARRAY DATA SET
 -9                     DATA SUBSET FOR TERRAIN MODEL
  A  RIDGE 2-KM HIGH, 30-KM WIDE ALONG EQUATOR
  0      RETURN TO W ARRAY DATA SET
-10                     DATA SUBSET FOR TERRAIN PERTURBATION MODEL
  A  NO TERRAIN PERTURBATION
  0      RETURN TO W ARRAY DATA SET
-17                     DATA SUBSET FOR VISC/COND MODEL
  A  ARDC VISCOSITY AND THERMAL CONDUCTIVITY MODEL
  0      RETURN TO W ARRAY DATA SET
-18                     DATA SUBSET FOR VISC/COND PERTURBATION MODEL
  A  NO VISCOSITY/CONDUCTIVITY PERTURBATION
  0      RETURN TO W ARRAY DATA SET
-19                     DATA SUBSET FOR BACKGROUND PRESSURE MODEL
  A  EXPONENTIAL PRESSURE MODEL, SCALE HEIGHT = 8.5 KM
  0      RETURN TO W ARRAY DATA SET
-20                     DATA SUBSET FOR PRESSURE PERTURBATION MODEL
  A  NO PRESSURE PERTURBATION
  0      RETURN TO W ARRAY DATA SET
  0                     **********  END OF RUN SET NUMBER 1  ***********
```

INITIAL VALUES FOR THE W ARRAY
ONLY NONZERO VALUES PRINTED — ALL ANGLES IN RADIANS

N	W(N)
1	.637000000000000E+04
3	.130440097799511E+02
4	.313971742543171E-01
7	.314159265358979E+00
11	.785398163397446E+00
15	-.349065850398864E+00
16	.244346095279205E+01
17	.349065850398864E+00
20	.500000000000000E+01
22	.300000000000000E+01
23	.100000000000000E+04
24	.157079632679490E+01
26	.500000000000000E+03
27	-.100000000000000E+01
28	.100000000000000E+04
29	.100000000000000E+03
33	.999999000000000E+03
41	.300000000000000E+01
42	.999999999999997E-06
43	.500000000000000E+02
44	.100000000000000E+00
45	.100000000000000E+03
46	.100000000000000E-07
47	.500000000000000E+00
57	.200000000000000E+01
58	.200000000000000E+01
60	.200000000000000E+01
71	.500000000000000E+02
72	.100000000000000E+01
75	.150000000000000E+00
77	.570000000000000E+02
81	.100000000000000E+01
82	.100000000000000E+01
83	-.156985871271585E-01
84	-.470957613814755E-01
85	.784929356357926E-01
86	.470957613814755E-01
87	.156985871271585E-01
89	.300000000000000E+03
96	.100000000000000E+03
100	.600000000000000E+01
102	.300000000000000E+01
103	.500000000000000E-02
104	.350000000000000E+00
105	.100000000000000E+01
150	.100000000000000E+01
175	.200000000000000E+01
177	.200000000000000E+01
178	.500000000000000E+00
179	.125000000000000E+03
180	.525902668759810E-01
181	.196232339089482E-01
182	.250000000000000E+02
183	.784929356357927E-02
184	.392464678178964E-02
200	.700000000000000E+01
202	.100000000000000E+01
225	.200000000000000E+01
227	.200000000000000E+01
228	.500000000000000E+00
230	.164835164835164E-01
231	-.164835164835164E-01
233	.784929356357927E-02
234	.392464678178964E-02
250	.100000000000000E+01
252	.290000000000000E+02
253	.290000000000000E+02
275	.200000000000000E+01
300	.400000000000000E+01
302	.200000000000000E+01
303	.200000000000000E+01
305	.470957613814754E-02
500	.100000000000000E+01
502	.100000000000000E+01
503	.145800000000000E-05
504	.110400000000000E+03
505	.191000000000000E+01
550	.100000000000000E+01
552	.100000000000000E+01
553	.101328000000000E+06
554	.850000000000000E+01

AZIMUTH ANGLE OF TRANSMISSION = 45.000000 DEG TRANSMITTER LATITUDE = 1.798926 DEG FREQUENCY = .050000 HZ
ELEVATION ANGLE OF TRANSMISSION = -20.000000 DEG TRANSMITTER LONGITUDE = .000000 DEG SINGLE STEP ERROR = 1.000000E-06

ERROR	EVENT	ELEVATION ABOVE SEA LEVEL KM	ELEVATION ABOVE TERRAIN KM	RANGE KM	AZIMUTH DEVIATION XMTR DEG	AZIMUTH DEVIATION LOCAL DEG	ELEVATION ANGLE XMTR DEG	ELEVATION ANGLE LOCAL DEG	PULSE TIME SEC	PHASE TIME SEC	ABSORPTION DB	PATH LENGTH KM
-.1E-13	XMTR	13.0440	13.0000	.0000				-20.000	.0000	.0000	.0000	.0000
.2E-06	RCVR	5.0367	5.0000	29.4887	-3.840	-3.838	-15.304	-12.169	91.9612	91.9612	.0000	30.6167
.2E-06	GRND REF	.0313	.0000	56.3108	-2.735	-2.735	-13.252	10.682	172.2877	172.2877	.0000	57.9268
.8E-07	RCVR	5.0270	5.0000	83.1414	-2.343	-2.340	-5.874	12.148	252.6076	252.6076	.0000	85.2361
-.1E-06		30.1362	30.1186	179.8168	-3.794	-3.792	4.603	5.546	553.4076	553.4076	.0000	185.6886
-.1E-06	APOGEE	30.8025	30.7860	196.4513	-3.954	-3.953	4.264	-.461	601.4076	601.4076	.0000	202.4308
-.1E-06	WAVE REV	30.8025	30.7860	196.4513	-3.954	-3.953	4.264	-.461	601.4076	601.4076	.0000	202.4308
.1E-06		11.0830	11.0709	283.7756	-4.435	-4.436	-1.671	-18.721	870.2076	870.2076	.0000	292.7749
.3E-06	RCVR	5.0112	5.0000	307.3288	-4.374	-4.375	-2.877	-12.129	943.0763	943.0763	.0000	317.1400
.3E-06	MAX HOPS	5.0112	5.0000	307.3288	-4.374	-4.375	-2.877	-12.129	943.0763	943.0763	.0000	317.1400

THIS RAY CALCULATION TOOK 2.430 SEC

ELEVATION ANGLE OF TRANSMISSION = .0000 DEG

-.7E-14	XMTR	13.0440	13.0000	.0000				.000	.0000	.0000	.0000	.0000
.1E-07	APOGEE	19.8306	19.8069	114.8628	-4.945	-4.945	2.856	-.376	352.1000	352.1000	.0000	115.4148
.1E-07	WAVE REV	19.8306	19.8069	114.8628	-4.945	-4.945	2.856	-.376	352.1000	352.1000	.0000	115.4148
.1E-07		19.1628	19.1412	135.8244	-4.991	-4.991	1.962	-3.544	416.1000	416.1000	.0000	136.4540
.4E-07	MIN DIST	13.0453	13.0303	225.0470	-4.938	-4.939	-1.012	-.003	689.9096	689.9096	.0000	226.1364
.3E-07	WAVE REV	13.0683	13.0535	229.2405	-4.930	-4.932	-1.025	.687	702.7096	702.7096	.0000	230.3388
.5E-07	APOGEE	19.8297	19.8195	339.8931	-4.937	-4.942	-.388	-.372	1041.9096	1041.9096	.0000	341.5344
.5E-07	WAVE REV	19.8297	19.8195	339.8931	-4.937	-4.942	-.388	-.372	1041.9096	1041.9096	.0000	341.5344
.1E-06		17.9660	17.9568	377.5546	-4.964	-4.970	-.953	-5.329	1157.1096	1157.1096	.0000	379.3655
.7E-07	MIN DIST	13.0423	13.0348	450.1421	-4.932	-4.941	-2.025	-.001	1379.8701	1379.8701	.0000	452.3210
.7E-07	MAX HOPS	13.0423	13.0348	450.1421	-4.932	-4.941	-2.025	-.001	1379.8701	1379.8701	.0000	452.3210

THIS RAY CALCULATION TOOK .903 SEC

ELEVATION ANGLE OF TRANSMISSION = 20.0000 DEG

-.7E-14	XMTR	13.0440	13.0000	.0000				20.000	.0000	.0000	.0000	.0000
-.4E-06	APOGEE	30.8011	30.7734	83.6250	-5.591	-5.592	11.572	-.390	256.1000	256.0999	.0000	86.3124
-.4E-06	WAVE REV	30.8011	30.7734	83.6250	-5.591	-5.592	11.572	-.390	256.1000	256.0999	.0000	86.3124
-.4E-06		30.2160	30.1900	96.9373	-5.605	-5.605	9.576	-5.195	294.5000	294.4999	.0000	99.7046
.1E-06	RCVR	5.0170	5.0000	194.6869	-5.322	-5.324	-3.233	-12.129	598.2812	598.2810	.0000	201.1925
.2E-06	GRND REF	.0152	.0000	221.5510	-4.860	-4.863	-4.358	10.662	678.8281	678.8280	.0000	228.5831
.1E-06	RCVR	5.0137	5.0000	248.4283	-4.498	-4.500	-2.966	12.121	759.3772	759.3771	.0000	255.9751
.3E-08		30.1249	30.1149	345.1581	-4.646	-4.651	1.271	5.571	1060.1772	1060.1771	.0000	356.4343
.2E-08	APOGEE	30.7976	30.7881	361.7989	-4.694	-4.699	1.172	-.437	1108.1772	1108.1771	.0000	373.1773
.2E-08	WAVE REV	30.7976	30.7881	361.7989	-4.694	-4.699	1.172	-.437	1108.1772	1108.1771	.0000	373.1773
.3E-06		11.0982	11.0907	449.1534	-4.851	-4.860	-2.268	-18.731	1376.9772	1376.9772	.0000	463.5327
.5E-06	RCVR	5.0070	5.0000	472.7741	-4.790	-4.799	-3.098	-12.126	1450.0603	1450.0603	.0000	487.9710
.5E-06	MAX HOPS	5.0070	5.0000	472.7741	-4.790	-4.799	-3.098	-12.126	1450.0603	1450.0603	.0000	487.9710

THIS RAY CALCULATION TOOK 1.968 SEC

AZIMUTH ANGLE OF TRANSMISSION = 45.000000 DEG TRANSMITTER LATITUDE = 1.798926 DEG FREQUENCY = .050000 HZ
ELEVATION ANGLE OF TRANSMISSION = 40.000000 DEG TRANSMITTER LONGITUDE = .000000 DEG SINGLE STEP ERROR = 1.000000E-06

ERROR	EVENT	ELEVATION ABOVE SEA LEVEL KM	ELEVATION ABOVE TERRAIN KM	RANGE KM	AZIMUTH DEVIATION XMTR DEG	AZIMUTH DEVIATION LOCAL DEG	ELEVATION ANGLE XMTR DEG	ELEVATION ANGLE LOCAL DEG	PULSE TIME SEC	PHASE TIME SEC	ABSORPTION DB	PATH LENGTH KM
-.7E-14	XMTR	13.0440	13.0000	.0000				40.000	.0000	.0000	.0000	.0000
.6E-07		43.9246	43.8912	48.7564	-6.654	-6.654	32.014	28.195	169.7000	169.7000	.0000	58.0370
-.6E-06		88.4749	88.4526	134.7274	-7.168	-7.222	28.443	39.168	438.5000	438.4999	.0001	155.8842
-.7E-06	APOGEE	104.2225	104.2036	175.8021	-7.340	-5.047	26.407	-1.194	555.3000	555.2998	.0016	201.2805
-.7E-06	WAVE REV	104.2225	104.2036	175.8021	-7.340	-5.047	26.407	-1.194	555.3000	555.2998	.0016	201.2805
-.8E-06		101.0975	101.0797	192.8408	-7.530	-3.080	23.481	-21.450	596.9000	596.8998	.0024	218.9577
.6E-06		62.3998	62.3857	263.9313	-8.907	-3.505	9.343	-26.431	827.3000	827.2997	.0031	301.0331
-.1E-06		15.0673	15.0566	359.8298	-9.527	-4.128	-1.297	-39.337	1124.9000	1124.8997	.0031	409.0699
.5E-06	RCVR	5.0103	5.0000	374.1414	-9.536	-4.137	-2.911	-35.775	1178.0787	1178.0784	.0031	426.5820
.4E-06	GRND REF	.0101	.0000	381.4687	-9.488	-4.092	-3.670	34.996	1204.2519	1204.2517	.0031	435.4618
.4E-06	RCVR	5.0099	5.0000	388.7966	-9.442	-4.046	-2.930	35.772	1230.4251	1230.4249	.0031	444.3416
.2E-05		48.1493	48.1410	462.4781	-9.681	-4.287	2.238	23.933	1478.4251	1478.4251	.0031	530.3500
.7E-06		93.4113	93.4046	554.2751	-10.088	-4.698	5.685	35.429	1763.2251	1763.2256	.0034	633.9752
.5E-06	APOGEE	104.7397	104.7335	592.3256	-10.201	-4.812	6.050	-1.123	1867.2251	1867.2256	.0050	674.8220
.5E-06	WAVE REV	104.7397	104.7335	592.3256	-10.201	-4.812	6.050	-1.123	1867.2251	1867.2256	.0050	674.8220
.4E-06		98.6801	98.6742	618.2918	-10.256	-4.869	5.031	-27.897	1934.4251	1934.4256	.0063	702.0891
.2E-05		57.6827	57.6776	694.9466	-10.509	-5.125	.526	-24.084	2180.8251	2180.8258	.0068	790.0545
-.2E-06		8.8419	8.8375	788.1424	-10.575	-5.196	-3.849	-37.480	2478.4251	2478.4263	.0068	896.3113
.2E-05	RCVR	5.0043	5.0000	793.7415	-10.564	-5.185	-4.148	-35.793	2498.7527	2498.7538	.0068	903.1062
.2E-05	MAX HOPS	5.0043	5.0000	793.7415	-10.564	-5.185	-4.148	-35.793	2498.7527	2498.7538	.0068	903.1062

THIS RAY CALCULATION TOOK 2.999 SEC

ELEVATION ANGLE OF TRANSMISSION = 60.0000 DEG

-.7E-14	XMTR	13.0440	13.0000	.0000				60.000	.0000	.0000	.0000	.0000
-.2E-06		46.3009	46.2626	25.0438	-9.587	-9.587	52.778	54.898	124.9000	124.9000	.0000	41.7284
-.4E-08		89.3597	89.3273	60.1377	-10.437	-10.438	51.268	60.151	284.9000	284.8999	.0001	97.5354
-.5E-06		132.3433	132.3186	116.6785	-9.041	-9.240	44.786	21.235	444.9000	444.8998	.0357	170.6495
-.4E-06	APOGEE	144.8719	144.8545	199.2131	-7.589	-1.829	32.272	-.221	572.1000	572.0997	.5014	256.4120
-.4E-06	WAVE REV	144.8719	144.8545	199.2131	-7.589	-1.829	32.272	-.221	572.1000	572.0997	.5014	256.4120
-.4E-06		144.7473	144.7304	205.5626	-7.656	-1.487	31.401	-2.205	581.7000	581.6997	.5557	262.9118
-.4E-06		98.5307	98.5184	308.1062	-8.967	-2.280	13.990	-57.611	792.9000	792.8996	.9118	380.9940
.9E-05		42.8401	42.8290	352.0479	-9.918	-3.232	3.232	-56.821	997.7000	997.7001	.9121	452.4670
.3E-05	RCVR	5.0104	5.0000	378.8921	-10.259	-3.574	-2.917	-59.417	1138.5475	1138.5483	.9121	498.9910
.9E-06	GRND REF	.0103	.0000	382.0800	-10.249	-3.572	-3.669	58.546	1156.1759	1156.1768	.9121	504.9226
.1E-05	RCVR	5.0102	5.0000	385.2681	-10.240	-3.563	-2.925	59.414	1173.8043	1173.8052	.9121	510.8543
.5E-05		55.5496	55.5403	422.6504	-10.644	-3.967	3.809	55.842	1359.4043	1359.4055	.9121	573.9536
-.2E-05		111.6528	111.6443	468.6814	-11.217	-4.542	9.657	46.144	1564.2043	1564.2058	.9138	647.1544
-.2E-05	APOGEE	144.7403	144.7336	567.1420	-11.193	-4.522	10.360	-1.201	1743.4043	1743.4054	1.3398	755.3699
-.2E-05	WAVE REV	144.7403	144.7336	567.1420	-11.193	-4.522	10.360	-1.201	1743.4043	1743.4054	1.3398	755.3699
-.2E-05		129.1384	129.1325	632.9859	-11.142	-4.473	7.426	-28.754	1852.2043	1852.2051	1.6910	824.9860
.2E-05		71.4679	71.4625	692.1644	-11.446	-4.779	1.676	-58.729	2060.2043	2060.2046	1.7111	909.4548
.6E-06		10.1142	10.1093	739.1827	-11.686	-5.021	-3.551	-60.623	2284.2043	2284.2055	1.7111	987.0659
.4E-05	RCVR	5.0049	5.0000	742.5637	-11.689	-5.024	-3.958	-59.423	2302.9500	2302.9512	1.7111	993.1950
.4E-05	MAX HOPS	5.0049	5.0000	742.5637	-11.689	-5.024	-3.958	-59.423	2302.9500	2302.9512	1.7111	993.1950

THIS RAY CALCULATION TOOK 3.219 SEC

AZIMUTH ANGLE OF TRANSMISSION = 45.000000 DEG TRANSMITTER LATITUDE = 1.798926 DEG FREQUENCY = .050000 HZ
ELEVATION ANGLE OF TRANSMISSION = 80.000000 DEG TRANSMITTER LONGITUDE = .000000 DEG SINGLE STEP ERROR = 1.000000E-06

ERROR	EVENT	ELEVATION ABOVE SEA LEVEL KM	ELEVATION ABOVE TERRAIN KM	RANGE KM	AZIMUTH DEVIATION XMTR DEG	AZIMUTH DEVIATION LOCAL DEG	ELEVATION ANGLE XMTR DEG	ELEVATION ANGLE LOCAL DEG	PULSE TIME SEC	PHASE TIME SEC	ABSORPTION DB	PATH LENGTH KM
.0E+00	XMTR	13.0440	13.0000	.0000				80.000	.0000	.0000	.0000	.0000
-.7E-07		35.1397	35.0968	6.6778	-20.387	-20.387	73.094	79.301	73.7000	73.7000	.0000	23.0919
-.9E-06		77.2842	77.2436	21.0030	-20.997	-20.997	71.681	79.854	203.3000	203.2999	.0000	67.6482
-.1E-05		108.2005	108.1614	32.1000	-21.928	-21.929	71.049	76.820	302.5000	302.4998	.0009	100.5561
-.1E-05		147.3742	147.3380	48.3230	-19.107	-19.110	69.768	69.185	382.5000	382.4998	.1114	143.1468
-.1E-05		198.2845	198.2527	73.8397	-15.606	-15.609	67.609	64.942	462.5000	462.4997	48.2402	200.5408
-.1E-05	EXTINC	224.5590	224.5294	88.0081	-14.390	-14.394	66.634	64.191	500.9000	500.8997	1076.3153	230.6701
										THIS RAY CALCULATION TOOK		.964 SEC
ELEVATION ANGLE OF TRANSMISSION = 100.0000 DEG												
-.7E-14	XMTR	13.0440	13.0000	.0000				80.000	.0000	.0000	.0000	.0000
.2E-12	MAX LONG	13.3109	13.2669	.0332	-135.240	44.760	82.899	80.016	.9000	.9000	.0000	.2690
-.8E-07		32.0143	31.9693	2.3953	-124.524	55.476	82.768	79.618	63.7000	63.7000	.0000	19.1228
-.5E-06		70.8034	70.7559	7.8116	-122.131	57.869	82.213	79.622	182.1000	182.1000	.0000	58.2976
-.1E-05		103.9528	103.9032	12.5474	-114.124	65.875	82.014	78.188	290.9000	290.8999	.0005	91.8275
-.1E-05	MAX LONG	110.6394	110.5893	13.5646	-115.247	64.752	81.950	76.537	308.5000	308.4998	.0012	98.5992
-.1E-05		140.9497	140.8962	19.2197	-127.481	52.517	81.266	70.665	370.9000	370.8998	.0511	129.6767
-.1E-05		190.9721	190.9095	33.5431	-144.932	35.066	79.006	66.040	450.9000	450.8997	20.1684	182.4295
-.1E-05	EXTINC	224.9996	224.9286	45.5105	-151.291	28.707	77.457	65.030	500.5000	500.4996	1126.0582	218.9079
										THIS RAY CALCULATION TOOK		.977 SEC
ELEVATION ANGLE OF TRANSMISSION = 120.0000 DEG												
-.7E-14	XMTR	13.0440	13.0000	.0000				60.000	.0000	.0000	.0000	.0000
-.1E-06		46.1915	46.1409	16.1398	-165.235	14.765	63.861	56.548	123.3000	123.3000	.0000	36.9103
.4E-06		90.1163	90.0541	36.7256	-162.825	17.175	64.177	62.055	283.3000	283.2999	.0001	85.5976
.4E-06		119.2382	119.1634	54.4176	-163.537	16.462	62.382	41.494	382.5000	382.4999	.0047	120.1510
.6E-06		152.4306	152.2250	135.0070	-169.420	5.792	44.937	3.174	548.9000	548.9000	.9310	211.3774
.2E-06	APOGEE	152.7178	152.4727	145.0531	-169.378	2.943	42.894	-.188	564.9000	564.9000	1.1915	221.6716
.2E-06	WAVE REV	152.7178	152.4727	145.0531	-169.378	2.943	42.894	-.188	564.9000	564.9000	1.1915	221.6716
-.1E-05		111.3236	109.6405	243.7566	-164.096	-3.210	20.668	-48.079	766.5000	766.5000	2.3500	335.7976
.6E-06	MAX LONG	93.6766	92.4536	253.9614	-163.165	-2.285	16.333	-61.003	827.3000	827.2999	2.3514	356.7367
-.2E-05	MAX LONG	79.4894	78.5126	259.9170	-162.436	-1.561	13.070	-61.038	881.7000	881.6999	2.3515	372.5074
.8E-05		54.7302	54.1010	272.6007	-161.359	-.490	7.422	-56.142	971.3000	971.3000	2.3516	400.8575
-.6E-07	RCVR	5.3003	5.0000	299.0948	-159.875	.978	-2.826	-57.476	1153.6795	1153.6806	2.3516	457.5233
-.7E-06	GRND REF	.2797	.0000	302.3604	-159.847	.553	-3.774	54.094	1171.9866	1171.9878	2.3516	463.5177
-.5E-06	RCVR	5.2607	5.0000	305.6826	-159.813	.580	-2.831	56.842	1190.2861	1190.2873	2.3516	469.5109
.7E-05		56.6194	56.4724	334.2104	-158.498	1.889	5.884	55.667	1380.6861	1380.6876	2.3516	528.8274
-.2E-05	MAX LONG	81.0713	80.9539	347.1532	-157.769	2.617	9.444	60.760	1470.2861	1470.2882	2.3516	556.9184
-.4E-06	MAX LONG	94.3487	94.2425	353.1353	-157.340	3.046	11.270	60.149	1521.4861	1521.4881	2.3518	571.7558
-.3E-05		112.9029	112.8138	365.1172	-156.847	3.538	13.507	45.584	1585.4861	1585.4879	2.3536	594.2539
-.3E-05	APOGEE	147.4966	147.4612	453.9279	-156.085	4.301	14.257	-.783	1771.0861	1771.0874	2.9599	694.3670
-.3E-05	WAVE REV	147.4966	147.4612	453.9279	-156.085	4.301	14.257	-.783	1771.0861	1771.0874	2.9599	694.3670
-.2E-05		134.5112	134.4879	509.7279	-155.833	4.554	10.956	-24.695	1873.4861	1873.4872	3.4692	753.3817
-.9E-06	MAX LONG	93.3241	93.3063	551.2271	-155.276	5.113	5.734	-60.529	2017.4861	2017.4867	3.5120	813.9165
-.3E-05	MAX LONG	80.0572	80.0402	557.3032	-155.031	5.358	4.297	-60.571	2068.6861	2068.6867	3.5121	828.7383
-.9E-06		76.6838	76.6669	558.9313	-154.973	5.416	3.933	-59.875	2081.4861	2081.4866	3.5121	832.5357
.1E-05		13.1140	13.1003	594.5164	-154.227	6.163	-2.667	-59.566	2315.0861	2315.0875	3.5121	905.9410
-.2E-05	RCVR	5.0134	5.0000	599.1689	-154.193	6.198	-3.461	-56.730	2345.7311	2345.7326	3.5121	915.2955
-.2E-05	MAX HOPS	5.0134	5.0000	599.1689	-154.193	6.198	-3.461	-56.730	2345.7311	2345.7326	3.5121	915.2955
										THIS RAY CALCULATION TOOK		3.209 SEC

AZIMUTH ANGLE OF TRANSMISSION = 45.000000 DEG TRANSMITTER LATITUDE = 1.798926 DEG FREQUENCY = .050000 HZ
ELEVATION ANGLE OF TRANSMISSION = 140.000000 DEG TRANSMITTER LONGITUDE = .000000 DEG SINGLE STEP ERROR = 1.000000E-06

ERROR	EVENT	ELEVATION ABOVE SEA LEVEL KM	ELEVATION ABOVE TERRAIN KM	RANGE KM	AZIMUTH DEVIATION XMTR DEG	AZIMUTH DEVIATION LOCAL DEG	ELEVATION ANGLE XMTR DEG	ELEVATION ANGLE LOCAL DEG	PULSE TIME SEC	PHASE TIME SEC	ABSORPTION DB	PATH LENGTH KM
-.7E-14	XMTR	13.0440	13.0000	.0000				40.000	.0000	.0000	.0000	.0000
-.2E-06		41.9304	41.8733	30.7729	-170.963	9.037	42.927	34.744	147.3000	147.3000	.0000	42.3367
-.2E-06		72.7148	72.6319	68.5015	-170.511	9.475	40.560	40.574	307.3000	307.2999	.0000	91.3556
-.5E-06		105.4267	105.3047	99.5121	-169.250	10.185	42.160	27.018	467.3000	467.2999	.0010	137.0069
-.2E-06	APOGEE	111.7581	111.5888	123.0044	-169.527	7.625	37.922	-.231	534.5000	534.4999	.0048	162.0291
-.2E-06	WAVE REV	111.7581	111.5888	123.0044	-169.527	7.625	37.922	-.231	534.5000	534.4999	.0048	162.0291
-.7E-06		99.0190	98.7170	154.3398	-168.405	-1.721	28.212	-39.256	627.3000	627.2999	.0091	197.3682
.4E-05		50.6802	49.2224	203.6148	-161.833	-10.394	9.505	-32.617	854.5000	854.5001	.0095	270.1590
.2E-05	RCVR	5.8098	5.0000	255.5846	-157.368	-6.592	-2.768	-36.018	1083.9361	1083.9370	.0095	341.4045
.2E-05	GRND REF	.6338	.0000	263.3761	-157.096	-6.666	-3.879	27.499	1112.8739	1112.8748	.0095	350.8503
.1E-05	RCVR	5.5009	5.0000	271.3368	-156.827	-6.406	-2.810	33.954	1141.7055	1141.7065	.0095	360.2767
.1E-05		51.4803	51.3472	329.9398	-153.800	-3.387	5.126	29.986	1388.1055	1388.1070	.0095	436.8222
.2E-05	MAX LONG	77.5366	77.4586	365.2769	-152.219	-1.808	8.298	40.528	1528.9055	1528.9074	.0096	482.1444
.5E-06	MAX LONG	96.7313	96.6704	384.5933	-151.260	-.849	10.441	38.317	1624.9055	1624.9075	.0098	510.2986
.2E-07		100.4016	100.3440	389.2695	-151.074	-.663	10.786	32.940	1644.1055	1644.1075	.0100	516.4371
.2E-06	APOGEE	109.2373	109.1943	417.3020	-150.307	.103	10.980	-.377	1727.3055	1727.3075	.0129	547.2455
.2E-06	WAVE REV	109.2373	109.1943	417.3020	-150.307	.103	10.980	-.377	1727.3055	1727.3075	.0129	547.2455
.8E-06		98.8690	98.8362	446.8125	-149.588	.822	8.767	-35.440	1816.9055	1816.9075	.0158	580.0213
.4E-06	MAX LONG	95.7525	95.7208	450.5518	-149.468	.942	8.285	-39.400	1832.9055	1832.9075	.0159	585.0253
.9E-06	MAX LONG	76.5533	76.5264	470.0849	-148.799	1.612	5.524	-40.094	1928.9055	1928.9075	.0161	613.1416
.1E-05		52.8328	52.8115	502.7766	-148.075	2.336	2.238	-30.029	2056.9055	2056.9078	.0162	654.3369
.1E-05	RCVR	5.0143	5.0000	565.8781	-147.184	3.229	-3.356	-33.478	2313.8622	2313.8650	.0162	734.3758
.1E-05	MAX HOPS	5.0143	5.0000	565.8781	-147.184	3.229	-3.356	-33.478	2313.8622	2313.8650	.0162	734.3758

THIS RAY CALCULATION TOOK 2.778 SEC

***** H A R P A *****
HAMILTONIAN ACOUSTIC RAY-TRACING PROGRAM FOR THE ATMOSPHERE

BY
R. M. JONES, J. P. RILEY AND T. M. GEORGES
WAVE PROPAGATION LABORATORY
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
BOULDER, COLORADO 80303

RUN SET NUMBER 2

ATMOSPHERIC MODEL ID — S03

ATMOSPHERIC MODEL DESCRIPTION — SAMPLE CASE FOR HARPA DOCUMENTATION REV. 2-10-86

MODEL TYPE	SUBROUTINE NAME	DATA SET ID	DESCRIPTION
DISPERSION RELATION	AWWWL		ACOUSTIC WAVE *** WITH WIND ****** WITH LOSSES
BACKGROUND WIND VELOCITY	ULOGZ2	3.00	LOGARITHMIC EASTWARD WIND PROFILE, U*=.5 M/S, Z0=1 KM
WIND VELOCITY PERTURBATION	NPWIND	.00	NO WIND PERTURBATION
BACKGROUND SOUND SPEED	GAMRTDM	.00	SOUND SPEED IN TERMS OF TEMPERATURE MODEL
SOUND SPEED PERTURBATION	CBLOB2	2.00	50% INCREASE IN SQ. SOUND SPEED AT 125KM HT, 335KM N, 125KM E
BACKGROUND TEMPERATURE	TTANH5	1.00	U.S. STANDARD ATMOSPHERE 1962 TEMPERATURE PROFILE
TEMPERATURE PERTURBATION	TBLOB2	2.00	50% CYLINDRICAL INCREASE IN TEMPERATURE AT 105KM N., 105 KM W
MOLECULAR WEIGHT	MCONST	29.00	MOLECULAR WEIGHT = 29
BACKGROUND TERRAIN	GLORENZ	2.00	RIDGE 2-KM HIGH, 30-KM WIDE ALONG EQUATOR
TERRAIN PERTURBATION	NPTERR	.00	NO TERRAIN PERTURBATION
BACKGROUND VISCOSITY/ THERMAL CONDUCTIVITY	MUARDC	1.00	ARDC VISCOSITY AND THERMAL CONDUCTIVITY MODEL
VISCOSITY/THERMAL CONDUCTIVITY PERTURBATION	NPABSR	.00	NO VISCOSITY/CONDUCTIVITY PERTURBATION
BACKGROUND PRESSURE	PEXP	1.00	EXPONENTIAL PRESSURE MODEL, SCALE HEIGHT = 8.5 KM
PRESSURE PERTURBATION	NPPRES	.00	NO PRESSURE PERTURBATION
RECEIVER SURFACE	RTERR	.00	RECEIVER SURFACE 5 KM ABOVE TERRAIN

INPUT DATA FILE FOR RUN SET NUMBER 2

```
S03-2    SAMPLE CASE FOR HARPA DOCUMENTATION        REV. 2-10-86
 71        0.          NUMBER OF INTEGRATION STEPS PER PRINT
 72        0.          OUTPUT RAYSETS  (1=YES; 0=NO)
 73        1.          DIAGNOSTIC PRINTOUT (1=YES; 0=NO)
 81        2.          RAYPLOT PROJECTION (1=VERT; 2=HORIZ) PLANE
 82        3.          PLOT-EXPANSION FACTOR
  0                    **********  END OF RUN SET NUMBER 2  ***********
```

INITIAL VALUES FOR THE W ARRAY
ONLY NONZERO VALUES PRINTED — ALL ANGLES IN RADIANS

N	W(N)	
1	.637000000000000E+04	
3	.130440097799511E+02	
4	.313971742543171E-01	
7	.314159265358979E+00	
11	.785398163397446E+00	
15	-.349065850398864E+00	
16	.244346095279205E+01	
17	.349065850398864E+00	
20	.500000000000000E+01	
22	.300000000000000E+01	
23	.100000000000000E+04	
24	.157079632679490E+01	
26	.500000000000000E+03	
27	-.100000000000000E+01	
28	.100000000000000E+04	
29	.100000000000000E+03	
33	.999999000000000E+03	
41	.300000000000000E+01	
42	.999999999999997E-06	
43	.500000000000000E+02	
44	.100000000000000E+00	
45	.100000000000000E+03	
46	.100000000000000E-07	
47	.500000000000000E+00	
57	.200000000000000E+01	
58	.200000000000000E+01	
60	.200000000000000E+01	
71	.999999999999999E+30	INPUT OVERRIDDEN
73	.100000000000000E+01	
75	.150000000000000E+00	
77	.570000000000000E+02	
81	.200000000000000E+01	
82	.300000000000000E+01	
83	-.156985871271585E-01	
84	-.470957613814755E-01	
85	.784929356357926E-01	
86	.470957613814755E-01	
87	.156985871271585E-01	
89	.300000000000000E+03	
96	.100000000000000E+03	
100	.600000000000000E+01	
102	.300000000000000E+01	
103	.500000000000000E-02	
104	.350000000000000E+00	
105	.100000000000000E+01	
150	.100000000000000E+01	

N	W(N)
175	.200000000000000E+01
177	.200000000000000E+01
178	.500000000000000E+00
179	.125000000000000E+03
180	.525902668759810E-01
181	.196232339089482E-01
182	.250000000000000E+02
183	.784929356357927E-02
184	.392464678178964E-02
200	.700000000000000E+01
202	.100000000000000E+01
225	.200000000000000E+01
227	.200000000000000E+01
228	.500000000000000E+00
230	.164835164835164E-01
231	-.164835164835164E-01
233	.784929356357927E-02
234	.392464678178964E-02
250	.100000000000000E+01
252	.290000000000000E+02
253	.290000000000000E+02
275	.200000000000000E+01
300	.400000000000000E+01
302	.200000000000000E+01
303	.200000000000000E+01
305	.470957613814754E-02
500	.100000000000000E+01
502	.100000000000000E+01
503	.145800000000000E-05
504	.110400000000000E+03
505	.191000000000000E+01
550	.100000000000000E+01
552	.100000000000000E+01
553	.101328000000000E+06
554	.850000000000000E+01

AZIMUTH ANGLE OF TRANSMISSION = 45.000000 DEG
ELEVATION ANGLE OF TRANSMISSION = -20.000000 DEG

TRANSMITTER LATITUDE = 1.798926 DEG
TRANSMITTER LONGITUDE = .000000 DEG

FREQUENCY = .050000 HZ
SINGLE STEP ERROR = 1.000000E-06

ERROR	EVENT	ELEVATION ABOVE SEA LEVEL KM	ELEVATION ABOVE TERRAIN KM	RANGE KM	AZIMUTH DEVIATION XMTR DEG	AZIMUTH DEVIATION LOCAL DEG	ELEVATION ANGLE XMTR DEG	ELEVATION ANGLE LOCAL DEG	PULSE TIME SEC	PHASE TIME SEC	ABSORPTION DB	PATH LENGTH KM
								-20.000	.0000	.0000	.0000	.0000
-.1E-13	XMTR	13.0440	13.0000	.0000								
.2E-06	BACK UP0	4.7586	4.7222	30.8625	-3.791	-3.790	-15.146	-11.856	96.1000	96.1000	.0000	32.0196
.2E-06	BACK UP1	5.0367	5.0000	29.4888	-3.840	-3.838	-15.304	-12.169	91.9614	91.9614	.0000	30.6168
.2E-06	RCVR	5.0367	5.0000	29.4887	-3.840	-3.838	-15.304	-12.169	91.9612	91.9612	.0000	30.6167
.2E-06	BACK UP0	-.4292	-.4600	58.7368	-2.616	-2.612	-13.171	-10.714	179.5612	179.5613	.0000	60.3988
.2E-06	BACK UP1	.0313	.0000	56.3108	-2.735	-2.731	-13.252	-10.703	172.2877	172.2877	.0000	57.9268
.2E-06	GRND REF	.0313	.0000	56.3108	-2.735	-2.735	-13.252	10.682	172.2877	172.2877	.0000	57.9268
.8E-07	BACK UP0	5.0597	5.0326	83.3006	-2.344	-2.341	-5.842	12.186	253.0877	253.0877	.0000	85.3987
.8E-07	BACK UP1	5.0270	5.0000	83.1414	-2.343	-2.340	-5.874	12.148	252.6076	252.6076	.0000	85.2361
.8E-07	RCVR	5.0270	5.0000	83.1414	-2.343	-2.340	-5.874	12.148	252.6076	252.6076	.0000	85.2361
-.1E-06	APOGEE	30.8025	30.7860	196.4513	-3.954	-3.953	4.264	-.461	601.4076	601.4076	.0000	202.4308
-.1E-06	WAVE REV	30.8025	30.7860	196.4513	-3.954	-3.953	4.264	-.461	601.4076	601.4076	.0000	202.4308
.3E-06	BACK UP0	4.7476	4.7365	308.6340	-4.367	-4.368	-2.925	-11.832	947.0076	947.0076	.0000	318.4730
.3E-06	BACK UP1	5.0112	5.0000	307.3289	-4.374	-4.375	-2.877	-12.129	943.0764	943.0765	.0000	317.1400
.3E-06	RCVR	5.0112	5.0000	307.3288	-4.374	-4.375	-2.877	-12.129	943.0763	943.0763	.0000	317.1400
.3E-06	MAX HOPS	5.0112	5.0000	307.3288	-4.374	-4.375	-2.877	-12.129	943.0763	943.0763	.0000	317.1400

THIS RAY CALCULATION TOOK 2.009 SEC

ELEVATION ANGLE OF TRANSMISSION = .0000 DEG

-.7E-14	XMTR	13.0440	13.0000	.0000								
.1E-07	APOGEE	19.8306	19.8069	114.8628	-4.945	-4.945	2.856	.000	.0000	.0000	.0000	.0000
.1E-07	WAVE REV	19.8306	19.8069	114.8628	-4.945	-4.945	2.856	-.376	352.1000	352.1000	.0000	115.4148
.4E-07	GRAZE 1	13.0538	13.0389	227.5993	-4.933	-4.935	-1.021	.417	697.7000	697.7000	.0000	228.6941
.4E-07	GRAZE 1	13.0453	13.0303	225.0474	-4.938	-4.939	-1.012	-.003	689.9110	689.9110	.0000	226.1369
.4E-07	GRAZE 1	13.0453	13.0303	225.0470	-4.938	-4.939	-1.012	-.003	689.9096	689.9096	.0000	226.1364
.4E-07	MIN DIST	13.0453	13.0303	225.0470	-4.938	-4.939	-1.012	-.003	689.9096	689.9096	.0000	226.1364
.4E-07	MIN DIST	13.0453	13.0303	225.0470	-4.938	-4.939	-1.012	-.003	689.9096	689.9096	.0000	226.1364
.3E-07	WAVE REV	13.0683	13.0535	229.2405	-4.930	-4.932	-1.025	.687	702.7096	702.7096	.0000	230.3388
.5E-07	APOGEE	19.8297	19.8195	339.8931	-4.937	-4.942	-.388	-.372	1041.9096	1041.9096	.0000	341.5344
.5E-07	WAVE REV	19.8297	19.8195	339.8931	-4.937	-4.942	-.388	-.372	1041.9096	1041.9096	.0000	341.5344
.7E-07	GRAZE 1	13.0505	13.0431	452.6454	-4.930	-4.939	-2.035	.411	1387.5096	1387.5097	.0000	454.8295
.7E-07	GRAZE 1	13.0423	13.0348	450.1425	-4.932	-4.941	-2.025	-.001	1379.8714	1379.8714	.0000	452.3214
.7E-07	GRAZE 1	13.0423	13.0348	450.1421	-4.932	-4.941	-2.025	-.001	1379.8701	1379.8701	.0000	452.3210
.7E-07	MIN DIST	13.0423	13.0348	450.1421	-4.932	-4.941	-2.025	-.001	1379.8701	1379.8701	.0000	452.3210
.7E-07	MAX HOPS	13.0423	13.0348	450.1421	-4.932	-4.941	-2.025	-.001	1379.8701	1379.8701	.0000	452.3210

THIS RAY CALCULATION TOOK .908 SEC

AZIMUTH ANGLE OF TRANSMISSION = 45.000000 DEG TRANSMITTER LATITUDE = 1.798926 DEG FREQUENCY = .050000 HZ
ELEVATION ANGLE OF TRANSMISSION = 20.000000 DEG TRANSMITTER LONGITUDE = .000000 DEG SINGLE STEP ERROR = 1.000000E-06

ERROR	EVENT	ELEVATION ABOVE SEA LEVEL KM	ELEVATION ABOVE TERRAIN KM	RANGE KM	AZIMUTH DEVIATION XMTR DEG	AZIMUTH DEVIATION LOCAL DEG	ELEVATION ANGLE XMTR DEG	ELEVATION ANGLE LOCAL DEG	PULSE TIME SEC	PHASE TIME SEC	ABSORPTION DB	PATH LENGTH KM
								20.000	.0000	.0000	.0000	.0000
-.7E-14	XMTR	13.0440	13.0000	.0000								
-.4E-06	APOGEE	30.8011	30.7734	83.6250	-5.591	-5.592	11.572	-.390	256.1000	256.0999	.0000	86.3124
-.4E-06	WAVE REV	30.8011	30.7734	83.6250	-5.591	-5.592	11.572	-.390	256.1000	256.0999	.0000	86.3124
.1E-06	BACK UP0	4.7875	4.7706	195.8209	-5.307	-5.309	-3.291	-11.869	601.7000	601.6998	.0000	202.3515
.1E-06	BACK UP1	5.0170	5.0000	194.6869	-5.322	-5.324	-3.233	-12.129	598.2812	598.2811	.0000	201.1925
.1E-06	RCVR	5.0170	5.0000	194.6869	-5.322	-5.324	-3.233	-12.129	598.2812	598.2810	.0000	201.1925
.2E-06	BACK UP0	-.4426	-.4577	223.9645	-4.806	-4.807	-4.450	-10.681	686.0812	686.0810	.0000	231.0486
.2E-06	BACK UP1	.0152	.0000	221.5510	-4.860	-4.862	-4.358	-10.669	678.8281	678.8280	.0000	228.5831
.2E-06	GRND REF	.0152	.0000	221.5510	-4.860	-4.863	-4.358	10.662	678.8281	678.8280	.0000	228.5831
.1E-06	BACK UP0	5.0443	5.0306	248.5778	-4.497	-4.499	-2.958	12.156	759.8281	759.8280	.0000	256.1279
.1E-06	BACK UP1	5.0137	5.0000	248.4283	-4.498	-4.500	-2.966	12.121	759.3772	759.3771	.0000	255.9751
.1E-06	RCVR	5.0137	5.0000	248.4283	-4.498	-4.500	-2.966	12.121	759.3772	759.3771	.0000	255.9751
.2E-08	APOGEE	30.7976	30.7881	361.7989	-4.694	-4.699	1.172	-.437	1108.1772	1108.1771	.0000	373.1773
.2E-08	WAVE REV	30.7976	30.7881	361.7989	-4.694	-4.699	1.172	-.437	1108.1772	1108.1771	.0000	373.1773
.5E-06	BACK UP0	4.7578	4.7507	474.0078	-4.784	-4.794	-3.131	-11.845	1453.7772	1453.7772	.0000	489.2314
.5E-06	BACK UP1	5.0070	5.0000	472.7741	-4.790	-4.799	-3.098	-12.126	1450.0604	1450.0604	.0000	487.9710
.5E-06	RCVR	5.0070	5.0000	472.7741	-4.790	-4.799	-3.098	-12.126	1450.0603	1450.0603	.0000	487.9710
.5E-06	MAX HOPS	5.0070	5.0000	472.7741	-4.790	-4.799	-3.098	-12.126	1450.0603	1450.0603	.0000	487.9710

THIS RAY CALCULATION TOOK 1.995 SEC

ELEVATION ANGLE OF TRANSMISSION = 40.0000 DEG

								40.000	.0000	.0000	.0000	.0000
-.7E-14	XMTR	13.0440	13.0000	.0000								
-.7E-06	APOGEE	104.2225	104.2036	175.8021	-7.340	-5.047	26.407	-1.194	555.3000	555.2998	.0016	201.2805
-.7E-06	WAVE REV	104.2225	104.2036	175.8021	-7.340	-5.047	26.407	-1.194	555.3000	555.2998	.0016	201.2805
.5E-06	BACK UP0	4.7800	4.7697	374.4830	-9.535	-4.136	-2.946	-35.687	1179.3000	1179.2997	.0031	426.9943
.5E-06	BACK UP1	5.0103	5.0000	374.1414	-9.536	-4.137	-2.911	-35.775	1178.0786	1178.0784	.0031	426.5820
.5E-06	RCVR	5.0103	5.0000	374.1414	-9.536	-4.137	-2.911	-35.775	1178.0787	1178.0784	.0031	426.5820
.4E-06	BACK UP0	-1.0136	-1.0236	382.9177	-9.471	-4.073	-3.822	-34.925	1209.4787	1209.4784	.0031	437.2394
.4E-06	BACK UP1	.0101	.0000	381.4687	-9.488	-4.089	-3.670	-34.999	1204.2520	1204.2517	.0031	435.4618
.4E-06	GRND REF	.0101	.0000	381.4687	-9.488	-4.092	-3.670	34.996	1204.2519	1204.2517	.0031	435.4618
.4E-06	BACK UP0	5.1658	5.1559	389.0277	-9.442	-4.046	-2.908	35.833	1231.2519	1231.2517	.0031	444.6205
.4E-06	BACK UP1	5.0099	5.0000	388.7966	-9.442	-4.046	-2.930	35.772	1230.4251	1230.4249	.0031	444.3416
.4E-06	RCVR	5.0099	5.0000	388.7966	-9.442	-4.046	-2.930	35.772	1230.4251	1230.4249	.0031	444.3416
.5E-06	APOGEE	104.7397	104.7335	592.3256	-10.201	-4.812	6.050	-1.123	1867.2251	1867.2256	.0050	674.8220
.5E-06	WAVE REV	104.7397	104.7335	592.3256	-10.201	-4.812	6.050	-1.123	1867.2251	1867.2256	.0050	674.8220
.2E-05	BACK UP0	4.6132	4.6089	794.3212	-10.562	-5.183	-4.179	-35.647	2500.8251	2500.8263	.0068	903.8062
.2E-05	BACK UP1	5.0043	5.0000	793.7415	-10.564	-5.185	-4.148	-35.793	2498.7527	2498.7538	.0068	903.1062
.2E-05	RCVR	5.0043	5.0000	793.7415	-10.564	-5.185	-4.148	-35.793	2498.7527	2498.7538	.0068	903.1062
.2E-05	MAX HOPS	5.0043	5.0000	793.7415	-10.564	-5.185	-4.148	-35.793	2498.7527	2498.7538	.0068	903.1062

THIS RAY CALCULATION TOOK 2.989 SEC

AZIMUTH ANGLE OF TRANSMISSION = 45.000000 DEG TRANSMITTER LATITUDE = 1.798926 DEG FREQUENCY = .050000 HZ
ELEVATION ANGLE OF TRANSMISSION = 60.000000 DEG TRANSMITTER LONGITUDE = .000000 DEG SINGLE STEP ERROR = 1.000000E-06

ERROR	EVENT	ELEVATION ABOVE SEA LEVEL KM	ELEVATION ABOVE TERRAIN KM	RANGE KM	AZIMUTH DEVIATION XMTR DEG	AZIMUTH DEVIATION LOCAL DEG	ELEVATION ANGLE XMTR DEG	ELEVATION ANGLE LOCAL DEG	PULSE TIME SEC	PHASE TIME SEC	ABSORPTION DB	PATH LENGTH KM
-.7E-14	XMTR	13.0440	13.0000	.0000				60.000	.0000	.0000	.0000	.0000
-.4E-06	APOGEE	144.8719	144.8545	199.2131	-7.589	-1.829	32.272	-.221	572.1000	572.0997	.5014	256.4120
-.4E-06	WAVE REV	144.8719	144.8545	199.2131	-7.589	-1.829	32.272	-.221	572.1000	572.0997	.5014	256.4120
.3E-05	BACK UP0	4.5785	4.5681	379.1757	-10.259	-3.574	-2.982	-59.317	1140.1000	1140.1009	.9121	499.5078
.3E-05	BACK UP1	5.0104	5.0000	378.8921	-10.259	-3.574	-2.917	-59.417	1138.5475	1138.5483	.9121	498.9910
.3E-05	RCVR	5.0104	5.0000	378.8921	-10.259	-3.574	-2.917	-59.417	1138.5475	1138.5483	.9121	498.9910
.9E-06	BACK UP0	-1.0303	-1.0406	382.7092	-10.243	-3.558	-3.825	-58.392	1159.7475	1159.7484	.9121	506.1395
.9E-06	BACK UP1	.0103	.0000	382.0800	-10.249	-3.565	-3.669	-58.549	1156.1759	1156.1768	.9121	504.9226
.9E-06	GRND REF	.0103	.0000	382.0800	-10.249	-3.572	-3.669	58.546	1156.1759	1156.1768	.9121	504.9226
.1E-05	BACK UP0	5.2243	5.2141	385.4089	-10.241	-3.563	-2.894	59.464	1174.5759	1174.5768	.9121	511.1106
.1E-05	BACK UP1	5.0102	5.0000	385.2681	-10.240	-3.563	-2.925	59.414	1173.8043	1173.8052	.9121	510.8543
.1E-05	RCVR	5.0102	5.0000	385.2681	-10.240	-3.563	-2.925	59.414	1173.8043	1173.8052	.9121	510.8543
-.2E-05	APOGEE	144.7403	144.7336	567.1420	-11.193	-4.522	10.360	-1.201	1743.4043	1743.4054	1.3398	755.3699
-.2E-05	WAVE REV	144.7403	144.7336	567.1420	-11.193	-4.522	10.360	-1.201	1743.4043	1743.4054	1.3398	755.3699
.4E-05	BACK UP0	4.8787	4.8738	742.6466	-11.689	-5.024	-3.968	-59.394	2303.4043	2303.4055	1.7111	993.3461
.4E-05	BACK UP1	5.0049	5.0000	742.5637	-11.689	-5.024	-3.958	-59.423	2302.9500	2302.9512	1.7111	993.1950
.4E-05	RCVR	5.0049	5.0000	742.5637	-11.689	-5.024	-3.958	-59.423	2302.9500	2302.9512	1.7111	993.1950
.4E-05	MAX HOPS	5.0049	5.0000	742.5637	-11.689	-5.024	-3.958	-59.423	2302.9500	2302.9512	1.7111	993.1950

THIS RAY CALCULATION TOOK 3.260 SEC

ELEVATION ANGLE OF TRANSMISSION = 80.0000 DEG

.0E+00	XMTR	13.0440	13.0000	.0000				80.000	.0000	.0000	.0000	.0000
-.1E-05	EXTINC	224.5590	224.5294	88.0081	-14.390	-14.394	66.634	64.191	500.9000	500.8997	1076.3153	230.6701

THIS RAY CALCULATION TOOK .944 SEC

ELEVATION ANGLE OF TRANSMISSION = 100.0000 DEG

-.7E-14	XMTR	13.0440	13.0000	.0000				80.000	.0000	.0000	.0000	.0000
.2E-12	MAX LONG	13.3109	13.2669	.0332	-135.240	44.760	82.899	80.016	.9000	.9000	.0000	.2690
-.1E-05	MAX LONG	110.6394	110.5893	13.5646	-115.247	64.752	81.950	76.537	308.5000	308.4998	.0012	98.5992
-.1E-05	EXTINC	224.9996	224.9286	45.5105	-151.291	28.707	77.457	65.030	500.5000	500.4996	1126.0582	218.9079

THIS RAY CALCULATION TOOK .967 SEC

AZIMUTH ANGLE OF TRANSMISSION = 45.000000 DEG TRANSMITTER LATITUDE = 1.798926 DEG FREQUENCY = .050000 HZ
ELEVATION ANGLE OF TRANSMISSION = 120.000000 DEG TRANSMITTER LONGITUDE = .000000 DEG SINGLE STEP ERROR = 1.000000E-06

ERROR	EVENT	ELEVATION ABOVE SEA LEVEL KM	ELEVATION ABOVE TERRAIN KM	RANGE KM	AZIMUTH DEVIATION XMTR DEG	AZIMUTH DEVIATION LOCAL DEG	ELEVATION ANGLE XMTR DEG	ELEVATION ANGLE LOCAL DEG	PULSE TIME SEC	PHASE TIME SEC	ABSORPTION DB	PATH LENGTH KM
-.7E-14	XMTR	13.0440	13.0000	.0000				60.000	.0000	.0000	.0000	.0000
.2E-06	APOGEE	152.7178	152.4727	145.0531	-169.378	2.943	42.894	-.188	564.9000	564.9000	1.1915	221.6716
.2E-06	WAVE REV	152.7178	152.4727	145.0531	-169.378	2.943	42.894	-.188	564.9000	564.9000	1.1915	221.6716
.6E-06	MAX LONG	93.6766	92.4536	253.9614	-163.165	-2.285	16.333	-61.003	827.3000	827.2999	2.3514	356.7367
-.2E-05	MAX LONG	79.4894	78.5126	259.9170	-162.436	-1.561	13.070	-61.038	881.7000	881.6999	2.3515	372.5074
-.6E-07	BACK UP0	5.2948	4.9945	299.0982	-159.875	.978	-2.827	-57.473	1153.7000	1153.7012	2.3516	457.5298
-.6E-07	BACK UP1	5.3003	5.0000	299.0948	-159.875	.978	-2.826	-57.476	1153.6795	1153.6806	2.3516	457.5233
-.6E-07	RCVR	5.3003	5.0000	299.0948	-159.875	.978	-2.826	-57.476	1153.6795	1153.6806	2.3516	457.5233
-.7E-06	BACK UP0	-.5223	-.7987	302.9344	-159.849	.997	-3.924	-54.285	1174.8795	1174.8806	2.3516	464.5041
-.7E-06	BACK UP1	.2797	.0000	302.3604	-159.847	1.001	-3.774	-54.763	1171.9866	1171.9878	2.3516	463.5177
-.7E-06	GRND REF	.2797	.0000	302.3604	-159.847	.553	-3.774	54.094	1171.9866	1171.9878	2.3516	463.5177
-.5E-06	BACK UP0	5.6107	5.3512	305.8975	-159.809	.585	-2.765	57.003	1191.5866	1191.5878	2.3516	469.9225
-.5E-06	BACK UP1	5.2607	5.0000	305.6826	-159.813	.580	-2.831	56.842	1190.2861	1190.2873	2.3516	469.5109
-.5E-06	RCVR	5.2607	5.0000	305.6826	-159.813	.580	-2.831	56.842	1190.2861	1190.2873	2.3516	469.5109
-.2E-05	MAX LONG	81.0713	80.9539	347.1532	-157.769	2.617	9.444	60.760	1470.2861	1470.2882	2.3516	556.9184
-.4E-06	MAX LONG	94.3487	94.2425	353.1353	-157.340	3.046	11.270	60.149	1521.4861	1521.4881	2.3518	571.7558
-.3E-05	APOGEE	147.4966	147.4612	453.9279	-156.085	4.301	14.257	-.783	1771.0861	1771.0874	2.9599	694.3670
-.3E-05	WAVE REV	147.4966	147.4612	453.9279	-156.085	4.301	14.257	-.783	1771.0861	1771.0874	2.9599	694.3670
-.9E-06	MAX LONG	93.3241	93.3063	551.2271	-155.276	5.113	5.734	-60.529	2017.4861	2017.4867	3.5120	813.9165
-.3E-05	MAX LONG	80.0572	80.0402	557.3032	-155.031	5.358	4.297	-60.571	2068.6861	2068.6867	3.5121	828.7383
-.2E-05	BACK UP0	4.6476	4.6343	599.3981	-154.193	6.198	-3.497	-56.556	2347.0861	2347.0875	3.5121	915.7272
-.2E-05	BACK UP1	5.0134	5.0000	599.1689	-154.193	6.198	-3.461	-56.730	2345.7311	2345.7326	3.5121	915.2955
-.2E-05	RCVR	5.0134	5.0000	599.1689	-154.193	6.198	-3.461	-56.730	2345.7311	2345.7326	3.5121	915.2955
-.2E-05	MAX HOPS	5.0134	5.0000	599.1689	-154.193	6.198	-3.461	-56.730	2345.7311	2345.7326	3.5121	915.2955

THIS RAY CALCULATION TOOK 3.174 SEC

ELEVATION ANGLE OF TRANSMISSION = 140.0000 DEG

-.7E-14	XMTR	13.0440	13.0000	.0000				40.000	.0000	.0000	.0000	.0000
-.2E-06	APOGEE	111.7581	111.5888	123.0044	-169.527	7.625	37.922	-.231	534.5000	534.4999	.0048	162.0291
-.2E-06	WAVE REV	111.7581	111.5888	123.0044	-169.527	7.625	37.922	-.231	534.5000	534.4999	.0048	162.0291
.2E-05	BACK UP0	5.6287	4.8252	255.8244	-157.357	-6.582	-2.808	-35.841	1084.9000	1084.9009	.0095	341.7092
.2E-05	BACK UP1	5.8098	5.0000	255.5846	-157.368	-6.592	-2.768	-36.018	1083.9362	1083.9370	.0095	341.4045
.2E-05	RCVR	5.8098	5.0000	255.5846	-157.368	-6.592	-2.768	-36.018	1083.9361	1083.9370	.0095	341.4045
.2E-05	BACK UP0	.1264	-.4906	264.2764	-157.076	-6.316	-3.984	-28.922	1115.9361	1115.9371	.0095	351.8883
.2E-05	BACK UP1	.6338	.0000	263.3761	-157.096	-6.336	-3.879	-29.668	1112.8739	1112.8748	.0095	350.8503
.2E-05	GRND REF	.6338	.0000	263.3761	-157.096	-6.666	-3.879	27.499	1112.8739	1112.8748	.0095	350.8503
.1E-05	BACK UP0	6.1439	5.6559	272.2417	-156.788	-6.368	-2.674	34.607	1145.2739	1145.2749	.0095	361.4027
.1E-05	BACK UP1	5.5670	5.0674	271.4310	-156.823	-6.402	-2.796	34.022	1142.0739	1142.0749	.0095	360.3933
.1E-05	BACK UP1	5.5009	5.0000	271.3369	-156.827	-6.406	-2.810	33.954	1141.7057	1141.7067	.0095	360.2768
.1E-05	RCVR	5.5009	5.0000	271.3368	-156.827	-6.406	-2.810	33.954	1141.7055	1141.7065	.0095	360.2767
.2E-05	MAX LONG	77.5366	77.4586	365.2769	-152.219	-1.808	8.298	40.528	1528.9055	1528.9074	.0096	482.1444
.5E-06	MAX LONG	96.7313	96.6704	384.5933	-151.260	-.849	10.441	38.317	1624.9055	1624.9075	.0098	510.2986
.2E-06	APOGEE	109.2373	109.1943	417.3020	-150.307	.103	10.980	-.377	1727.3055	1727.3075	.0129	547.2455
.2E-06	WAVE REV	109.2373	109.1943	417.3020	-150.307	.103	10.980	-.377	1727.3055	1727.3075	.0129	547.2455
.4E-06	MAX LONG	95.7525	95.7208	450.5518	-149.468	.942	8.285	-39.400	1832.9055	1832.9075	.0159	585.0253
.9E-06	MAX LONG	76.5533	76.5264	470.0849	-148.799	1.612	5.524	-40.094	1928.9055	1928.9075	.0161	613.1416
.1E-05	BACK UP0	4.6166	4.6024	566.4724	-147.183	3.230	-3.398	-33.043	2316.1055	2316.1083	.0162	735.0914
.1E-05	BACK UP1	5.0143	5.0000	565.8781	-147.184	3.229	-3.356	-33.478	2313.8622	2313.8650	.0162	734.3758
.1E-05	RCVR	5.0143	5.0000	565.8781	-147.184	3.229	-3.356	-33.478	2313.8622	2313.8650	.0162	734.3758
.1E-05	MAX HOPS	5.0143	5.0000	565.8781	-147.184	3.229	-3.356	-33.478	2313.8622	2313.8650	.0162	734.3758

THIS RAY CALCULATION TOOK 2.725 SEC

END OF INPUT DATA

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S03-1    SAMPLE CASE FOR HARPA DOCUMENTATION          REV. 2-10-86
ULOGZ2       3.0 NPWIND        .0   GAMRTDM       .0 CBLOB2       2.0
TTANH5       1.0 TBLOB2       2.0   MCONST      29.0 NO MODL       .0
PEXP         1.0 NPPRES        .0   MUARDC       1.0 NPABSR        .0
GLORENZ      2.0 NPTERR        .0   RTERR         .0 NO MODL       .0
LOGARITHMIC EASTWARD WIND PROFILE, U*=.5 M/S, Z0=1 KM
NO WIND PERTURBATION
SOUND SPEED IN TERMS OF TEMPERATURE MODEL
50% INCREASE IN SQ. SOUND SPEED AT 125KM HT, 335KM N, 125KM E
U.S. STANDARD ATMOSPHERE 1962 TEMPERATURE PROFILE
50% CYLINDRICAL INCREASE IN TEMPERATURE AT 105KM N., 105 KM W
MOLECULAR WEIGHT = 29
RIDGE 2-KM HIGH, 30-KM WIDE ALONG EQUATOR
S033   130440  1799      0    50000     3142   4500000  -2000000          0    0 3T
    50367   294887 -3840 -3838-12169   9196124   9196123      0     0     0    0 1R
      313   563108 -2735 -2735 10693  17228767  17228768      0     0     0    0 2G
    50270   831414 -2343 -2340 12148  25260761  25260764      0     0     0    0 2R
    50112  3073288 -4374 -4375-12129  94307633  94307634      0     0     0    0 3R
S033   130440  1799      0    50000     3142   4500000  -1500000          0    0 3T
    59174   560059 -3651 -3649   -11  16962526  16962525      0     0     0    0 1M
    59174   560059 -3651 -3649   -11  16962526  16962525      0     0     0    0 2M
    59185  3248490 -4500 -4501    -2  99099938  99099939      0     0     0    0 3M
S033   130440  1799      0    50000     3142   4500000  -1000000          0    0 3T
    95112   406604 -4161 -4160   -12  12374135  12374135      0     0     0    0 1M
    95112   406604 -4161 -4160   -12  12374135  12374135      0     0     0    0 2M
    95115  2807459 -4767 -4769    -3  85924969  85924971      0     0     0    0 3M
S033   130440  1799      0    50000     3142   4500000   -500000          0    0 3T
   119700   256779 -4424 -4424   -14   7831383   7831383      0     0     0    0 1M
   119700   256779 -4424 -4424   -14   7831383   7831383      0     0     0    0 2M
   119705  2542307 -4873 -4875    -3  77890316  77890317      0     0     0    0 3M
S033   130440  1799      0    50000     3142   4500000           0          0    0 3T
   130453  2250470 -4938 -4939    -3  68990961  68990962      0     0     0    0 1M
   130453  2250470 -4938 -4939    -3  68990961  68990962      0     0     0    0 2M
   130423  4501421 -4932 -4941    -1 137987009 137987013      0     0     0    0 3M
S033   130440  1799      0    50000     3142   4500000    500000          0    0 3T
   119724  2027348 -4988 -4989    -4  62186567  62186568      0     0     0    0 1M
   119724  2027348 -4988 -4989    -4  62186567  62186568      0     0     0    0 2M
   119693  4312567 -4949 -4957    -1 132228323 132228325      0     0     0    0 3M
S033   130440  1799      0    50000     3142   4500000   1000000          0    0 3T
    95149  1993238 -5015 -5017    -4  61147865  61147865      0     0     0    0 1M
    95149  1993238 -5015 -5017    -4  61147865  61147865      0     0     0    0 2M
    95110  4393846 -4931 -4939    -1 134683577 134683579      0     0     0    0 3M
S033   130440  1799      0    50000     3142   4500000   1500000          0    0 3T
    59270  2127216 -4948 -4950    -4  65140567  65140562      0     0     0    0 1M
    59270  2127216 -4948 -4950    -4  65140567  65140562      0     0     0    0 2M
    59192  4814803 -4791 -4801    -1 147243522 147243515      0     0     0    0 3M
S033   130440  1799      0    50000     3142   4500000   2000000          0    0 3T
    50170  1946869 -5322 -5324-12129  59828119  59828103      0     0     0    0 1R
      152  2215510 -4860 -4863 10665  67882811  67882797      0     0     0    0 2G
    50137  2484283 -4498 -4500 12121  75937724  75937711      0     0     0    0 2R
    50070  4727741 -4790 -4799-12126 145006034 145006027      0     0     0    0 3R
S033   130440  1799      0    50000     3142   4500000   2500000          0    0 3T
    50164  2044020 -5581 -5584-19279  62541213  62541173      0     0     0    0 1R
      154  2198518 -5299 -5304 18131  67332802  67332761      0     0     0    0 2G
    50145  2353069 -5054 -5059 19271  72124354  72124310      0     0     0    0 2R
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    50073  4608314 -5232 -5245-19276 141475510 141475369      0     0    0    0 3R
S033   130440  1799     0    50000     3142   4500000   3000000          0    0 3T
    50145  2387553 -5803 -5808-25431  71841724  71841676      0     0    0    0 1R
      139  2499430 -5617 -5624 24351  75461318  75461270      0     0    0    0 2G
    50133  2611336 -5446 -5453 25425  79080884  79080835      0     0    0    0 2R
    50065  5163074 -5562 -5579-25432 156441221 156441073      0     0    0    0 3R
S033   130440  1799     0    50000     3142   4500000   3500000          0    0 3T
    50063  5513279 -7508 -5984-29065 162974268 162974290      2     0    0    0 1R
       61  5608414 -7434 -5912 28128 166149079 166149107      2     0    0    0 2G
    50060  5703560 -7363 -5841 29063 169323893 169323927      2     0    0    0 2R
   615060 10006822 -7658 -6166-14096 295883893 295883991      5     0    0    0 3F
S033   130440  1799     0    50000     3142   4500000   4000000          0    0 3T
    50103  3741414 -9536 -4137-35775 117807866 117807837      3     0    0    0 1R
      101  3814687 -9488 -4092 34998 120425195 120425167      3     0    0    0 2G
    50099  3887966 -9442 -4046 35772 123042513 123042487      3     0    0    0 2R
    50043  7937415-10564 -5185-35793 249875267 249875381      7     0    0    0 3R
S033   130440  1799     0    50000     3142   4500000   4500000          0    0 3T
    50125  3091011 -9743 -3791-44213 102900551 102900586      6     0    0    0 1R
      123  3145487 -9709 -3762 43355 105086946 105086986      6     0    0    0 2G
    50121  3199967 -9676 -3729 44209 107273331 107273377      6     0    0    0 2R
    50058  6455868-11160 -5225-44221 215828181 215828361     16     0    0    0 3R
S033   130440  1799     0    50000     3142   4500000   5000000          0    0 3T
    50135  2885700-10288 -2785-49919  98659438  98659471     15     0    0    0 1R
      133  2930535-10275 -2780 49061 100647939 100647981     15     0    0    0 2G
    50131  2975374-10263 -2768 49914 102636428 102636484     15     0    0    0 2R
    50065  6062118-12249 -4762-49923 207558128 207558752     40     0    0    0 3R
S033   130440  1799     0    50000     3142   4500000   5500000          0    0 3T
    50133  3020692-11403  -647-53317 101084059 101084117     56     0    0    0 1R
      131  3060560-11420  -673 52507 102978779 102978846     56     0    0    0 2G
    50130  3100432-11437  -689 53313 104873491 104873569     56     0    0    0 2R
    50067  6218924-14191 -3448-53321 210124746 210125585    115     0    0    0 3R
S033   130440  1799     0    50000     3142   4500000   6000000          0    0 3T
    50104  3788921-10259 -3574-59417 113854747 113854834    912     0    0    0 1R
      103  3820800-10249 -3572 58548 115617591 115617680    912     0    0    0 2G
    50102  3852681-10240 -3563 59414 117380431 117380523    912     0    0    0 2R
    50049  7425637-11689 -5024-59423 230295002 230295121   1711     0    0    0 3R
S033   130440  1799     0    50000     3142   4500000   6500000          0    0 3T
    50057  5821218 -6448 -6098-64257 142399710 142400008183625     0    0    0 1R
       56  5847356 -6435 -6089 63372 144082823 144083135183625     0    0    0 2G
    50056  5873495 -6422 -6077 64256 145765935 145766261183625     0    0    0 2R
  1684896 10011309 -6189 -5873-18166 234725935 234726873365871     0    0    0 3F
S033   130440  1799     0    50000     3142   4500000   7000000          0    0 3T
  2195558  1936549 -7763 -7799 30028  59050000  59049975999999     0    0    0 1E
S033   130440  1799     0    50000     3142   4500000   7500000          0    0 3T
  2225112  1285167-10383-10389 49233  52810000  52809965999999     0    0    0 1E
S033   130440  1799     0    50000     3142   4500000   8000000          0    0 3T
  2245590   880081-14390-14394 64191  50090000  50089965999999     0    0    0 1E
S033   130440  1799     0    50000     3142   4500000   8500000          0    0 3T
  2247730   555666-22417-22421 77477  48650000  48649969999999     0    0    0 1E
S033   130440  1799     0    50000     3142   4500000   9000000          0    0 3T
  2251046   297077-44996-12280 90000  48250000  48249969999999     0    0    0 1E
S033   130440  1799     0    50000     3142   4500000   9500000          0    0 3T
  2248568   228757247892 67890 77673  48650000  48649969999999     0    0    0 1E
S033   130440  1799     0    50000     3142   4500000  10000000          0    0 3T
  2249996   455105208709 28707 65030  50050000  50049964999999     0    0    0 1E
```

```
S033   130440  1799      0    50000     3142   4500000  10500000          0    0  0 3T
  2233740   789299196959 16939 51415  52490000  52489964999999     0    0    0  0 1E
S033   130440  1799      0    50000     3142   4500000  11000000          0    0  0 3T
  2208428  1259606191906  8518 36751  57130000  57129972999999     0    0    0  0 1E
S033   130440  1799      0    50000     3142   4500000  11500000          0    0  0 3T
  2124423  2422518195818 -4466  9647  71370000  71370035999999     0    0    0  0 1E
S033   130440  1799      0    50000     3142   4500000  12000000          0    0  0 3T
    53003  2990948200125   978-57476 115367948 115368064   2352     0    0    0  0 1R
     2797  3023604200153   553 54429 117198663 117198779   2352     0    0    0  0 2G
    52607  3056826200187   580 56842 119028614 119028727   2352     0    0    0  0 2R
    50134  5991689205807  6198-56730 234573114 234573255   3512     0    0    0  0 3R
S033   130440  1799      0    50000     3142   4500000  12500000          0    0  0 3T
    60949  2479241201442 -6590-49243 105715988 105716092    185     0    0    0  0 1R
     9420  2525083201621 -7410 43874 107849212 107849323    185     0    0    0  0 2G
    58035  2573712201820 -7226 45970 109976807 109976925    185     0    0    0  0 2R
    50205  5082746211925  2861-45468 216607576 216608152    214     0    0    0  0 3R
S033   130440  1799      0    50000     3142   4500000  13000000          0    0  0 3T
    67320  2291697202541-11202-46567 101774969 101775077     44     0    0    0  0 1R
    15155  2342259202856-11710 40332 104050187 104050302     44     0    0    0  0 2G
    62782  2396807203195-11392 41940 106320535 106320655     44     0    0    0  0 2R
    50204  5018625215998  1379-41034 214865783 214866002     58     0    0    0  0 3R
S033   130440  1799      0    50000     3142   4500000  13500000          0    0  0 3T
    66041  2326700202456 -9909-42477 102595360 102595461     18     0    0    0  0 1R
    13438  2386724202782-10342 35491 105091010 105091118     18     0    0    0  0 2G
    60892  2450630203127-10017 38011 107580043 107580156     18     0    0    0  0 2R
    50180  5222047215158  1990-37119 219900993 219901351     26     0    0    0  0 3R
S033   130440  1799      0    50000     3142   4500000  14000000          0    0  0 3T
    58098  2555846202632 -6592-36018 108393614 108393701     10     0    0    0  0 1R
     6338  2633761202904 -6666 28584 111287389 111287482     10     0    0    0  0 2G
    55009  2713368203173 -6406 33954 114170553 114170650     10     0    0    0  0 2R
    50143  5658781212816  3229-33478 231386220 231386499     16     0    0    0  0 3R
```

APPENDIX B: BLANK INPUT-PARAMETER FORMS

This appendix provides blank Input Parameter Forms for all of the atmospheric models (including terrain and receiver-surface models) that we have developed for HARPA. The forms describe each model mathematically and list the variable input parameters you have to specify. We recommend reproducing these forms and filling them out when setting up atmospheric models for HARPA. The filled-out forms should then be saved as a record of the models you have defined.

The FORTRAN source codes for the corresponding model subroutines are listed in Appendix D under the model name. No forms are given for the do-nothing versions NTEMP, NPTEMP, NPSPEED, NPTERR, NPPRES, and NPWIND. The forms are arranged as follows:

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FORM TO SPECIFY INPUT DATA FOR A THREE-DIMENSIONAL RAYPATH CALCULATION

Name_____
Date_____

Atmospheric ID (3 characters)_____

Title (77 characters)_____

Transmitter: Height _____km, nm, ft (W3)
_____above terrain
_____above sea level
Latitude _____rad, deg, km (W4)
Longitude _____rad, deg, km (W5)
Frequency, initial _____rad/s, Hz, s (W7)
final _____ (W8)
step _____ (W9)
Azimuth angle, initial _____rad, deg clockwise of north (W11)
final _____ (W12)
step _____ (W13)
Elevation angle, initial_____rad, deg (W15)
final _____ (W16)
step _____ (W17)

Receiver: Height _____km, nm, ft (W20)
_____above sea level (rcvr model RHORIZ)
_____above terrain (rcvr model RTERR)
Distance from origin _____rad, deg, km (W30) (rcvr model RVERT)
Latitude of origin _____rad, deg, km (W31) (rcvr model RVERT)
Longitude of origin _____rad, deg, km (W32) (rcvr model RVERT)

Stop frequency stepping
when ray goes out of bounds _____(W21 = 1.)
Maximum height _____km (W26)
Minimum height _____km (W27)
Maximum range _____km (W28)
Maximum number of hops _____(W22)
Maximum number of steps per hop _____(W23)
Maximum allowable error per step _____(W42)

Additional calculations: = 1. to integrate
= 2. to integrate and print
Phase path _____(W57)
Absorption _____(W58)
Doppler shift _____(W59)
Path length _____(W60)

Printout: Every_____steps of the ray trace (W71)

Computer readable output (raysets): _____(W72 = 1.)
Diagnostic printing: _____(W73 = 1.)
Suppress all printout _____(W74 = 1.)

FORM TO SPECIFY INPUT PARAMETERS FOR PLOTTING A
PROJECTION OF THE RAYPATH

Model ID:_____

Plot directly during raypath calculations_____, or

plot from precomputed raypaths_____

in disk file_____

Normal or apogee plots:

Normal_____(W80=0.0)

Plot apogees only_____(W80=1.0)

Projection:

Vertical plane, polar plot, rectangular expansion_____(W81=1.0)

Horizontal plane, lateral expansion _____(W81=2.0)

Vertical plane, polar plot, radial expansion _____(W81=3.0)

Vertical plane, rectangular plot _____(W81=4.0)

Superimpose these raypath plots on the graph of the previous runset:

Yes_____(W81 negative.)

No _____(W81 positive.)

Vertical or lateral expansion factor _____(W82)

Coordinates of the left edge of the graph:

Latitude = _____(rad, deg, km) north (W83)

Longitude = _____(rad, deg, km) east (W84)

Coordinates of the right edge of the graph:

Latitude = _____(rad, deg, km) north (W85)

Longitude = _____(rad, deg, km) east (W86)

Distance between horizontal tick marks = _____rad, deg, km (W87)

Height above sea level of bottom of graph = _____km (W88)

Height above sea level of top of graph = _____km (W89)

Distance between vertical tick marks = _____km (W96)

FORM TO SPECIFY AN ATMOSPHERIC MODEL
(including terrain model)

Name_____ Date_____

Atmospheric ID (3 characters)_____

Coordinates of the north pole of the computational coordinate system:

North geographic latitude: _____rad, km, deg (W24)

East geographic longitude: _____rad, km, deg (W25)

Models:

	Subroutine Name	Data set ID
Dispersion relation	_____	
Wind velocity	_____	_____(W102)
Wind-velocity perturbation	_____	_____(W127)
Sound speed	_____	_____(W152)
Sound-speed perturbation	_____	_____(W177)
Temperature	_____	_____(W202)
Temperature perturbation	_____	_____(W227)
Molecular weight	_____	_____(W252)
Terrain	_____	_____(W302)
Terrain perturbation	_____	_____(W327)
Viscosity/conductivity	_____	_____(W502)
Viscosity/conductivity perturbation	_____	_____(W527)
Pressure	_____	_____(W552)
Pressure perturbation	_____	_____(W557)
Receiver surface*	_____	
Plot-annotation model*	_____	

*The receiver-surface model and plot-annotation model are not considered part of the atmospheric ID

FORM TO SPECIFY INPUT DATA FOR WIND-VELOCITY MODEL WLINEAR

This subroutine specifies constant radial (upward), zonal (eastward) and meridional (southward) winds, allowing a linear height gradient of the zonal component.

$$U_\theta = U_{\theta o}$$

$$U_\phi = U_{\phi o} + \frac{du_\phi}{dz} z$$

$$u_r = U_{ro}$$

$z = r - r_e$, where r_e is the Earth radius, and r is the radial coordinate of ray point.

Specify--

the model check for WLINEAR = __1.0__(W100)

the input data-format code = _____(W101)

an input data-set identification number = _____(W102)

an 80-character description of the wind-velocity profile:

---

the constant upward wind, U_{ro} = _____km/s, m/s (W103)

the constant southward wind, $U_{\theta o}$ = _____km/s, m/s (W104)

the ground value of the eastward wind, $U_{\phi o}$ = _____km/s, m/s (W105)

the height gradient of u_ϕ, du_ϕ/dz = _____km/s/km, m/s/km (W106)

(This subroutine can be used with its input parameters zero when no wind field is desired.)

OTHER MODELS REQUIRED: Any wind-perturbation model. Use NPWIND if no perturbation is desired.

FORM TO SPECIFY INPUT DATA FOR WIND-VELOCITY MODEL WTIDE

This subroutine represents the wind field of the atmospheric tides by zonal and meridional height profiles that are sinusoidal and in phase quadrature. The profiles progress downward with time, giving a corkscrew effect:

$$u_\theta = U_{\theta o} \sin \left\{2\pi \left(\frac{z}{\lambda_z} + \frac{t}{\tau}\right)\right\}$$

$$u_\phi = U_{\phi o} \cos \left\{2\pi \left(\frac{z}{\lambda_z} + \frac{t}{\tau}\right)\right\}$$

$z = r - r_e$, where r_e is the Earth radius, and r is the radial coordinate of the ray point.

Specify--

the model check for WTIDE = 5.0 (W100)

the input data-format code = _____(W101)

an input data-set identification number = _____(W102)

an 80-character description of the model, including description of parameter values:

---

the amplitude of the meridional component, $U_{\theta o}$ = _____km/s, m/s (W104)

the amplitude of the zonal component, $U_{\phi o}$ = _____km/s, m/s (W103)

the vertical wavelength, λ_z = _____km (W105)

the time in wave periods, t/τ = _____(W106)

the wave period, τ = _____sec (W107)

(The Earth's poles should be avoided in ray calculations because discontinuities appear there.)

OTHER MODELS REQUIRED: Any wind-perturbation model. Use NPWIND if no perturbation is desired.

FORM TO SPECIFY INPUT DATA FOR WIND-VELOCITY MODEL ULOGZ2

A logarithmic wind profile of the atmospheric boundary layer neglecting Coriolis forces. The eastward wind is given by

$$u_\phi = \frac{u_*}{k} \ln \frac{z}{z_0} \qquad \text{for} \qquad z > z_0 e$$

$$u_\phi = \frac{u_*}{k} \frac{z}{z_0 e} \qquad \text{for} \qquad z \leqslant z_0 e \quad ,$$

where $z = G(r,\theta,\phi)$ is determined by the terrain model and is the height above or some kind of distance from the terrain, depending on the terrain model, and r is the radial coordinate of the ray point.

Specify--

the model check for ULOGZ2 = ____6.0____(W100)

the input data-format code = _____(W101)

an input data-set identification number = _____(W102)

an 80-character description of the wind velocity profile:

_____

the reference wind speed, u_* = _____km/s, m/s (W103)

von Kármán's constant, k = _____(W104) (.35 recommended)

the roughness height, z_0 = _____km (W105)

OTHER MODELS REQUIRED: Any wind-perturbation model. Use NPWIND if no perturbation is desired.

($\overline{uw} = -u_*^2$ is the surface stress at the ground.)

FORM TO SPECIFY INPUT DATA FOR
WIND-VELOCITY MODEL VVORTX3

This subroutine models a vortex with a viscous core and a Gaussian intensity profile in the vertical. The axis of the vortex is vertical and may be positioned above any geographic latitude and longitude. The vortex rotates anticlockwise looking down. The core (inside r_o) is essentially a solid-rotating fluid, while outside r_o, $|u|$ falls off as the inverse radius.

$$u_\theta = - \frac{1.397\ R_e U_o r_o}{r^2} \left(1 - e^{-1.26\ r^2/r_o^{\ 2}}\right)(\phi - \phi_o) e^{-\left[\frac{h - h_{max}}{w_H}\right]^2}$$

$$u_\phi = \frac{1.397\ R_e U_o r_o}{r^2} \left(1 - e^{-1.26\ r^2/r_o^{\ 2}}\right)(\theta - \theta_o) e^{-\left[\frac{h - h_{max}}{w_H}\right]^2} ,$$

where $\theta_o = \pi/2 - \lambda_o$ and r is the radial distance from the vortex center. The numerical constants normalize the function so that $|U| = U_o$ at $r = r_o$. R_e is the radius of the Earth, θ is the colatitude, ϕ is the longitude, and h is the height above sea level.

Specify--

the model check for VVORTX3 = 9.0 (W100)

the input data-format code = _____(W101)

an input data-set identification number = _____(W102)

an 80-character description of the model, including description of parameter values:

---

the maximum tangential wind, U_o = _____km/s, m/s (W103)

the radius of the vortex core (to $u = U_o$), r_o = _____km (W104)

the latitude of the vortex center, λ_o = _____rad, deg, km N (W105)

the longitude of the vortex center, ϕ_o = _____rad, deg, km E (W106)

the Gaussian width in height of the vortex, W_H = _____km, m (W107)

the height of the vortex, h_{max} = _____km, m (W108)

OTHER MODELS REQUIRED: Any wind-perturbation model. Use NPWIND if no perturbation is desired.

FORM TO SPECIFY INPUT DATA FOR WIND-VELOCITY MODEL WGAUSS2

This subroutine specifies a zonal (eastward) wind field whose intensity decays in a Gaussian manner in all three space dimensions.

$$u_\phi = U_{\phi o} \exp\{- \left(\frac{z-z_o}{W_z}\right)^2 - \left(\frac{\theta-\theta_o}{W_\theta}\right)^2 - \left(\frac{\phi-\phi_o}{W_\phi}\right)^2 \}$$

$z = r - r_e$, where r_e is the Earth radius, $\theta_o = \pi/2 - \lambda_o$, and r is the radial coordinate of the ray point. θ is the colatitude. ϕ is the longitude. Notice that this wind field does not satisfy continuity if $W_\phi \neq 0$.

Specify--

the model check for WGAUSS2 = 8.0 (W100)

the input data-format code = _____(W101)

an input data-set identification number = _____(W102)

an 80-character description of the model, including description of parameter values:

---

the maximum value of u_ϕ, $U_{\phi o}$ = _____km/s, m/s (W103)

the height where u_ϕ, maximizes, z_o = _____km (W107)

the Gaussian width in height of u_ϕ, W_z = _____km (W104)*

the latitude where u_ϕ maximizes, λ_o = _____rad, deg, km N (W108)

the meridional width of u_ϕ, W_θ = _____rad, deg, km (W105)*

the longitude where u_ϕ, maximizes, ϕ_o = _____rad, deg, km E (W109)

the zonal width of u_ϕ, W_ϕ = _____rad, deg, km (W106)*

OTHER MODELS REQUIRED: Any wind-perturbation model. Use NPWIND if no perturbation is desired.

*Setting W_z, W_θ or W_ϕ = 0 results in no space variation in that direction.

FORM TO SPECIFY
SOUND-SPEED MODEL GAMRTDM

This model specifies sound speed in terms of a background temperature model using

$$C^2 = \frac{\gamma RT}{M} \quad ,$$

where γ = 1.4, R is the universal gas constant, T is the absolute temperature in Kelvins, and $M(r,\theta,\phi)$ is a model of the mean molecular weight of the atmosphere. See Sec. 6.3 for further description of this model.

Specify --

The model check for GAMRTDM = ___1.0___(W150)

OTHER MODELS REQUIRED: Any background temperature model; any molecular weight model.

FORM TO SPECIFY INPUT DATA FOR SOUND-SPEED MODEL CSTANH

This model represents the sound speed (squared) profile by a sequence of linear segments that are smoothly joined by hyperbolic functions:

$$C^2 = C_o^2 + \frac{b_1}{2}(z-z_o) + \sum_{i=1}^{n} \delta_i \left(\frac{b_{i+1} - b_i}{2}\right) \ln\left\{\frac{\cosh\left(\frac{z-z_i}{\delta_i}\right)}{\cosh\left(\frac{z_i-z_o}{\delta_i}\right)}\right\} + \frac{b_{n+1}}{2}(z-z_o)$$

$$\frac{dC^2}{dz} = b_1 + \sum_{i=1}^{n} \left(\frac{b_{i+1} - b_i}{2}\right) \left\{\tanh\left(\frac{z-z_i}{\delta_i}\right) + 1\right\}$$

$$b_i = (C_i^2 - C_{i-1}^2)/(z_i - z_{i-1}) \quad .$$

$z = r - r_e$, where r_e is the Earth radius, and r is the radial coordinate of the ray point. Thus, δ_i is the half-thickness of a region centered at approximately z_i km, in which dC^2/dz changes from b_i to b_{i+1}. Start by drawing a profile with linear segments, and get C_i^2 and z_i from the corners. Then select δ_i to round the corners. The final profile will not go through (C_i^2, z_i).

Specify--

the model check for CSTANH = 2.0 (W150)

the input data-format code = _____ (W151)

an input data-set identification number = _____ (W152)

an 80-character description of the model with parameters:

_____

and the profile values:

the number of points in the profile -2 = n = _____

the profile:

i	z_i (km,m)	C_i (km/s, m/s)	δ_i (km,m)

OTHER MODELS REQUIRED: Any sound-speed-perturbation model. Use NPSPEED if no perturbation is desired. FUNCTION ALCOSH.

FORM TO SPECIFY INPUT DATA FOR SOUND-SPEED PERTURBATION MODEL CBLOB2

An increase (or decrease) in sound speed in a localized region that decays in a Gaussian manner in all three spatial directions.

$$C^2(r,\theta,\phi) = C_o^2(r,\theta,\phi)\left(1 + \Delta \exp\left\{-\left(\frac{z-z_o}{W_z}\right)^2 - \left(\frac{\theta-\theta_o}{W_\theta}\right)^2 - \left(\frac{\phi-\phi_o}{W_\phi}\right)^2\right\}\right)$$

$C_o^2(r,\theta,\phi)$ is the <u>square</u> of the sound speed specified by a sound-speed model. (r,θ,ϕ) are the coordinates of the ray point in an Earth-centered spherical polar-coordinate system. $\theta_o = \pi/2 - \lambda_o$ and $z = r - r_e$, where r_e is the Earth radius.

Specify--

the model check for subroutine CBLOB2 = 2.0 (W175)

the input data-format code = _____(W176)

an input data-set identification number = _____(W177)

an 80-character description for the sound-speed perturbation model, including description of parameter values:

_____

the strength of the fractional increase (or decrease), Δ = _____(W178)

the height of maximum effect, z_o = _____km (W179)

the latitude of maximum effect, λ_o = _____rad, deg, km N (W180)

the longitude of maximum effect, ϕ_o = _____rad, deg, km E (W181)

the Gaussian width in height of the effect, W_z = _____km (W182)*

the meridional width of the effect, W_θ = _____rad, deg, km (W183)*

the zonal width of the effect, W_ϕ = _____rad, deg, km (W184)*

OTHER MODELS REQUIRED: none.

---

* Setting W_z, W_θ, or W_ϕ = zero results in no space variation in that direction.

FORM TO SPECIFY INPUT DATA FOR
ATMOSPHERIC TEMPERATURE MODEL TLINEAR

This subroutine specifies an atmospheric temperature that increases linearly with height.

$$T = T_o + (\frac{dT}{dz})\ z$$

$z = r - r_e$, where r_e is the Earth radius and r is the radial coordinate of the ray point.

Specify--

the model check for TLINEAR = 1.0 (W200)

the input data-format code = _____(W201)

an input data-set identification number = _____(W202)

an 80-character description of the model, including description of parameter values:

_____

the ground temperature, T_o = _____°K (W203)

the temperature gradient, dT/dz = _____°K/km (W204)

(set = 0 for isothermal atmosphere)

OTHER MODELS REQUIRED: Any temperature-perturbation model. Use NPTEMP if no perturbations are desired.

FORM TO SPECIFY INPUT DATA FOR TEMPERATURE MODEL TTANH5

This model represents the temperature profile by a sequence of linear segments that are smoothly joined by hyperbolic functions:

$$T = T_o + \frac{c_1}{2}(z-z_o) + \sum_{i=1}^{n} \delta_i \left(\frac{c_{i+1} - c_i}{2}\right) \ell n \left\{ \frac{\cosh\left(\frac{z-z_i}{\delta_i}\right)}{\cosh\left(\frac{z_i-z_o}{\delta_i}\right)} \right\} + \frac{c_{n+1}}{2}(z-z_o)$$

$$\frac{dT}{dz} = c_1 + \sum_{i=1}^{n} \left(\frac{c_{i+1} - c_i}{2}\right) \left\{\tanh\left(\frac{z-z_i}{\delta_i}\right) + 1\right\}$$

$$c_i = (T_i - T_{i-1})/(z_i - z_{i-1}) \quad .$$

$z = r - r_e$, where r_e is the Earth radius, and r is the radial coordinate of the ray point. Thus, δ_i is the half-thickness of a region centered at approximately z_i km, in which dT/dz changes from c_i to c_{i+1}. Start by drawing a profile using linear segments and get T_i and z_i from the corners. Then select δ_i to round the corners. The final profile will not go through (T_i, z_i).

Specify--

the model check for TTANH5 = 7.0 (W200)

the input data-format code = _____ (W201)

an input data-set identification number = _____ (W202)

an 80-character description of the model with parameters:

_____

and the profile values:

the number of points in the profile -2 = n = _____

the profile: i	z_i (km,m)	T_i (°K)	δ_i (km,m)

OTHER MODELS REQUIRED: Any temperature-perturbation model. Use NPTEMP if no perturbations are desired. FUNCTION ALCOSH.

FORM TO SPECIFY INPUT DATA FOR ATMOSPHERIC TEMPERATURE MODEL TTABLE

This model represents the temperature profile by a sequence of cubic segments such that the temperature gradient is continuous through each profile point. This is not a cubic spline; the coefficients of the cubic fit in each segment depend on only the four nearest profile points.

The coefficients of the cubic are calculated as follows: each set of three successive points in the profile is first fit with a quadratic. The slope of that quadratic at the middle profile point is then assigned to that profile point. This procedure assigns a slope to every profile point except the first and last. A slope of zero is assigned to the first and last point. Between each pair of profile points the coefficients of the cubic are chosen so that the curve goes through the two points and matches the assigned slope at the two points. Those four conditions determine the four coefficients. Both the temperature and its gradient are continuous throughout the profile, even at the profile points.

Specify--

the model check number for TTABLE = 6.0 (W200)

the input data-format code = 2.0 (W201)

an input data-set identification number = _____ (W202)

an 80-character description of the profile:

_____

and the profile values:

the number of points in the profile, n = _____

the profile: height (km) Temperature (K)

OTHER MODELS REQUIRED: Subroutine GAUSEL and any temperature-perturbation model. Use NPTEMP if no perturbations are desired.

FORM TO SPECIFY INPUT DATA FOR
ATMOSPHERIC TEMPERATURE-PERTURBATION MODEL TBLOB2

An increase (or decrease) in temperature in a localized region that decays in a Gaussian manner in all three spatial directions.

$$T(r,\theta,\phi) = T_o(r,\theta,\phi)\ \{1 + \Delta\ \exp\left[-\left(\frac{z-z_o}{W_z}\right)^2 - \left(\frac{\theta-\theta_o}{W_\theta}\right)^2 - \left(\frac{\phi-\phi_o}{W_\phi}\right)^2\right]\}$$

$T_o(r,\theta,\phi)$ is the temperature specified by a temperature model. (r,θ,ϕ) are the coordinates of the ray point in an Earth-centered spherical polar coordinate system. $\theta_o = \pi/2 - \lambda_o$ and $z = r - r_e$, where r_e is the Earth radius.

Specify--

the model check for subroutine TBLOB2 = 2.0 (W225)

the input data-format code = _____ (W226)

an input data-set identification number = _____ (W227)

an 80-character description for the temperature-perturbation model, including description of parameter values:

_____

the strength of the increase (or decrease), Δ = _____ (W228)

the height of maximum effect, z_o = _____ km (W229)

the latitude of maximum effect, λ_o = _____ rad, deg, km N (W230)

the longitude of maximum effect, ϕ_o = _____ rad, deg, km E (W231)

the Gaussian width in height of the effect, W_z = _____ km (W232)*

the meridional width of the effect, W_θ = _____ rad, deg, km (W233)*

the zonal width of the effect, W_ϕ = _____ rad, deg, km (W234)*

OTHER MODELS REQUIRED: none.

* Setting W_z, W_θ, or W_ϕ = zero results in no space variation in that direction.

FORM TO SPECIFY INPUT DATA FOR
ATMOSPHERIC MOLECULAR-WEIGHT MODEL MCONST

A constant molecular weight (independent of height, longitude, latitude, and time)

Specify--

the model check for MCONST = 1.0 (W250)

the input data-format code = _____(W251)

an input data-set identification number = _____(W252)

an 80-character description of the molecular weight:

_____

the value of the constant molecular weight, M = _____(W253)

OTHER MODELS REQUIRED: none.

FORM TO SPECIFY INPUT DATA FOR
VISCOSITY/CONDUCTIVITY MODEL MUARDC

This subroutine calculates the atmospheric molecular viscosity using the ARDC formula for viscosity and calculates atmospheric thermal conductivity from the value of viscosity using a Prandtl number specified by the user. This model is used only to calculate acoustic absorption when either AWWWL or ANWWL is used.

The ARDC formula for viscosity is (U.S. Standard Atmosphere, 1976, p. 19, NOAA, NASA, USAF, U.S. Government Printing Office, Washington, D.C., October 1976)

$$\mu = \beta\ T^{3/2}/(S+T)\ ,$$

where T is the atmospheric temperature in Kelvins.

The atmospheric thermal conductivity using the Prandtl approximation (e.g., Francis Weston Sears, Thermodynamics, Addison-Wesley, 1956, pp. 267-9) is

$$\kappa = \gamma\ R\mu/((\gamma-1)M\ Pr),$$

where γ is the ratio specific heats = 1.4,
R is the universal gas constant,
and M is the mean atmospheric molecular weight.

Specify --

the model check for subroutine MUARDC = ___1.0___(W500)

the input data-format code = _____(W501)

an input data-set identification number = _____(W502)

an 80-character description for the absorption model, including description of parameter values:

---

the viscosity constant, β = _____kg s^{-1} m^{-1} $K^{-1/2}$ (W503)
(1.458×10^{-6} kg s^{-1} m^{-1} $K^{-1/2}$ suggested)

Sutherland's constant, S = _____Kelvins (W504)
(110.4 Kelvins suggested)

Prandtl number, Pr = _____(W505) (0.733 suggested)

OTHER MODELS REQUIRED: Any atmospheric temperature model and any atmospheric molecular weight model.

FORM TO SPECIFY INPUT DATA FOR
PRESSURE MODEL PEXP

This model is used only to calculate absorption when either AWWWL or ANWWL is used. The pressure is given by

$$P = P_0 \exp(-z/H),$$

where z is the height above sea level.

Specify --

the model check for subroutine PEXP = 1.0 (W550)

the input data-format code = _____(W551)

an input data-set identification number = _____(W552)

an 80-character description for the pressure model, including description of parameter values:

---

the pressure at sea level, P_0 = _____Newtons/m^2 (W553)

(1.01328×10^5 Newtons/m^2 suggested)

the pressure scale height, H = _____km, m (W554)

OTHER MODELS REQUIRED: Any pressure-perturbation model. Use NPPRES if no perturbation is desired.

FORM TO SPECIFY INPUT DATA FOR
TERRAIN MODEL GHORIZ

A constant-height terrain model, i.e., a sphere concentric with the Earth.

$$g(r,\theta,\phi) = h - z_o ,$$

where $h = r - r_e$,

$$\frac{\partial g}{\partial r} = 1 , \frac{\partial g}{\partial \theta} = 0 , \frac{\partial g}{\partial \phi} = 0 ,$$

$$\frac{\partial^2 g}{\partial r^2} = \frac{\partial^2 g}{\partial r \partial \theta} = \frac{\partial^2 g}{\partial \theta \partial r} = \frac{\partial^2 g}{\partial r \partial \phi} = \frac{\partial^2 g}{\partial \phi \partial r} = \frac{\partial^2 g}{2\theta 2} = \frac{\partial^2 g}{\partial \theta \partial \phi} = \frac{\partial^2 g}{\partial \phi \partial \theta} = \frac{\partial^2 g}{\partial \phi^2} = 0 ,$$

and r_e is the radius of the Earth.

Specify --

The model check number for GHORIZ = 1.0 (W300)

The input data-format code number = _____ (W301)

The input data-set identification number = _____ (W302)

an 80-character description of the model including parameters:

_____

The constant terrain height, z_o = _____ km, (W303)

OTHER MODELS REQUIRED: Any terrain-perturbation model. Use NPTERR if no perturbation is desired.

FORM TO SPECIFY INPUT DATA FOR TERRAIN MODEL GLORENZ

An east-west Lorentzian-shaped ridge.

$$g(r,\theta,\phi) = h - z,$$

where

$$h = r - r_e ,$$

$$z = z_o/(1 + ((\theta-\theta_o)/\Delta\theta)^2) + z_B ,$$

$$\theta_o = \pi/2 - \lambda_o ,$$

and r_e is the radius of the Earth.

Specify--

the model check number for GLORENZ = ____4.0_____(W300)

the input data-format code number = _____(W301)

the input data-set identification number = _____(W302)

an 80-character description of the model including parameters:

_____

the height of the ridge, z_o = _____km, m (W303)

the latitude of the ridge center, λ_o = _____rad, deg, km (W304)

the half-width of the ridge, $\Delta\theta$ = _____rad, deg, km (W305)

base of the ridge (negative if below sea level) z_B = _____m,km (W306)

OTHER MODELS REQUIRED: Any terrain-perturbation model. Use NPTERR if no perturbation is desired.

FORM TO SPECIFY INPUT DATA FOR TERRAIN MODEL GTANH

This model represents the terrain by a sequence of linear segments that are smoothly joined by hyperbolic functions:

$$g(r,\theta,\phi) = h - z(\theta), \text{ where}$$

$$z(\theta) = z_o + \frac{c_1}{2}(\theta-\theta_o) - \sum_{i=1}^{n} \delta_i \left(\frac{c_{i+1} - c_i}{2}\right) \ln\left\{\frac{\cosh\left(\frac{\theta-\theta_i}{\delta_i}\right)}{\cosh\left(\frac{\theta_i-\theta_o}{\delta_i}\right)}\right\} + \frac{c_{n+1}}{2}(\theta-\theta_o)$$

$$\frac{dz}{d\theta} = c_1 + \sum_{i=1}^{n} \left(\frac{c_{i+1} - c_i}{2}\right)\left\{-\tanh\left(\frac{\theta-\theta_i}{\delta_i}\right) + 1\right\}$$

$$c_i = (z_i - z_{i-1})/(\theta_i - \theta_{i-1})$$

$h = r - r_e$, where r_e is the Earth radius, and r is the radial coordinate of the ray point. $\theta_i = \pi/2 - \lambda_i$. Thus, δ_i is the half-thickness of a region centered at approximately θ_i, in which $dz/d\theta$ changes from c_i to c_{i+1}. Start by drawing a profile using linear segments, and θ_i and z_i from the corners. Then select δ_i to round the corners. The final profile will not go through (θ_i, z_i).

Specify--

the model check for GTANH = 3.0 (W300)

the input data-format code = _____ (W301)

an input data-set identification number = _____ (W302)

an 80-character description of the model with parameters:

_____

and the profile values:

the number of points in the profile -2 = n = _____

the profile: i	λ_i (rad,deg)	z_i (km,m)	δ_i (rad,deg)

OTHER MODELS REQUIRED: Any terrain-perturbation model. Use NPTERR if no perturbation is desired. FUNCTION ALCOSH.

FORM TO SPECIFY INPUT DATA
FOR RECEIVER-SURFACE MODEL RHORIZ

A receiver-surface model that is a horizontal surface (i.e., a sphere concentric with the Earth).

$$f(r,\theta,\phi) = h - z_R \ ,$$

where

$$h = r - r_e$$

and

r_e is the Earth radius

$$\frac{\partial f}{\partial t} = \frac{\partial f}{\partial \theta} = \frac{\partial f}{\partial \phi} = 0$$

$$\frac{\partial f}{\partial r} = 1.0 \quad .$$

Specify--

the model check number for subroutine RHORIZ = 1.0 (W275)

the input data-format code number = _____(W276)

an 80-character description of the model including parameters:

_____

the receiver surface height, z_R = _____km (W20)

OTHER MODELS REQUIRED: none.

FORM TO SPECIFY INPUT DATA
FOR RECEIVER-SURFACE MODEL RTERR

A receiver-surface model in which the receiver surface is a fixed height above the terrain surface.

$$f(r,\theta,\phi) = g(r,\theta,\phi) + z_R$$

$$\frac{\partial f}{\partial r} = \frac{\partial g}{\partial r}\ ,\ \frac{\partial f}{\partial \theta} = \frac{\partial g}{\partial \phi}\ ,\ \frac{\partial f}{\partial \phi} = \frac{\partial g}{\partial \phi}\ ,$$

where $g(r,\theta,\phi)$ and its derivatives are specified in common block /GG/ by the terrain model.

Specify--

the model check number for subroutine RTERR = ___3.0___(W275)

the input data-format code number = _____(W276)

an 80-character description of the model including parameters:

_____

the height of the receiver surface above the terrain, z_R = _____km (W20)

OTHER MODELS REQUIRED: Any terrain model.

FORM TO SPECIFY INPUT DATA FOR
RECEIVER-SURFACE MODEL RVERT

A receiver surface that is a vertical (conical) surface a constant distance from a given origin on the Earth's surface

$$f(r,\theta,\phi) = \sin\lambda_o \cos\theta + \cos\lambda_o \sin\theta \cos(\phi-\phi_o) - \cos\alpha_o$$

$$\frac{\partial f}{\partial t} = \frac{\partial f}{\partial r} = 0$$

$$\frac{\partial f}{\partial \theta} = -\sin\lambda_o \sin\theta + \cos\lambda_o \cos\theta \cos(\phi-\phi_o)$$

$$\frac{\partial f}{\partial \phi} = -\cos\lambda_o \sin\theta \sin(\phi-\phi_o) \ .$$

Specify--

the model check number for subroutine RVERT = 2.0 (W275)

the input data-format code number = _____(W276)

an 80-character description of the model including parameters:

---

the distance of the surface from the origin,

α_o = _____rad, deg, km (278)

the latitude of the origin, λ_o = _____rad, deg, km N (W279)

the longitude of the origin, ϕ_o = _____rad, deg, km E (W280)

OTHER MODELS REQUIRED: none.

APPENDIX C: CDC 250 PLOT PACKAGE AND DISSPLA INTERFACE

This appendix describes the plotting commands used by DDPLOT, our local microfilm plotting system, and also an interface called DDSPLA to the DISSPLA* plot package in common use. Figure C1 shows the steps necessary to obtain graphical output from HARPA, if you have DISSPLA. If you do not have DISSPLA and want graphical output on your own plotting system, you will have to insert the equivalent instructions used by your system into a skeleton plotting routine DDALT. This information was taken with permission from "User's Guide to Cathode-Ray Plotter Subroutines" by L. David Lewis, ESSA Technical Memorandum ERL TM-ORSS5, January 1970. The routines used in this version of HARPA assume DISSPLA version 9.0 and are listed in Appendix D.

The CDC-250 Microfilm Recorder, under control of the NOAA Boulder CDC-CYBER 750 computer, plots data on the face of a high-resolution cathode ray tube, which is photographed onto standard size, perforated, 35-mm film.

The plotting area, called a frame, is a square. Plotting positions are described in rectangular coordinates. Coordinate values are integers in the range 0 - 1023; (0,0) is the "lower left-hand corner."

Plotting specifications are transmitted to the DDPLOT routines via the following COMMON.

```
COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY
```

The usage of each of the eight variables is listed below, followed by an explanation of the subroutine calls.

IN	Intensity. IN=0 specifies normal intensity. IN=1 specifies high intensity.
IOR	Orientation IOR=0 specifies upright orientation. IOR=1 specifies rotated orientation (90° counter-clockwise).

*DISSPLA is the proprietary product of ISSCO, Inc.

IT — Italics (Font).
IT=0 specifies non-italic (Roman) symbols.
IT=1 specifies italic symbols.

IS — Symbol size.
IS=0 specifies miniature size.
IS=1 specifies small size.
IS=2 specifies medium size.
IS=3 specifies large size.

IC — Symbol case.
IC=0 specifies uppercase.
IC=1 specifies lowercase.

ICC — Character code, 0-63 (R1 format).
ICC and IC together specify the symbol plotted.

IX — X-coordinate, 0-1023.

IY — Y-coordinate, 0-1023.

CALL DDINIT (N,ID) is required to initialize the plotting process.

ID is a string of characters to identify the person getting the plot and giving the telephone extension and the place to deliver the microfilm plot.

N is the number of characters in the string "ID."

CALL DDBP defines a vector origin in position IX, IY.

CALL DDVC plots a vector (straight line), with intensity IN, from the vector origin defined by the previous DDBP or DDVC call, to the vector end position at IX, IY. A single call to DDBP followed by successive calls to DDVC (with changing IX and IY) plots connected vectors.

CALL DDTAB initializes tabular plotting.

CALL DDTEXT (N,NT) plots a given array in a tabular mode after initiating tabular plotting by using DDTAB, as described above. NT is an array of length N, containing "text" for tabular plotting. Text consists of character codes, packed eight per word (A8 Format). Text characters are plotted as tabular symbols until the command character ≠ (octal code 14, card code 4,8, or the alphabetic shift counterpart of the = on the keypunch) occurs. The command character is not plotted. DDTEXT interprets the next character as a command; after the command is processed, tabular plotting resumes until ≠ is again encountered. ≠ means end of text: DDTEXT returns to the calling routine.

CALL DDFR causes a frame advance operation. Plotting on the current frame is completed, and the film advances to the next frame.

CALL DDEND — empties the plot buffer and releases the plotting command file to the microfilm plot queue.

DISSPLA CALLS

HARPA calls the following DISSPLA routines directly, rather than through the DDPLOT package. Therefore, if you want to do plotting with a plotting package other than DISSPLA, you will have to convert the following DISSPLA calls to corresponding calls in your plotting package.

CALL DASH — sets dashed-line mode. That is, all plotted curves will be dashed instead of solid.

CALL RESET('DASH') — sets solid-line mode. That is, all plotted curves will be solid lines after this call.

HARPA calls a routine named SETANN. SETANN is an entry point in SUBROUTINE FULANN and also in SUBROUTINE SMPANN. When running HARPA, you must make a choice whether to load FULANN or SMPANN. If you do not have the DISSPLA plotting package, then load SMPANN because it makes no special characater-generating calls to DISSPLA routines. If you do have the DISSPLA plotting package, then load FULANN. SUBROUTINE FULANN calls the following DISSPLA subroutines directly. If you have the DISSPLA plotting package, then the manual will explain the meaning of these routines. If you do not have the DISSPLA plotting package, then load SMPANN, and ignore these routines.

HEIGHT

MX1ALF

MX2ALF

SCMPLX

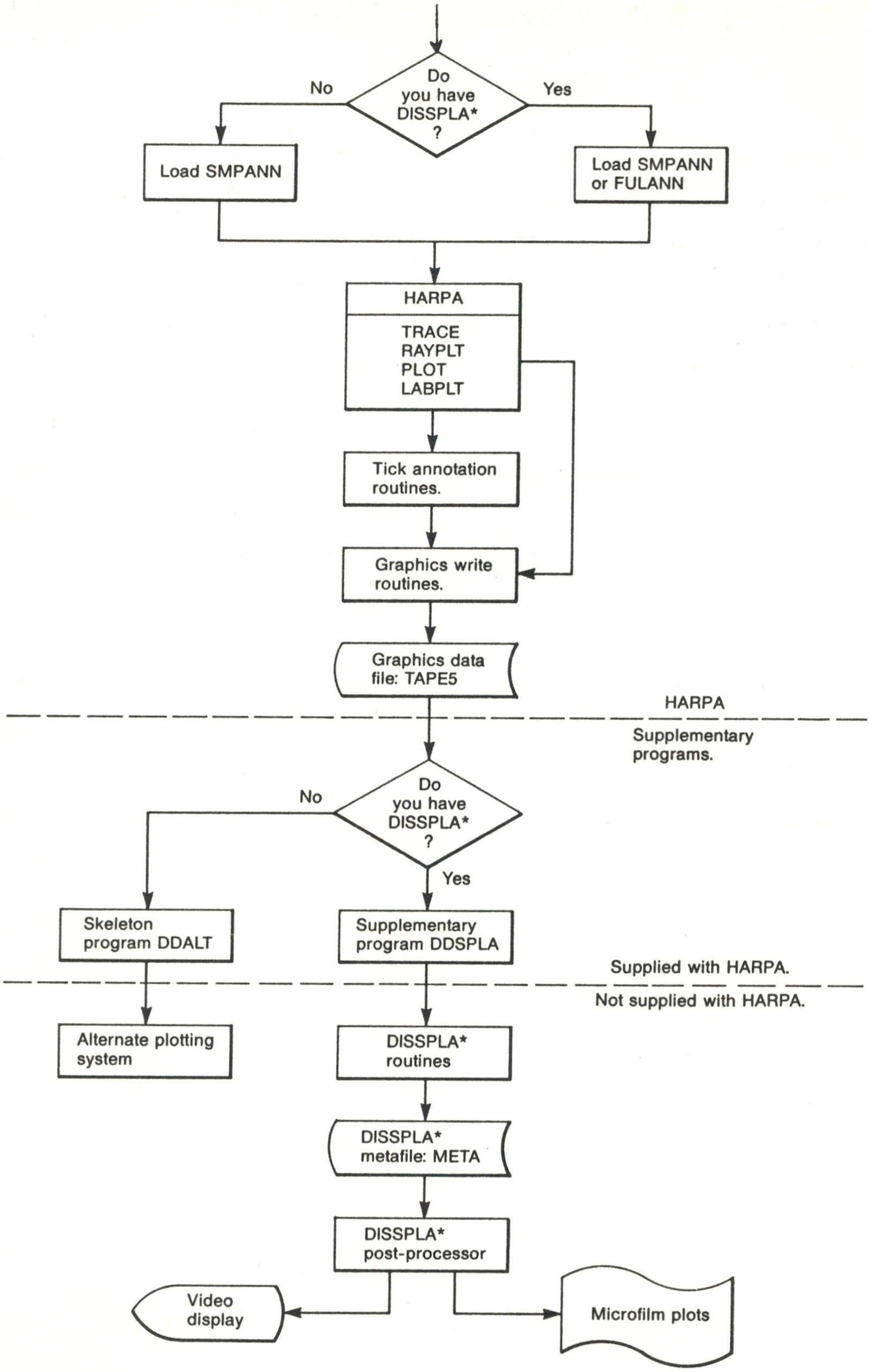

Figure C1. An organization chart that shows how graphical output is produced by a series of programs, some of which are a part of HARPA, and others of which are either supplied along with HARPA or are commercial packages.

APPENDIX D: FORTRAN SOURCE CODE LISTING

This appendix contains the FORTRAN source-code listing for HARPA, including all of its subroutines and atmospheric models. Their order is the same as the order of the programs in Files 3 through 7 of the distribution tape and the list in Section 7.1. Table D1 lists the routines in alphabetical order, the page where the source code can be found, and the approximate size of each module in bytes.

Where DATA statements are used to initialize variables contained in labeled-common blocks, the sequence number (col. 73-80) contains the code "BL." To adhere strictly to the FORTRAN 77 standard, these statements must be put into separate BLOCK DATA modules. Most FORTRAN environments permit our syntax, however.

```
**********************************************************************
WARNING:  THIS LISTING IS PROVIDED FOR INFORMATION PURPOSES ONLY.  THOSE WHO
WANT TO USE THE PROGRAM MUST OBTAIN THE SOURCE CODE ON MAGNETIC TAPE FROM THE
AUTHORS (SEE SECTION 3.1).  COPYING THE CODE LISTED HERE WILL NOT PRODUCE A
USABLE PROGRAM.
**********************************************************************
```

Table D1--Alphabetical list of source-code modules

Module Name	Source Bytes	Page	Module Name	Source Bytes	Page
ALCOSH	384	295	NUMSTG	512	291
ANWNL	4736	321	OPNREP	896	294
ANWWL	5376	326	OVERRD	1024	294
ARCTIC	1792	316	PCROSS	768	257
ATMOSHD	8192	286	PEXP	3712	385
AWWNL	5120	323	PLOT	3200	302
AWWWL	5760	329	PLOTBL	128	317
BACKUP	3968	264	PLTANH	2816	309
CBLOB2	4480	354	PLTANOT	2432	311
CLEAR	256	250	PLTHLB	128	309
CONBLK	7424	273	PLTLB	1792	314
CSTANH	4992	349	PRINTR	14720	278
DASH	128	319	PUTDES	512	291
DDALT	6016	405	PUTKST	2176	293
DDBP	512	317	RAYPLT	8320	297
DDEND	256	319	RAYTRC	8576	229
DDFR	128	319	RCROSS	2688	257
DDINIT	256	317	READW	8960	243
DDSPLA	15488	399	READW1	6656	237
DDTAB	128	318	REFLECT	2944	266
DDTEXT	384	318	RENORM	512	278
DDVC	512	318	RERR	512	292
DFCNST	1536	234	RERROR	256	293
DFSYS	1152	233	RESET	128	319
DRAWTKS	1280	313	RHORIZ	3584	390
FIT	2432	268	RKAM	1408	260
FULANN	1792	397	RKAM1	3072	262
GAMRTDM	3968	347	RTERR	3584	391
GAUSEL	2688	295	RVERT	8832	394
GET	3456	271	SCMPLX	128	320
GET1	2944	269	SET2	128	278
GHORIZ	3328	373	SETXY	384	307
GLORENZ	4480	375	SFILL	512	292
GTANH	5376	378	SFILTR	128	295
GTUNIT	128	240	SMPANN	1536	396
HAMLTN	2944	258	SREAD1	512	242
HEIGHT	128	320	STOPIT	256	293
ITEST	256	271	STRIM	512	292
LABPLT	6400	305	TBLOB2	4480	367
MCONST	3456	371	TIKLINE	640	311
MUARDC	4096	381	TLINEAR	3840	356
MX1ALF	128	320	TRACE	9344	252
MX2ALF	128	320	TTABLE	6016	361
ND2B	384	250	TTANH5	5120	359
NPABSR	3200	384	UCON	2432	250
NPPRES	3072	388	ULOGZ2	4480	337
NPSPEED	3072	352	VVORTX3	4992	340
NPTEMP	3072	369	WCHANGE	512	277
NPTERR	384	381	WGAUSS2	4480	343
NPWIND	3456	345	WLINEAR	4096	333
NTEMP	3328	365	WTIDE	4352	335

RAY-TRACING CORE (Tape File 3)

```
      PROGRAM RAYTRC                                                          RAYTRC 2
      MAIN PROGRAM FOR THE RAY TRACING PACKAGE.                               RAYTRC 3
C     SETS THE INITIAL CONDITIONS FOR EACH RAY AND CALLS TRACE                RAYTRC 4
C                                                                             RAYTRC 5
C                                                                             CRAYDEV2
C     COMMON DECK "RAYDEV" INSERTED HERE                                      CRAYDEV4
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                                    CRAYDEV5
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN                     RAYTRC 7
      LOGICAL WCHANGE,FIRST                                                   RAYTRC 8
      REAL WS(400)                                                            CFILEC 2
C     COMMON DECK "FILEC" INSERTED HERE                                       CFILEC 4
      COMMON /FILEC/NPLTDP                                                    CERR   2
C     COMMON DECK "CERR" INSERTED HERE                                        CERR   3
      COMMON/ERR/NERG,NERR,NERT,NERP                                          CGG    2
C     COMMON DECK "GG" INSERTED HERE                                          CGG    4
      REAL MODG                                                               CGG    5
      COMMON/GG/MODG(4)                                                       CGG    6
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                        CGG    7
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME                  CHDR   2
C     COMMON DECK "HDR" INSERTED HERE                                         CHDR   4
      CHARACTER*10 INITID*80,DAT,TOD                                          CHDR   5
      COMMON/HDR/SEC                                                          CHDR   6
      COMMON/HDRC/INITID,DAT,TOD                                              CCONST 2
C     COMMON DECK "CONST" INSERTED HERE                                       CCONST 4
      COMMON/PCONST/CREF,RGAS,GAMMA                                           CCONST 5
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                               CFLAG  2
C     COMMON DECK "FLAG" INSERTED HERE                                        CFLAG  4
      LOGICAL NEWWR,NEWWP,NEWTRC,PENET                                        CFLAG  5
      COMMON /FLG/ NTYP,NEWWR,NEWWP,NEWTRC,PENET,LINES,IHOP,HPUNCH            CFLAG  6
      COMMON/FLGP/NSET                                                        CRINPLE2
C     COMMON DECK "RINPLEX" INSERTED HERE                                     CRINPLE4
      REAL KAY2,KAY2I                                                         CRINPLE5
      COMPLEX PNP,POLAR,LPOLAR                                                CRINPLE6
      LOGICAL SPACE                                                           CRINPLE7
      CHARACTER DISPM*6                                                       CRINPLE8
      COMMON/RINPL/DISPM                                                      CRINPLE9
      COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                       CRINPL10
      COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I                                   CRINPL11
      COMMON/RIN/PNP(10),POLAR,LPOLAR,SGN                                     CRK    2
C     COMMON DECK "RK" INSERTED HERE                                          CRK    4
C     DEFINE SIZE REQUIRED FOR RAY STATE SAVE ARRAY                           CRK    5
      PARAMETER (LRKAMS=87+2*100,NXRKMS=12+LRKAMS,MXEQPT=21)                  CRK    6
      PARAMETER (NRKSAV=NXRKMS+MXEQPT-1)                                      CRK    7
      COMMON /RK/ NEQS,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART          RKAMCOM2
C     COMMON DECK "RKAM" INSERTED HERE                                        RKAMCOM4
      REAL KR,KTH,KPH                                                         RKAMCOM5
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)             CWWR   2
C     COMMON DECK "WWR" INSERTED HERE                                         CWW1   3
      PARAMETER (NWARSZ=1000)                                                 CWW1   4
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                         CWW2   2
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                      CWW2   3
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),          CWW2   4
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),            CWW2   5
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                CWW2   6
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),               CWW2   7
     8 (RCVRH,W(20)),
```

```
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2    8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2    9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))        CWW2   13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),        CWW2   14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))              CWW2   15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                   CWW2   16
C                                                                       RAYTRC19
      CHARACTER TMP80*80                                                RAYTRC20
C                                                                       RAYTRC21
      DATA FIRST/.TRUE./                                                RAYTRC22
C                                                                       RAYTRC23
C     INITIALIZE FILES , SET CONTANTS AND MAKE SYSTEM CALLS             RAYTRC24
      CALL STDINI                                                       RAYTRC25
C     INITIALIZE LINE COUNTS FOR CURRENT AND LAST HEADER                RAYTRC26
      LINES=0                                                           RAYTRC27
      LHDRPG=0                                                          RAYTRC28
C                                                                       RAYTRC29
      REWIND NRYIND                                                     RAYTRC30
C  INITIALIZE RAYSET FILE                                               RAYTRC31
5     READ(NRYIND,'(A)',END=8) TMP80                                    RAYTRC32
      WRITE(9,'(A)') TMP80                                              RAYTRC33
      GO TO 5                                                           RAYTRC34
C                                                                       RAYTRC35
8     WRITE(9,'(A)') '****SOFT EOF***++++'                              RAYTRC36
      REWIND NRYIND                                                     RAYTRC37
C     READ IN USERS NAME AND TELEPHONE EXTENSION FOR IDENTIFYING        RAYTRC38
C     MICROFILM PLOTS.                                                  RAYTRC39
C                                                                       RAYTRC40
C     REPOSITION DINP AFTER IDENTIFIER                                  RAYTRC41
      READ(NRYIND,'(A)',END=6000) TMP80                                 RAYTRC42
C                                                                       RAYTRC43
C********* READ W ARRAY AND PRINT NON-ZERO VALUES                       RAYTRC44
      IRUN=0                                                            RAYTRC45
      NSET=0                                                            RAYTRC46
C                                                                       RAYTRC47
10    CALL READW                                                        RAYTRC48
      NSET=NSET+1                                                       RAYTRC49
      ICODE=ND2B(INT(RAYFNC))                                           RAYTRC50
C PROCESS RAYPATH CALCULATIONS ONLY IF W(29) IS BEING USED              RAYTRC51
      IF((RAYFNC.NE.0.).AND.(AND(ICODE,4).EQ.0)) GO TO 10               RAYTRC52
C                                                                       RAYTRC53
C********* LET ROUTINES PRINTR AND RAYPLT KNOW THERE IS A NEW W ARRAY   RAYTRC54
      NEWWP=.TRUE.                                                      RAYTRC55
      NEWWR=.TRUE.                                                      RAYTRC56
      IRUN=IRUN+1                                                       RAYTRC57
C                                                                       RAYTRC58
C     SET BINARY RAY FILE UNIT TO ZERO IF NO OUTPUT WANTED              RAYTRC59
      NPLTDP=0                                                          RAYTRC60
      IF(BINRAY.NE.0.0) NPLTDP=NDEVBIN                                  RAYTRC61
C                                                                       RAYTRC62
C******** INITIALIZE THE MODELS VIA 'DISPER'                           RAYTRC63
      CALL IDISPER                                                      RAYTRC64
```

```
C                                                                       RAYTRC65
      IF(FIRST.AND.PLT.NE.0.) CALL DDINIT(8,INITID)                     RAYTRC66
      IF(PLT.NE.0.) FIRST=.FALSE.                                       RAYTRC67
C                                                                       RAYTRC68
C     PREVENT RERUNNING SAME MODEL CASES                                RAYTRC69
      IF(IRUN.EQ.1) GO TO 12                                            RAYTRC70
      IF(.NOT.WCHANGE(WS(1),W(1))) GO TO 10                             RAYTRC71
      PRINT *,'PROCESSING FOR RUNSET #',NSET                            RAYTRC72
C                                                                       RAYTRC73
12    CALL RMOVE(WS,W,400)                                              RAYTRC74
C                                                                       RAYTRC75
C                                                                       RAYTRC76
      OW=0.                                                             RAYTRC77
      BETA=0.                                                           RAYTRC78
      AZ1=0.                                                            RAYTRC79
C                                                                       RAYTRC80
      CALL HEADER1                                                      RAYTRC81
C                                                                       RAYTRC82
C********* PRINT OUT THE CONTENTS OF THE 'W' ARRAY                      RAYTRC83
C********* DETERMINE TRANSMITTER LOCATION IN COMPUTATIONAL COORDINATE   RAYTRC84
C********* SYSTEM (GEOMAGNETIC COORDINATES IF DIPOLE FIELD IS USED)     RAYTRC85
      SP=SIN (PLAT)                                                     RAYTRC86
      CP=SIN (PID2-PLAT)                                                RAYTRC87
      SDPH=SIN (TLON-PLON)                                              RAYTRC88
      CDPH=SIN (PID2-(TLON-PLON))                                       RAYTRC89
      SL=SIN (TLAT)                                                     RAYTRC90
      CL=SIN (PID2-TLAT)                                                RAYTRC91
      ALPHA=ATAN2(-SDPH*CP,-CDPH*CP*SL+SP*CL)                           RAYTRC92
      TH0=ACOS (CDPH*CP*CL+SP*SL)                                       RAYTRC93
      PH0=ATAN2(SDPH*CL,CDPH*SP*CL-CP*SL)                               RAYTRC94
C                                                                       RAYTRC95
      R=EARTHR                                                          RAYTRC96
      TH=TH0                                                            RAYTRC97
      PH=PH0                                                            RAYTRC98
      CALL TOPOG                                                        RAYTRC99
C                                                                       RAYTR100
C     OBTAIN ABSOLUTE HEIGHT OF THE TRANSMITTER.                        RAYTR101
C     IF IT WAS SPECIFIED AS RELATIVE TO THE TERRAIN, THEN REMOVE       RAYTR102
C     THE FLAG VALUE 10**40 WHICH WAS ADDED AT INPUT.                   RAYTR103
C                                                                       RAYTR104
      TMP=XMTRH                                                         RAYTR105
      IF(XMTRH .EQ. 1.E-40) XMTRH=0.0                                   RAYTR106
      IF( ABS(XMTRH) .GE. 1.E20 ) XMTRH=XMTRH*1.E-40                    RAYTR107
      IF(TMP.NE.XMTRH) XMTRH=XMTRH-G/PGR                                RAYTR108
C                                                                       RAYTR109
C     CHECK THAT TRANSMITTER IS ABOVE TERRAIN.                          RAYTR110
C                                                                       RAYTR111
      IF(-G/PGR .LE. XMTRH) GO TO 655                                   RAYTR112
C                                                                       RAYTR113
      PRINT 640, IRUN                                                   RAYTR114
      WRITE(3,640) IRUN                                                 RAYTR115
640   FORMAT('0****** TRANSMITTER BELOW TERRAIN. RUN ',I3               RAYTR116
     1 ,' TERMINATED.'/'SEE W-ARRAY PRINTOUT. INPUT CONTINUES.'//)      RAYTR117
      CALL SETOVR                                                       RAYTR118
      CALL PRINTW                                                       RAYTR119
      GO TO 10
```

```
C                                                                       RAYTR120
655   CALL SETOVR                                                       RAYTR121
      CALL PRINTW                                                       RAYTR122
      CALL IPRINTR                                                      RAYTR123
C******** INITIALIZE PRINT CONTROL PARAMTERS                           RAYTR124
      LINSPP=PAGLN                                                      RAYTR125
      LNPHPG=LINSPP/2                                                   RAYTR126
      IF(LNPHPG.LT.40) LNPHPG=LINSPP                                    RAYTR127
C                                                                       RAYTR128
C********* LOOP ON FREQUENCY, AZIMUTH ANGLE, AND ELEVATION ANGLE        RAYTR129
      NFREQ=1                                                           RAYTR130
      IF (FSTEP.NE.0.) NFREQ=(FEND-FBEG)/FSTEP+1.5                      RAYTR131
      NAZ=1                                                             RAYTR132
      IF (AZSTEP.NE.0.) NAZ=(AZEND-AZBEG)/AZSTEP+1.5                    RAYTR133
      NBETA=1                                                           RAYTR134
      IF (ELSTEP.NE.0.) NBETA=(ELEND-ELBEG)/ELSTEP+1.5                  RAYTR135
      DO 50 NF=1,NFREQ                                                  RAYTR136
      OW=FBEG+(NF-1)*FSTEP                                              RAYTR137
      DO 45 J=1,NAZ                                                     RAYTR138
      AZ1=AZBEG+(J-1)*AZSTEP                                            RAYTR139
      AZA=AZ1*DEGS                                                      RAYTR140
      GAMMA1=PI-AZ1+ALPHA                                               RAYTR141
      SGAMMA=SIN (GAMMA1)                                               RAYTR142
      CGAMMA=SIN (PID2-GAMMA1)                                          RAYTR143
      DO 40 I=1,NBETA                                                   RAYTR144
      BETA=ELBEG+(I-1)*ELSTEP                                           RAYTR145
      EL=BETA*DEGS                                                      RAYTR146
      CBETA=SIN (PID2-BETA)                                             RAYTR147
      R=EARTHR+XMTRH                                                    RAYTR148
      TH=TH0                                                            RAYTR149
      PH=PH0                                                            RAYTR150
      KR=SIN (BETA)                                                     RAYTR151
      KTH=CBETA*CGAMMA                                                  RAYTR152
      KPH=CBETA*SGAMMA                                                  RAYTR153
      TPULSE=0.                                                         RAYTR154
      RSTART=1.                                                         RAYTR155
C********* THE FOLLOWING LINE NEEDED FOR RAY TRACING IN COMPLEX SPACE   RAYTR156
      SGN=1.0                                                           RAYTR157
C********* CALL MODELS                                                 RAYTR158
      CALL DISPER                                                       RAYTR159
C                                                                       RAYTR160
      LINPG=LINES-LHDRPG                                                RAYTR161
      IF(I.EQ.1   .OR.   LINPG.GE.LINSPP-20) THEN                       RAYTR162
C                                                                       RAYTR163
C     PUT OUT SUBHEADERS FROM MEDIA AND PRINTR ROUTINES                 RAYTR164
         CALL HEADER2                                                   RAYTR165
         CALL PRNHD1(' ')                                               RAYTR166
C                                                                       RAYTR167
C     COMPUTE LINE COUNT OF THIS HEADER                                 RAYTR168
         LHDRPG=LINES/LINSPP*LINSPP                                     RAYTR169
      ELSEIF(LINPG.GE.LNPHPG-10 .AND. LINPG.LE.LNPHPG) THEN             RAYTR170
C     PUT OUT PAGE FEED WITH SUBHEADER IF AT HALF PAGE                  RAYTR171
         CALL PRNHD2('1')                                               RAYTR172
      ELSE                                                              RAYTR173
C     PUT OUT SUBHEADER                                                 RAYTR174
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         CALL PRNHD2(' ')                                                    RAYTR175
       ENDIF                                                                 RAYTR176
C                                                                            RAYTR177
       IF (KAY2.GT.0.) GO TO 30                                              RAYTR178
       WRITE(3,2900) OMEGMIN,OMEGMAX                                         RAYTR179
 2900 FORMAT (58H0TRANSMITTER IN EVANESCENT REGION, TRANSMISSION IMPOSSIRAYTR180
     1BLE/20H0MINIMUM FREQUENCY =,E17.10,20H MAXIMUM FREQUENCY =,E17.10)RAYTR181
       GO TO 44                                                              RAYTR182
30     CALL RENORM(KR,KAY2,3)                                                RAYTR183
       CALL CLEAR(RKVARS,NEQS-6)                                             RAYTR184
       CALL TOPOG                                                            RAYTR185
       IF(NERG.GT.0) RKVARS(NERG)=G                                          RAYTR186
       IF(NERR.GT.0) RKVARS(NERR)=PGR                                        RAYTR187
       IF(NERT.GT.0) RKVARS(NERT)=PGTH                                       RAYTR188
       IF(NERP.GT.0) RKVARS(NERP)=PGPH                                       RAYTR189
C                                                                            RAYTR190
C      CALCULATE ONE RAY PATH                                                RAYTR191
       CALL TRACE                                                            RAYTR192
       OSEC=SEC                                                              RAYTR193
       CALL SYSSEC(SEC)                                                      RAYTR194
       DIFF=SEC-OSEC                                                         RAYTR195
C                                                                            RAYTR196
C      ADD TO LINES COUNT FOR ELAPSED TIME REPORT                            RAYTR197
       LINES=LINES+2                                                         RAYTR198
       WRITE(3,3500) DIFF                                                    RAYTR199
3500   FORMAT (/T93,'THIS RAY CALCULATION TOOK ',F8.3,' SEC')                RAYTR200
C                                                                            RAYTR201
       IF (PENET.AND.ONLY.NE.0..AND.IHOP.EQ.1) GO TO 44                      RAYTR202
    40 CONTINUE                                                              RAYTR203
44     IF(PLT.GT.0.AND.(NAZ.LE.1.OR.NBETA.GT.1)) CALL ENDPLT                 RAYTR204
    45 CONTINUE                                                              RAYTR205
       IF(PLT.GT.0.AND.NAZ.GT.1.AND.NBETA.LE.1)CALL ENDPLT                   RAYTR206
       IF(PENET.AND.ONLY.NE.0..AND.IHOP.EQ.1.AND.NAZ.EQ.1.AND.NBETA.EQ.1)RAYTR207
      1 GO TO 55                                                             RAYTR208
    50 CONTINUE                                                              RAYTR209
   55  IF (RAYSET.NE.0.) WRITE(9,5000)                                       RAYTR210
 5000 FORMAT (78X,1H-)                                                       RAYTR211
       GO TO 10                                                              RAYTR212
6000   PRINT *,'DINP EMPTY OR NOT FOUND'                                     RAYTR213
       STOP                                                                  RAYTR214
       END                                                                   RAYTR215
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       SUBROUTINE DFSYS                                                      DFSYS  2
       CHARACTER DAT*(*),DATX*10                                             DFSYS  3
       CHARACTER TIM*(*),TIMX*10                                             DFSYS  4
C                                                                            DFSYS  5
C      ALL ROUTINES WHICH RELY ON SYSTEM BASED FUNCTIONS, SUCH AS TIME       DFSYS  6
C      OF DAY OR MAY BENEFIT FROM SYSTEM AVAILABLE ROUTINES FOR BETTER       DFSYS  7
C      PERFORMANCE, SUCH AS 'RMOVE' HAVE BEEN COLLECTED IN THIS ROUTINE.     DFSYS  8
C                                                                            DFSYS  9
       ENTRY RMOVE(X,Y,N)                                                    DFSYS 10
```

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C     MOVE 'N' COMPONENTS OF ARRAY 'Y' TO ARRAY 'X'.                          DFSYS 11
C     THIS LOGIC WILL HANDLE OVERLAP CASES ONLY FOR X(M)=X(M+N1)              DFSYS 12
C     WITH N1>0, M=1,N.                                                       DFSYS 13
      REAL X(N),Y(N)                                                          DFSYS 14
C                                                                             DFSYS 15
      IF(N.LE.0) RETURN                                                       DFSYS 16
C     USE CYBER BUILT-IN ROUTINE                                              DFSYS 17
C      CALL MOVLEV(Y,X,N)                                                     DFSYS 18
C                                                                             DFSYS 19
C     THE EQUIVALENT FORTRAN CODING FOR THIS ROUTINE ARE THE FOLLOWING        DFSYS 20
C     TWO LINES.                                                              DFSYS 21
      DO 10 I=1,N                                                             DFSYS 22
10    X(I)=Y(I)                                                               DFSYS 23
C                                                                             DFSYS 24
      RETURN                                                                  DFSYS 25
      ENTRY SYSSEC(SECS)                                                      DFSYS 26
C                                                                             DFSYS 27
C     OBTAIN CURENT TIME OF DAY IN SECONDS FROM SYSTEM ROUTINE                DFSYS 28
      SECS=0                                                                  DFSYS 29
C     SYSTEM CALL NEEDED FOR THE CYBER NOS OP SYS                             DFSYS 30
C      CALL SECOND(SECS)                                                      DFSYS 31
C     SYSTEM CALL NEEDED FOR CRAY COMPUTER UNDER CTSS                         DFSYS 32
C      CALL TIMEUSED(ICPU,IO,ISYS,MEM)                                        DFSYS 33
C      SECS=ICPU/1.E6                                                         DFSYS 34
      RETURN                                                                  DFSYS 35
C                                                                             DFSYS 36
      ENTRY SYSTIM(TIM)                                                       DFSYS 37
C                                                                             DFSYS 38
C     OBTAIN CURENT TIME OF DAY AS A CHARACTER STRING FROM SYSTEM ROUTI       DFSYS 39
      TIM='TIME'                                                              DFSYS 40
C     SYSTEM CALL NEEDED FOR THE CYBER NOS OP SYS                             DFSYS 41
C      CALL TIME(TIM)                                                         DFSYS 42
C     SYSTEM CALL NEEDED FOR THE CRAY CTSS OP SYS                             DFSYS 43
C     CALL TIMEDATE(TIM,DATX,MACH)                                            DFSYS 44
      RETURN                                                                  DFSYS 45
C                                                                             DFSYS 46
      ENTRY SYSDAT(DAT)                                                       DFSYS 47
C                                                                             DFSYS 48
C     OBTAIN CURENT DATE AS A CHARACTER STRING FROM SYSTEM ROUTINE            DFSYS 49
      DAT='DATE'                                                              DFSYS 50
C     SYSTEM CALL NEEDED FOR THE CYBER NOS OP SYS                             DFSYS 51
C      CALL DATE(DAT)                                                         DFSYS 52
C     SYSTEM CALL NEEDED FOR THE CRAY CTSS OP SYS                             DFSYS 53
C     CALL TIMEDATE(TIMX,DAT,MACH)                                            DFSYS 54
      RETURN                                                                  DFSYS 55
      ENTRY MORTEM                                                            DFSYS 56
      STOP 'POST MORTEM'                                                      DFSYS 57
      END                                                                     DFSYS 58
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      SUBROUTINE DFCNST                                                       DFCNST 3
C                                                                             DFCNST 6
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C     THIS MODULE PROVIDES CONSTANTS WHICH ARE EXPLICITLY DEPENDENT      DFCNST 7
C     ON MACHINE ARCHITECTURE AND SHOULD BE EXAMINED WHEN MAKING ANY     DFCNST 8
C     MIGRATION OF THE RAY TRACING ROUTINES.                             DFCNST 9
C                                                                        DFCNST10
C     COMMON DECK "RMACH" INSERTED HERE                                  CRMACH 2
      COMMON/CRMACH/RMACH(5)                                             CRMACH 4
C                                                                        DFCNST12
C     SINGLE PRECISION MACHINE CONSTANTS                                 DFCNST13
C      (SEE DIGITAL SIGNAL PROCESSING, IEEE PRESS 1979 P S-7)            DFCNST14
C                                                                        DFCNST15
C     THE CONSTANTS ARE DERIVED FROM THE FOLLOWING                       DFCNST16
C     FORM FOR FLOATING POINT NUMBERS:                                   DFCNST17
C                                                                        DFCNST18
C        SIGN (B**E)*( (X(1)/B) + ... + (X(T)/B**T) )                    DFCNST19
C     FOR MOST MACHINES THE BASE B=2.                                    DFCNST20
C     FOR THE CYBER 60-BIT MACHINES                                      DFCNST21
C        T=48, EMIN=-974 AND EMAX=1070.                                  DFCNST22
C     FOR THE PDP-11 AND VAX-11 MACHINES                                 DFCNST23
C        T=24, EMIN=-127 AND EMAX=127                                    DFCNST24
C                                                                        DFCNST25
C     RMACH(1)  SMALLEST POSITIVE MAGNITUDE = B**(EMIN-1)                DFCNST26
C     RMACH(2)  LARGEST MAGNITUDE           = B**EMAX*(1-B**(-T))        DFCNST27
C     RMACH(3)  SMALLEST RELATIVE SPACING   = B**(-T)                    DFCNST28
C     RMACH(4)  LARGEST RELATIVE SPACING    = B**(1-T)                   DFCNST29
C     RMACH(5)                              = LOG10(B=2)                 DFCNST30
C                                                                        DFCNST31
C     CONSTANTS HERE ARE FOR CDC 6000/7000/CYBER SERIES COMPUTERS        DFCNST32
C     PLEASE SUBSTITUTE FOR OTHER MACHINES                               DFCNST33
C                                                                        DFCNST34
C                                                                        DFCNST35
C      INTEGER SMALL(2)                                                  DFCNST36
C      INTEGER LARGE(2)                                                  DFCNST37
C      INTEGER RIGHT(2)                                                  DFCNST38
C      INTEGER DIVER(2)                                                  DFCNST39
C      INTEGER LOG10(2)                                                  DFCNST40
CC                                                                       DFCNST41
C       EQUIVALENCE (RMACH(1),SMALL(1))                                  DFCNST42
C       EQUIVALENCE (RMACH(2),LARGE(1))                                  DFCNST43
C       EQUIVALENCE (RMACH(3),RIGHT(1))                                  DFCNST44
C       EQUIVALENCE (RMACH(4),DIVER(1))                                  DFCNST45
C       EQUIVALENCE (RMACH(5),LOG10(1))                                  DFCNST46
C                                                                        DFCNST47
C     MACHINE CONSTANTS FOR CYBER 170/180 COMPUTERS                      DFCNST48
C                                                                        DFCNST49
      DATA RMACH(1) / O"0001400000000000000" /                           DFCNST50
      DATA RMACH(2) / O"3776777777777777777" /                           DFCNST51
      DATA RMACH(3) / O"1640400000000000000" /                           DFCNST52
      DATA RMACH(4) / O"1641400000000000000" /                           DFCNST53
      DATA RMACH(5) / O"1716464202324117572O" /                          DFCNST54
C                                                                        DFCNST55
C***REFERENCES  FOX, P.A., HALL, A.D., SCHRYER, N.L, *FRAMEWORK FOR      DFCNST56
C                 A PORTABLE LIBRARY*, ACM TRANSACTIONS ON MATHE-        DFCNST57
C                 MATICAL SOFTWARE, VOL. 4, NO. 2, JUNE 1978,            DFCNST58
C                 PP. 177-188.                                           DFCNST59
C***ROUTINES CALLED  XERROR                                              DFCNST60
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C***END PROLOGUE  R1MACH                                                DFCNST61
C     MACHINE CONSTANTS FOR VAX 11/780                                  DFCNST62
C     (EXPRESSED IN INTEGER AND HEXADECIMAL)                            DFCNST63
C    ***THE HEX FORMAT BELOW MAY NOT BE SUITABLE FOR UNIX SYSYEMS***    DFCNST64
C    *** THE INTEGER FORMAT SHOULD BE OK FOR UNIX SYSTEMS***            DFCNST65
C                                                                       DFCNST66
C     DATA SMALL(1), SMALL(2) /         128,           0 /            DFCNST67
C     DATA LARGE(1), LARGE(2) /      -32769,          -1 /            DFCNST68
C     DATA RIGHT(1), RIGHT(2) /        9344,           0 /            DFCNST69
C     DATA DIVER(1), DIVER(2) /        9472,           0 /            DFCNST70
C     DATA LOG10(1), LOG10(2) /  546979738,  -805796613 /            DFCNST71
C                                                                       DFCNST72
C     DATA SMALL(1), SMALL(2) / Z00000080, Z00000000 /                  DFCNST73
C     DATA LARGE(1), LARGE(2) / ZFFFF7FFF, ZFFFFFFFF /                  DFCNST74
C     DATA RIGHT(1), RIGHT(2) / Z00002480, Z00000000 /                  DFCNST75
C     DATA DIVER(1), DIVER(2) / Z00002500, Z00000000 /                  DFCNST76
C     DATA LOG10(1), LOG10(2) / Z209A3F9A, ZCFF884FB /                  DFCNST77
C                                                                       DFCNST78
C   MACHINE CONSTANTS FOR VAX 11/780 (G-FLOATING)                       DFCNST79
C     (EXPRESSED IN INTEGER AND HEXADECIMAL)                            DFCNST80
C    ***THE HEX FORMAT BELOW MAY NOT BE SUITABLE FOR UNIX SYSYEMS***    DFCNST81
C    *** THE INTEGER FORMAT SHOULD BE OK FOR UNIX SYSTEMS***            DFCNST82
C                                                                       DFCNST83
C     DATA SMALL(1), SMALL(2) /          16,           0 /            DFCNST84
C     DATA LARGE(1), LARGE(2) /      -32769,          -1 /            DFCNST85
C     DATA RIGHT(1), RIGHT(2) /       15552,           0 /            DFCNST86
C     DATA DIVER(1), DIVER(2) /       15568,           0 /            DFCNST87
C     DATA LOG10(1), LOG10(2) /  1142112243, 2046775455 /            DFCNST88
C                                                                       DFCNST89
C     DATA SMALL(1), SMALL(2) / Z00000010, Z00000000 /                  DFCNST90
C     DATA LARGE(1), LARGE(2) / ZFFFF7FFF, ZFFFFFFFF /                  DFCNST91
C     DATA RIGHT(1), RIGHT(2) / Z00003CC0, Z00000000 /                  DFCNST92
C     DATA DIVER(1), DIVER(2) / Z00003CD0, Z00000000 /                  DFCNST93
C     DATA LOG10(1), LOG10(2) / Z44133FF3, Z79FF509F /                  DFCNST94
C     MACHINE CONSTANTS FOR THE CRAY 1                                  DFCNST95
C                                                                       DFCNST96
C     DATA SMALL(1) / 201354000000000000000B /                          DFCNST97
C     DATA SMALL(2) / 000000000000000000000B /                          DFCNST98
C                                                                       DFCNST99
C     DATA LARGE(1) / 577767777777777777777B /                          DFCNS100
C     DATA LARGE(2) / 000007777777777777774B /                          DFCNS101
C                                                                       DFCNS102
C     DATA RIGHT(1) / 376434000000000000000B /                          DFCNS103
C     DATA RIGHT(2) / 000000000000000000000B /                          DFCNS104
C                                                                       DFCNS105
C     DATA DIVER(1) / 376444000000000000000B /                          DFCNS106
C     DATA DIVER(2) / 000000000000000000000B /                          DFCNS107
C                                                                       DFCNS108
C     DATA LOG10(1) / 377774642023241175717B /                          DFCNS109
C     DATA LOG10(2) / 000007571421742254654B /                          DFCNS110
C                                                                       DFCNS111
C                                                                       DFCNS112
      END                                                               DFCNS113
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      SUBROUTINE READW1(AB,NWOK,MSET,MX,NTBL,ITBL,FRMTBL,GP)                READW1 2
C     HANDLES INPUT OF TABULAR DATA REQUIRED BY SOME MODELS.                READW1 3
C     COMMON DECK "RAYDEV" INSERTED HERE                                    CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                                  CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN                   CRAYDEV5
C     COMMON DECK "CUCON" INSERTED HERE                                     CUCON  2
      COMMON/UCONV/CNVV(4,4)                                                CUCON  4
      CHARACTER PCV*3,CNVC*2                                                CUCON  5
      COMMON/UCONC/PCV(4),CNVC(4,4)                                         CUCON  6
C     COMMON DECK "CONST" INSERTED HERE                                     CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                         CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                             CCONST 5
C     COMMON DECK "WWR" INSERTED HERE                                       CWWR   2
      PARAMETER (NWARSZ=1000)                                               CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                       CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                    CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),        CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),          CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),              CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),             CWW2   6
     8 (RCVRH,W(20)),                                                       CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))    CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                          CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                          CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                         CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),           CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))            CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),            CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                  CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                       CWW2  16
      LOGICAL NWOK,AB                                                       READW1 8
C                                                                           READW1 9
      CHARACTER LINE*80,ALPHA*3,FBUF*3                                      READW110
      PARAMETER (NVAR=6,ALPHA='  A',NACDE=-1,NFIELD=13)                     READW111
      INTEGER IPV(NVAR),NTBL(10),ITBL(10),FRMTBL(10)                        READW112
      CHARACTER*8 PU(NVAR)                                                  READW113
      REAL GP(*),V(NVAR),CONV(NVAR)                                         READW114
C                                                                           READW115
C     THE DATA STRUCTURE EXPECTED BY THIS PROGRAM FOR A DATA BLOCK IS       READW116
C     SPECIFIED FOR A GIVEN MODEL BY THE THREE ARRAYS NTBL,ITBL,FRMTBL.     READW117
C     THE TYPE OF DATA EXPECTED FOR A GIVEN FORMAT GROUP IS TAKEN FROM      READW118
C     ARRAY FRMTBL. IT MUST HAVE AN ENTRY FOR A GIVEN TYPE OF FORMAT        READW119
C     WHICH IS EITHER ZERO, IF THAT FORMAT IS NOT ALLOWED OR AN ENTRY       READW120
C     WHOSE VALUE IS EQUAL TO THAT FORMAT TYPE. CURRENTLY ONLY TWO          READW121
C     FORMAT TYPES ARE ALLOWED, 1 FOR ALPHA AND 2 FOR NUMERIC.              READW122
C     TO ALLOW MORE FLEXIBLITY IN THE INPUT FILE THE NUMERIC FORMAT         READW123
C     TYPE IN TURN ALLOWS FOR 3 DIFFERENT DATA FORMATS, SEE BELOW.          READW124
C                                                                           READW125
C     OFFSETS INTO THE GENERAL ARRAY 'GP' FOR EACH FORMAT ARE GIVEN         READW126
C     IN THE ARRAY 'NTBL'. THE SPACING BETWEEN DATA VALUES IN EACH LINE     READW127
C     READ IS GIVEN IN ARRAY 'ITBL'. THIS SCHEME DOES NOT ALLOW FOR X,Y     READW128
C     ,Z CYCLES BUT RATHER SEPARATE ARRAYS OF X VALUES, THEN Y VALUES,      READW129
```

```
C       AND THEN Z VALUES(ETC. UP TO 'NVAR' VARIABLES).                    READW130
C                                                                          READW131
        NWOK=.TRUE.                                                        READW132
C                                                                          READW133
C       INITIALIZE ANY ALPHANUMERIC ARRAYS TO BLANKS                       READW134
        IF(FRMTBL(1).EQ.1) CALL SET2(GP(NTBL(1)),1H ,NTBL(2)-NTBL(1))      READW135
C                                                                          READW136
C       BEGIN MULTI-FORMAT LOOP                                            READW137
5       READ(NRYIND,'(A,A)',END=200) FBUF,LINE                             READW138
        IF(NDEVTMP.GT.0) WRITE(NDEVTMP,'(A,A)') FBUF,LINE                  READW139
        IF(FBUF.EQ.ALPHA) THEN                                             READW140
           NFRM=NACDE                                                      READW141
        ELSE                                                               READW142
           READ(FBUF,10) NFRM                                              READW143
        ENDIF                                                              READW144
10      FORMAT(BZ,I3,A)                                                    READW145
        IF(NFRM .EQ. 0) RETURN                                             READW146
C                                                                          READW147
C       FORMAT #1 IS ASSIGNED TO ALPHANUMERIC INPUT AND LARGER NUMBERS     READW148
C       FOR NUMERIC INPUT.                                                 READW149
C                                                                          READW150
C       CHECK NOW FOR NUMERICAL FORMATS.                                   READW151
C       THESE ARE PROVIDED FOR EASE OF INPUT OF TABULATED DATA             READW152
C       AND ARE PARTLY 'TRANSPARENT' TO THE MODEL INVOLVED. I.E.           READW153
C       THE USER HAS THE OPTION OF SPECIFING THE NUMBER OF DATA COLUMNS.   READW154
C       INPUT FORMAT NUMBER SPECIFIES THE NUMBER OF COLUMNS OF INPUT DATA  READW155
C       I.E. FOR VALUE 1 A SINGLE DATA COLUMN IS EXPECTED, FOR A VALUE     READW156
C       2 TWO DATA COLUMNS ARE EXPECTED, ETC.                              READW157
C                                                                          READW158
C       DETERMINE FORMAT NUMBER                                            READW159
        IF(NFRM.EQ.NACDE) THEN                                             READW160
           IT=1                                                            READW161
C       ALPHANUMERIC FORMATS MUST BE FIRST IN LIST                         READW162
C       SINCE NO OFFSET SPECIFIER IS ALLOWED IN A FULL ALPHA LINE          READW163
           IF(FRMTBL(1).EQ.1) GO TO 100                                    READW164
        ELSE                                                               READW165
           READ(LINE,'(I2)') IT                                            READW166
           IT=MAX0(IT,2)                                                   READW167
           IF(IT.LE.MX) GO TO 100                                          READW168
        ENDIF                                                              READW169
C                                                                          READW170
15      AB=.TRUE.                                                          READW171
        PRINT 20, MSET,NFRM,MX                                             READW172
20      FORMAT(' FOR SET',I5,' FORMAT NUMBER',I5,' EXCEEDS LIMIT OF',I5)   READW173
C        ERROR IN INPUT DATA , STOP HERE                                   READW174
        STOP                                                               READW175
C                                                                          READW176
C       THE 'NTBL' TABLE PROVIDES A LIST OF OFFSETS TO VARIABLE GROUPS IN  READW177
C       MODEL ARRAYS, 'ITBL' GIVES ELEMENT SEPARATION TO ALLOW FOR 2-      READW178
C       DIMENSIONAL ARRAYS AND 'FRMTBL' SPECIFIES THE INPUT FORMAT.        READW179
C                                                                          READW180
100     N1=NTBL(IT)                                                        READW181
        N3=ITBL(IT)                                                        READW182
        N2=NTBL(IT+1)-N3                                                   READW183
C                                                                          READW184
```

```
      IF(NFRM.NE.NACDE) GO TO 110                                          READW185
C                                                                          READW186
      READ(LINE,1010)((GP(I+J-1),I=N1,N2,N3),J=1,N3)                       READW187
1010  FORMAT(10A8)                                                         READW188
      GO TO 5                                                              READW189
C                                                                          READW190
110   IF(NFRM.LT.1 .OR. NFRM.GT.NVAR) GO TO 200                            READW191
C     HANDLE NUMERIC FORMATS                                               READW192
C                                                                          READW193
C     N1 IS STARTING ELEMENT WHICH WILL BE AFTER THE DATA COUNT            READW194
C     VALUE(NEED NELS*N3+1 TOTAL ELEMENTS)                                 READW195
      N1=N1+1                                                              READW196
      N=0                                                                  READW197
C                                                                          READW198
C     # ELEMENTS IS EQUAL TO FORMAT NUMBER                                 READW199
      NELS=NFRM                                                            READW100
C     READ UNITS CONVERSION SPECIFICATION LINE                             READW101
      READ(LINE,1018) (PU(I),I=1,3)                                        READW102
      IF(PU(2).NE.' ') READ(LINE,2024) DELIM                               READW103
      IF(PU(2).EQ.' ') READ(LINE,1020) DELIM,(PU(I),I=1,NELS)              READW104
C                                                                          READW105
C  ALLOW FOR BLANK CONVERSION LINE PRODUCED BY EIGENRAY ROUTINE            READW106
      IF(DELIM.EQ.0) READ(LINE,2024) DELIM                                 READW107
C                                                                          READW108
C     READ NEXT LINE AND EXTRACT UNIT CONVERSION SPECS IF PRESENT          READW109
C     IN FLOATING FORMAT                                                   READW110
      READ(NRYIND,'(A)') LINE                                              READW111
      CALL GTUNIT(LINE,PU,NFIELD,NELS, NCARY)                              READW112
C     CARRY COUNT IS ZERO IF LINE CONTAINED UNITS SPECIFIERS               READW113
      IF(NCARY.EQ.0.AND.NDEVTMP.GT.0) WRITE(NDEVTMP,'(A)') LINE            READW114
C                                                                          READW115
1018  FORMAT(10(A,5X))                                                     READW116
1020  FORMAT(BZ,3X,G10.3,8X,10A)                                           READW117
2024  FORMAT(T43,G10.3)                                                    READW118
1025  FORMAT(BZ,10G13.6)                                                   READW119
C                                                                          READW120
C     LOOK UP CONVERSION CONSTANTS                                         READW121
      DO 2030 I=1,NELS                                                     READW122
2030  CALL UCON(IPV(I),PU(I),CONV(I))                                      READW123
C                                                                          READW124
C     DELIMITOR TESTING REQUIRES THE INNER LOOP BE EXECUTED                READW125
C     AT LEAST ONCE                                                        READW126
      NX=MAX0(1,N3)                                                        READW127
      N2=MAX0(N2,N1)                                                       READW128
C     BEGIN SINGLE DATA FORMAT LOOP                                        READW129
      DO 150 J=0,10000                                                     READW130
         IF(NELS.GT.1) THEN                                                READW131
            IF(NCARY.EQ.0) READ(NRYIND,'(A)') LINE                         READW132
            NCARY=0                                                        READW133
            IF(NDEVTMP.GT.0) WRITE(NDEVTMP,'(A)') LINE                     READW134
            READ(LINE,1025) (V(I),I=1,NELS)                                READW135
         ENDIF                                                             READW136
         K=0                                                               READW137
         DO 145 I=N1+J,N2+J,NX                                             READW138
               K=K+1                                                       READW139
```

```
            IF(NELS.EQ.1) THEN                                              READW140
               IF(NCARY.EQ.0) READ(NRYIND,'(A)',END=10000) LINE             READW141
               NCARY=0                                                      READW142
               IF(NDEVTMP.GT.0) WRITE(NDEVTMP,'(A)') LINE                   READW143
C     FOR SINGLE COLUMN CASE READ NOW                                       READW144
               READ(LINE,1020) V(K)                                         READW145
            ENDIF                                                           READW146
            IF(V(K) .EQ. DELIM) GO TO 160                                   READW147
C                                                                           READW148
C           APPLY ANY SCALING CONVERSIONS                                   READW149
            V(K)=V(K)*CONV(K)                                               READW150
            IF(J.LT.N3) GP(I)=V(K)                                          READW151
145         N=N+1                                                           READW152
150   CONTINUE                                                              READW153
C                                                                           READW154
10000 IF(V(1).NE.DELIM) CALL RERROR('READW1','NO DELIM',FLOAT(MSET))        READW155
C                                                                           READW156
C     SAVE NUMBER OF VALUES AND ELEMENTS(AS FRACTIONAL PART)                READW157
160   IF(N1.GT.1) GP(N1-1)=N+NELS/10.                                       READW158
C                                                                           READW159
C     CONTINUE MULTI-FORMAT LOOP                                            READW160
      GO TO 5                                                               READW161
C                                                                           READW162
200   CALL RERROR('READW1','BAD FORMAT',FLOAT(MSET))                        READW163
C                                                                           READW164
      END                                                                   READW165
```

```
      SUBROUTINE GTUNIT(LINE,PU,NFIELD,NVAR, LN)                            READW166
C     GTUNIT IS USED TO EXTRACT UNIT CONVERSION SPECIFIERS FROM TABULAR      READW167
C     DATA INPUT.                                                           READW168
C     CONVERSION SPECIFICATIONS ARE TAKEN FROM 'LINE' INPUT STRING.         READW169
C     A FLOATING FORMAT FALLING WITHIN SUCCESSIVE FIELDS OF                 READW170
C     LENGTH 'NFIELD' IS PROVIDED FOR.                                      READW171
C     OUTPUT IS TO UNIT SPECIFIER ARRAY 'PU' FOR A MAXIMUM OF 'NVAR'        READW172
C     FIELDS. FOR A SUCCESS/FAIL RETURN VALUE, 'LN' GIVES THE NUMBER        READW173
C     OF NON-BLANK CHARACTERS USEFUL FOR UNIT DECODING, ZERO IMPLIES        READW174
C     NO USEFUL UNIT INFORMATION WAS FOUND.                                 READW175
C                                                                           READW176
      PARAMETER (MAXLN=130)                                                 READW177
      CHARACTER*(*) LINE,PU(NVAR),TMP*(MAXLN),TMP1*(MAXLN)                  READW178
      INTEGER STRIM                                                         READW179
C                                                                           READW180
      LN=STRIM(LINE)                                                        READW181
      IF(LN.LT.1) THEN                                                      READW182
         DO 5 I=1,NVAR                                                      READW183
5           PU(I)=' '                                                       READW184
         RETURN                                                             READW185
      ENDIF                                                                 READW186
C                                                                           READW187
      TMP=' '                                                               READW188
      CALL SFILTR(LINE,TMP,' 0123456789+-.E')                               READW189
```

```
      IF(STRIM(TMP).LT.1) RETURN                                          READW190
C     SIGNIFY WE CONSUMED THIS LINE                                       READW191
      LN=0                                                                READW192
C                                                                         READW193
      TMP1=LINE                                                           READW194
C     PLACE INTER-SPECIFIER DELIMITORS                                    READW195
      DO 10 I=NFIELD,NFIELD*NVAR,NFIELD                                   READW196
         IF(TMP1(I:I).NE.' ') THEN                                        READW197
            IF(TMP1(I+1:I+1).NE.' ') THEN                                 READW198
C     IF NO ROOM FOR A BLANK, ITS AN ERROR                                READW199
               CALL RERROR('GTUNIT','FORMAT ER1',FLOAT(I))                READW200
            ELSE                                                          READW201
               TMP1(I+1:I+1)='#'                                          READW202
            ENDIF                                                         READW203
         ELSE                                                             READW204
            TMP1(I:I)='#'                                                 READW205
         ENDIF                                                            READW206
10    CONTINUE                                                            READW207
C                                                                         READW208
C     NOW SQUEEZE OUT THE BLANKS                                          READW209
      CALL SFILTR(TMP1,TMP,' ')                                           READW210
C     HOPEFULLY SOMETHING LEFT                                            READW211
C                                                                         READW212
      NL=STRIM(TMP)                                                       READW213
      ILIN=1                                                              READW214
      DO 20 I=1,NVAR                                                      READW215
C     CHECK FOR EMPTY CONVERSIONS                                         READW216
         IF(TMP(ILIN:ILIN).EQ.'#') THEN                                   READW217
            ILIN=ILIN+1                                                   READW218
            PU(I)=' '                                                     READW219
            GO TO 20                                                      READW220
         ENDIF                                                            READW221
C     GET NEXT UNIT TYPE                                                  READW222
         PU(I)(1:2)=TMP(ILIN:ILIN+1)                                      READW223
C     GET NEXT PHYSICAL UNIT(BLANKS HAVE BEEN REMOVED)                    READW224
C     SHORT PHRASE IF A BLANK WAS REMOVED                                 READW225
         IF(TMP(ILIN+3:ILIN+3).NE.'#') THEN                               READW226
            IF(TMP(ILIN+4:ILIN+4).NE.'#') THEN                            READW227
C     IF INCORRECT GROUPING OF LETTERS, ITS AN ERROR                      READW228
               CALL RERROR('GTUNIT','FORMAT ER2',FLOAT(ILIN))             READW229
            ELSE                                                          READW230
C     ADD TWO LETTER UNIT                                                 READW231
               PU(I)(3:5)=' '//TMP(ILIN+2:ILIN+3)                         READW232
               ILIN=ILIN+5                                                READW233
            ENDIF                                                         READW234
         ELSE                                                             READW235
C     ADD ONE LETTER UNIT                                                 READW236
            PU(I)(3:5)='  '//TMP(ILIN+2:ILIN+2)                           READW237
            ILIN=ILIN+4                                                   READW238
         ENDIF                                                            READW239
20    CONTINUE                                                            READW240
C                                                                         READW241
C     SHOULD HAVE USED UP ALL THE TEXT BY NOW                             READW242
      IF(ILIN.LE.NL) CALL RERROR('GTUNIT','FORMAT ER3',FLOAT(ILIN))       READW243
      END                                                                 READW244
```

```
      SUBROUTINE SREAD1(AB,NWOK,NW)                                      SREAD1 9
C     THIS IS THE FALLTHROUGH FEATURE FOR READW WHEN ENCOUNTERING        SREAD110
C     A NON STANDARD LABELED COMMON BLOCK. SREAD1 WILL ADD TABULAR       SREAD111
C     DATA TO THE DEFAULT GP ARRAY PGP AND INCLUDE INDEX OFFSET          SREAD112
C     VALUES TO A LOOKUP ARRAY 'LIST'.                                   SREAD113
C     COMMON DECK "CPROCFL" INSERTED HERE                                CPROCFL2
      INTEGER PMX,PNTBL,PITBL,PFRMTBL,IDSP(10)                           CPROCFL4
C     PARAMETER DECK "PGROUPS"                                           PGROUPS2
      PARAMETER (NCHPG1=11,NWPV=250,NSPGP=NCHPG1+2*NWPV+1)               PGROUPS3
      PARAMETER (MNGRP=9,MXGRP=69,MXLIST=MXGRP-MNGRP+2)                  PGROUPS4
      COMMON/PROCFL/LIST(MXLIST)                                         CPROCFL6
      COMMON/PROCFL/PMX,PNTBL(10),PITBL(10),PFRMTBL(10),PGP(NSPGP)       CPROCFL7
      EQUIVALENCE (PGP,IDSP)                                             CPROCFL8
C                                                                        SREAD115
      CHARACTER ITOC*7                                                   SREAD116
C                                                                        SREAD117
      DATA LIST/MXLIST*0/                                                SAD1BL 2
      DATA PMX/2/                                                        SAD1BL 3
      DATA PNTBL/1,NCHPG1,NSPGP,7*0/                                     SAD1BL 4
      DATA PITBL/1,NWPV,8*0/                                             SAD1BL 5
      DATA PFRMTBL/1,2,8*0/                                              SAD1BL 6
C                                                                        SREAD120
      NWA=IABS(NW)-(MNGRP-2)                                             SREAD121
      IF(NWA.LT.2 .OR. NWA.GT.MXLIST) CALL STOPIT                        SREAD122
     1  ( 'SREAD1 NW='//ITOC(NW)//',LIST(1)='//ITOC(LIST(1)) )           SREAD123
C                                                                        SREAD124
      CALL READW1(AB,NWOK,NW,PMX,PNTBL,PITBL,PFRMTBL,PGP)                SREAD125
C                                                                        SREAD126
C     UPDATE THE LIST, LIST(1)=MAXIMUM USED ELEMENT                      SREAD127
      LIST(1)=MAX0(LIST(1),NWA)                                          SREAD128
      LIST(NWA)=PNTBL(1)                                                 SREAD129
C                                                                        SREAD130
C     GET NEXT NUMERICAL INDEX FROM THE POINTER ARRAY                    SREAD131
      NLN=PNTBL(2)                                                       SREAD132
C                                                                        SREAD133
C     NUMBER OF VALUES IS INTEGRAL PART OF FIRST ELEMENT                 SREAD134
      NPTS=PGP(NLN)                                                      SREAD135
C     NUMBER OF ROWS IS KEPT AS FRACTIONAL PART                          SREAD136
      NELS=(PGP(NLN)-NPTS)*10.+.5                                        SREAD137
      N2=NPTS/NELS                                                       SREAD138
      NMX=PITBL(2)                                                       SREAD139
C     MAKE ADJUSTMENTS TO LENGTHS AND OFFSETS                            SREAD140
      PITBL(2)=NMX-N2-(NCHPG1-1)                                         SREAD141
      NUP=NPTS+NCHPG1                                                    SREAD142
      PNTBL(1)=PNTBL(1)+NUP                                              SREAD143
      PNTBL(2)=PNTBL(2)+NUP                                              SREAD144
      NLN=NLN+1                                                          SREAD145
C                                                                        SREAD146
C     LOOP TO MOVE NELS-1 ROWS OF PGP(NMX,NELS) TO PGP(N2,NELS)          SREAD147
C     THUS MAKING PGP A CONTIGUOUS ARRAY                                 SREAD148
```

```
      NTO=NLN+N2                                                          SREAD149
      NFRM=NLN+NMX                                                        SREAD150
      DO 100 I=2,NELS                                                     SREAD151
      IF(NTO.GT.0 .AND. NFRM+N2-1.LE.NSPGP)                               SREAD152
     1         CALL RMOVE(PGP(NTO),PGP(NFRM),N2)                          SREAD153
      NTO=NTO+N2                                                          SREAD154
100   NFRM=NFRM+NMX                                                       SREAD155
      END                                                                 SREAD156
```

```
      FUNCTION READW(XX)                                                  READW  2
C     READS W ARRAY MAKING ANY NECESSARY CONVERSION OF UNITS.             READW  3
C     VARIABLE LENGTH 'TABULAR' DATA IS READ BY SUBROUTINE 'READW1'       READW  4
C     WHICH IS CALLED FOR NEGATIVE W-ARRAY INDICES.                       READW  5
C                                                                         READW  6
C     COMMON DECK "CONST" INSERTED HERE                                   CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                       CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                           CCONST 5
C     COMMON DECK "WWR" INSERTED HERE                                     CWWR   2
      PARAMETER (NWARSZ=1000)                                             CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                     CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                  CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),      CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),        CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),            CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),           CWW2   6
     8 (RCVRH,W(20)),                                                     CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))  CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                        CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                        CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                       CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),         CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))          CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),          CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                     CWW2  16
C     COMMON DECK "B1" INSERTED HERE                                      CB1    2
      INTEGER UMX,UNTBL,UITBL,UFRMTBL,IDSU(10)                            CB1    4
      COMMON/B1/UMX,UNTBL(10),UITBL(10),UFRMTBL(10),UGP(10)               CB1    5
      EQUIVALENCE (UGP,IDSU)                                              CB1    6
C     COMMON DECK "B2" INSERTED HERE                                      CB2    2
      INTEGER DUMX,DUNTBL,DUITBL,DUFRMTB,IDSDU(10)                        CB2    4
      COMMON/B2/DUMX,DUNTBL(10),DUITBL(10),DUFRMTB(10),DUGP(10)           CB2    5
      EQUIVALENCE (DUGP,IDSDU)                                            CB2    6
C     COMMON DECK "B3" INSERTED HERE                                      CB3    2
      INTEGER CMX,CNTBL,CITBL,CFRMTBL,IDSC(10)                            CB3    4
      COMMON/B3/CMX,CNTBL(10),CITBL(10),CFRMTBL(10),CGP(512)              CB3    5
      EQUIVALENCE (CGP,IDSC),(ANC,CGP(11))                                CB3    6
C     COMMON DECK "B4" INSERTED HERE                                      CB4    2
      INTEGER DCMX,DCNTBL,DCITBL,DCFRMTB,IDSDC(10)                        CB4    4
      COMMON/B4/DCMX,DCNTBL(10),DCITBL(10),DCFRMTB(10),DCGP(10)           CB4    5
      EQUIVALENCE (DCGP,IDSDC)                                            CB4    6
```

```
C       COMMON DECK "B5" INSERTED HERE                                    CB5     2
        INTEGER TMX,TNTBL,TITBL,TFRMTBL,IDST(10)                          CB5     4
        COMMON/B5/TMX,TNTBL(10),TITBL(10),TFRMTBL(10),TGP(262)            CB5     5
        EQUIVALENCE (TGP,IDST),(ANT,TGP(11))                              CB5     6
C       COMMON DECK "B6" INSERTED HERE                                    CB6     2
        INTEGER DTMX,DTNTBL,DTITBL,DTFRMTB,IDSDT(10)                      CB6     4
        COMMON/B6/DTMX,DTNTBL(10),DTITBL(10),DTFRMTB(10),DTGP(10)         CB6     5
        EQUIVALENCE (DTGP,IDSDT)                                          CB6     6
C       COMMON DECK "B7" INSERTED HERE                                    CB7     2
        INTEGER MMX,MNTBL,MITBL,MFRMTBL,IDSM(10)                          CB7     4
        REAL MGP                                                          CB7     5
        COMMON/B7/MMX,MNTBL(10),MITBL(10),MFRMTBL(10),MGP(10)             CB7     6
        EQUIVALENCE (MGP,IDSM)                                            CB7     7
C       COMMON DECK "B9" INSERTED HERE                                    CB8     2
        INTEGER GMX,GNTBL,GITBL,GFRMTBL,IDSG(10)                          CB8     4
        COMMON/B9/GMX,GNTBL(10),GITBL(10),GFRMTBL(10),GGP(113)            CB8     5
        EQUIVALENCE (GGP,IDSG),(ANG,GGP(11))                              CB8     6
C                                                                         READW  17
C       COMMON DECK "B10" INSERTED HERE                                   CB9     2
        INTEGER DGMX,DGNTBL,DGITBL,DGFRMTB,IDSDG(10)                      CB9     4
        COMMON/B10/DGMX,DGNTBL(10),DGITBL(10),DGFRMTB(10),DGGP(10)        CB9     5
        EQUIVALENCE (DGGP,IDSDG)                                          CB9     6
C                                                                         READW  19
C       COMMON DECK "B8" INSERTED HERE                                    CB10    2
        INTEGER RMX,RNTBL,RITBL,RFRMTBL,IDSR(10)                          CB10    4
        COMMON/B8/RMX,RNTBL(10),RITBL(10),RFRMTBL(10),RGP(10)             CB10    5
        EQUIVALENCE (RGP,IDSR)                                            CB10    6
C                                                                         READW  21
C       COMMON DECK "CB17" INSERTED HERE                                  CB17    2
        INTEGER VMX,VNTBL,VITBL,VFRMTBL,IDSV(10)                          CB17    4
        COMMON/B17/VMX,VNTBL(10),VITBL(10),VFRMTBL(10),VGP(53)            CB17    5
        EQUIVALENCE (VGP,IDSV),(ANV,VGP(11))                              CB17    6
C       COMMON DECK "CB18" INSERTED HERE                                  CB18    2
        INTEGER DVMX,DVNTBL,DVITBL,DVFRMTB,IDSDV(10)                      CB18    4
        COMMON/B18/DVMX,DVNTBL(10),DVITBL(10),DVFRMTB(10),DVGP(11)        CB18    5
        EQUIVALENCE (DVGP,IDSDV),(ANDV,DVGP(11))                          CB18    6
C       COMMON DECK "CB19" INSERTED HERE                                  CB19    2
        INTEGER PRMX,PRNTBL,PRITBL,PRFRMTB,IDSPR(10)                      CB19    4
        COMMON/B19/PRMX,PRNTBL(10),PRITBL(10),PRFRMTB(10),PRGP(11)        CB19    5
        EQUIVALENCE (PRGP,IDSPR),(ANP,PRGP(11))                           CB19    6
C       COMMON DECK "CB20" INSERTED HERE                                  CB20    2
        INTEGER DPMX,DPNTBL,DPITBL,DPFRMTB,IDSDP(10)                      CB20    4
        COMMON/B20/DPMX,DPNTBL(10),DPITBL(10),DPFRMTB(10),DPGP(11)        CB20    5
        EQUIVALENCE (DPGP,IDSDP),(ANDP,DPGP(11))                          CB20    6
C                                                                         READW  26
        PARAMETER (MXCMTS=83,BIGVAL=1.E30)                                READW  27
        CHARACTER*38 WFRMT,WNOTES(2)                                      READW  28
        CHARACTER*80 LINEX,NUMSTG                                         READW  29
        CHARACTER*100 STMP1,STMP2                                         READW  30
        INTEGER STRIM,WCOMTS(MXCMTS)                                      READW  31
        CHARACTER*1 DEG,KM,NM,FEET,CYCLE,PER,MSKMS                        READW  32
C       COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C       DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
        COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
        LOGICAL NWOK,AB,UCON                                              READW  34
```

```
C                                                                       READW 35
C     COMMON DECK "FLAG" INSERTED HERE                                  CFLAG  2
      LOGICAL NEWWR,NEWWP,NEWTRC,PENET                                  CFLAG  4
      COMMON /FLG/ NTYP,NEWWR,NEWWP,NEWTRC,PENET,LINES,IHOP,HPUNCH      CFLAG  5
      COMMON/FLGP/NSET                                                  CFLAG  6
C                                                                       READW 37
      CHARACTER PC*1                                                    READW 38
C                                                                       READW 39
      INTEGER XMX,XNTBL(10),XITBL(10),XFRMTBL(10)                       READW 40
      REAL XGP(11)                                                      READW 41
C                                                                       READW 42
      DATA XMX/2/                                                       READW 43
      DATA XNTBL/1,11,12,7*0/                                           READW 44
      DATA XITBL/1,9*0/                                                 READW 45
      DATA XFRMTBL/1,2,8*0/                                             READW 46
C                                                                       READW 47
      DATA WCOMTS,WNOTES/MXCMTS*1, ' ',' INPUT OVERRIDDEN'/             READW 48
C                                                                       READW 49
      AB=.FALSE.                                                        READW 50
      READW=0.0                                                         READW 51
C                                                                       READW 52
      IF(NDEVTMP.GT.0) REWIND NDEVTMP                                   READW 53
C                                                                       READW 54
      READ(NRYIND,1000,END=3) ID                                        READW 55
 1000 FORMAT (BZ,10A8)                                                  READW 56
      IF(NDEVTMP.GT.0) WRITE(NDEVTMP,1000) ID                           READW 57
      GO TO 4                                                           READW 58
C                                                                       READW 59
3     READW=1.0                                                         READW 60
      IF(NFRMAT.LT.0) RETURN                                            READW 61
C                                                                       READW 62
      PRINT 1040                                                        READW 63
      WRITE(3,1040)                                                     READW 64
1040  FORMAT(' END OF INPUT DATA')                                      READW 65
      CALL ENDPLT                                                       READW 66
33    IF(PLT.NE.0.0) CALL DDEND                                         READW 67
      STOP                                                              READW 68
C                                                                       READW 69
4     READ(NRYIND,'(A)',END=10001) STMP1                                READW 70
C                                                                       READW 71
      READ(STMP1,1100) NW,WWW,LINEX                                     READW 72
1100  FORMAT (BZ,I3,E14.7,A)                                            READW 73
      IF(NDEVTMP.GT.0.AND.(NFRMAT.NE.-2.OR.NW.LT.0))                    READW 74
     1      WRITE(NDEVTMP,'(A)') STMP1                                  READW 75
10001 IF (NW.EQ.0) GO TO 10                                             READW 76
      IF(NW.GT.MAXW) GO TO 3400                                         READW 77
C                                                                       READW 78
      IF (NW.LE.MAXW .AND. NW.GT.0) GO TO 5                             READW 79
C     TABULAR INPUT DATA                                                READW 80
      NWOK=.FALSE.                                                      READW 81
C 'OPEN' THE TEMP FILE                                                  READW 82
1150  FORMAT(I3,T18,A)                                                  READW 83
      NWP=-NW                                                           READW 84
      IF(NFRMAT.EQ.-2) THEN                                             READW 85
C     USE DUMMY ARRAYS TO ABSORB TABULAR DATA                           READW 86
```

```
   CALL READW1(AB,NWOK,NW,XMX,XNTBL,XITBL,XFRMTBL,XGP)                READW 87
ELSEIF(NWP.EQ.1) THEN                                                 READW 88
   CALL READW1(AB,NWOK,NW,UMX,UNTBL,UITBL,UFRMTBL,UGP)                READW 89
ELSEIF(NWP.EQ.2) THEN                                                 READW 90
   CALL READW1(AB,NWOK,NW,DUMX,DUNTBL,DUITBL,DUFRMTB,DUGP)            READW 91
ELSEIF(NWP.EQ.3) THEN                                                 READW 92
   CALL READW1(AB,NWOK,NW,CMX,CNTBL,CITBL,CFRMTBL,CGP)                READW 93
ELSEIF(NWP.EQ.4) THEN                                                 READW 94
   CALL READW1(AB,NWOK,NW,DCMX,DCNTBL,DCITBL,DCFRMTB,DCGP)            READW 95
ELSEIF(NWP.EQ.5) THEN                                                 READW 96
      CALL READW1(AB,NWOK,NW,TMX,TNTBL,TITBL,TFRMTBL,TGP)             READW 97
ELSEIF(NWP.EQ.6) THEN                                                 READW 98
   CALL READW1(AB,NWOK,NW,DTMX,DTNTBL,DTITBL,DTFRMTB,DTGP)            READW 99
ELSEIF(NWP.EQ.7) THEN                                                 READW100
   CALL READW1(AB,NWOK,NW,MMX,MNTBL,MITBL,MFRMTBL,MGP)                READW101
ELSEIF(NWP.EQ.8) THEN                                                 READW102
   CALL READW1(AB,NWOK,NW,RMX,RNTBL,RITBL,RFRMTBL,RGP)                READW103
ELSEIF(NWP.EQ.9) THEN                                                 READW104
   CALL READW1(AB,NWOK,NW,GMX,GNTBL,GITBL,GFRMTBL,GGP)                READW105
ELSEIF(NWP.EQ.10) THEN                                                READW106
   CALL READW1(AB,NWOK,NW,DGMX,DGNTBL,DGITBL,DGFRMTB,DGGP)            READW107
ELSEIF(NWP.EQ.17) THEN                                                READW108
   CALL READW1(AB,NWOK,NW,VMX,VNTBL,VITBL,VFRMTBL,VGP)                READW109
ELSEIF(NWP.EQ.18) THEN                                                READW110
   CALL READW1(AB,NWOK,NW,DVMX,DVNTBL,DVITBL,DVFRMTB,DVGP)            READW111
ELSEIF(NWP.EQ.19) THEN                                                READW112
   CALL READW1(AB,NWOK,NW,PRMX,PRNTBL,PRITBL,PRFRMTB,PRGP)            READW113
ELSEIF(NWP.EQ.20) THEN                                                READW114
   CALL READW1(AB,NWOK,NW,DPMX,DPNTBL,DPITBL,DPFRMTB,DPGP)            READW115
ELSE                                                                  READW116
   CALL SREAD1(AB,NWOK,NW)                                            READW117
ENDIF                                                                 READW118
IF(NWOK) GO TO 4                                                      READW119
C                                                                     READW120
3400  WRITE(3,4000) NW,MAXW                                           READW121
4000  FORMAT(15H1THE SUBSCRIPT ,I3,  ' ON THE W-ARRAY INPUT IS OUT OF BOREADW122
     1UNDS.  ALLOWABLE VALUES ARE -8 THROUGH,',I4,'.' )               READW123
      CALL EXIT                                                       READW124
C                                                                     READW125
5     READ(LINEX,70) DEG,KM,NM,FEET,CYCLE,PER,MSKMS                   READW126
70    FORMAT(7A)                                                      READW127
      W(NW)=WWW                                                       READW128
C                                                                     READW129
C     CHECK FOR A 'TERRAIN RELATIVE' HEIGHT SPECIFICATION.            READW130
C     IF SO ADD FLAG VALUE 10**40 TO BE TESTED FOR LATER IN 'RAYTRC'  READW131
C                                                                     READW132
      IF(MSKMS.EQ.'T' .AND. WWW.EQ.0.0) W(NW)=1.E-40                  READW133
      IF(WWW.EQ.0.0) GO TO 4                                          READW134
      IF(MSKMS.EQ.'T') WWW=WWW*1.E40                                  READW135
C                                                                     READW136
C     CHECK FOR KEYWORD UNITS SPECIFICATION, IF SO PERFORM CONVERSION READW137
C                                                                     READW138
      IF(.NOT.UCON(KU,LINEX(:10),CONV)) GO TO 60                      READW139
75    W(NW)=WWW*CONV                                                  READW140
      GO TO 4                                                         READW141
```

```
C                                                                       READW142
60    IF (DEG.EQ.'1') WWW=WWW*RAD                                       READW143
      IF (KM.EQ.'1') WWW=WWW/EARTHR                                     READW144
      IF (NM.EQ.'1') WWW=WWW*1.852                                      READW145
      IF (FEET.EQ.'1') WWW=WWW*3.048006096E-4                           READW146
      IF(CYCLE.EQ.'1') WWW=WWW*PIT2                                     READW147
      IF(PER.EQ.'1') WWW=PIT2/WWW                                       READW148
      IF(MSKMS.EQ.'1') WWW=WWW*1.E-3                                    READW149
      W(NW)=WWW                                                         READW150
      GO TO 4                                                           READW151
C                                                                       READW152
10    IF(.NOT.AB) RETURN                                                READW153
      PRINT 1200                                                        READW154
1200  FORMAT(' A DATA FORMATTING ERROR PREVENTS CONTINUED EXECUTION')    READW155
      CALL EXIT                                                         READW156
C                                                                       READW157
      ENTRY SETW(XX)                                                    READW158
C     THIS ENTRY IS CALLED ONCE BEFORE THE FIRST RUN SET IS READ        READW159
C                                                                       READW160
C INITIALIZE SOME MATHEMATICAL CONSTANTS                                READW161
      PI=4.0*ATAN(1.0)                                                  READW162
      PIT2=2.*PI                                                        READW163
      PID2=PI/2.                                                        READW164
      DEGS=180./PI                                                      READW165
      RAD=PI/180.                                                       READW166
      ALN10=ALOG(10.)                                                   READW167
CC********* INITIALIZE SOME VARIABLES IN THE W ARRAY                    READW168
      MAXW=NWARSZ                                                       READW169
      CALL CLEAR(W,MAXW)                                                READW170
      PLON=0.                                                           READW171
      PLAT=PID2                                                         READW172
      EARTHR=6370.                                                      READW173
      INTYP=3.                                                          READW174
      MAXERR=1.E-4                                                      READW175
      ERATIO=50.                                                        READW176
      STEP1=1.                                                          READW177
      STPMAX=100.                                                       READW178
      STPMIN=1.E-8                                                      READW179
      FACTR=0.5                                                         READW180
      HITLET=.15                                                        READW181
      MAXSTP=1000.0                                                     READW182
      HOP=1.                                                            READW183
      HMAX=500.0                                                        READW184
      EXTINC=999.999                                                    READW185
      PAGLN=66.0                                                        READW186
C                                                                       READW187
      CALL SETUCON                                                      READW188
C                                                                       READW189
      RETURN                                                            READW190
C                                                                       READW191
      ENTRY SETOVR(XX)                                                  READW192
C     THIS ENTRY IS CALLED AFTER EACH RUN SET IS READ                   READW193
C                                                                       READW194
C     PERFORM OVERRIDE ASSIGNMENTS TO W-ELEMENTS                        READW195
      CALL OVERRD(MAXSTP,0.0,1000.0,WCOMTS(23),2,1)                     READW196
```

```
      CALL OVERRD(ERATIO,0.0,50.0,WCOMTS(43),2,1)                       READW197
      CALL OVERRD(FACTR,0.0,0.5,WCOMTS(47),2,1)                         READW198
      CALL OVERRD(SKIP,0.0,BIGVAL,WCOMTS(71),2,1)                       READW199
      CALL OVERRD(HITLET,0.0,.15,WCOMTS(75),2,1)                        READW200
      IF(PAGLN.LT.30.0) PAGLN=0.0                                       READW201
      CALL OVERRD(PAGLN,0.0,66.0,WCOMTS(77),2,1)                        READW202
      CALL OVERRD(PFACTR,0.0,1.0,WCOMTS(82),2,1)                        READW203
      RETURN                                                            READW204
C                                                                       READW205
      ENTRY PRINTW(XX)                                                  READW206
C     THIS ENTRY IS CALLED AFTER EACH RUN SET IS READ                   READW207
C     TO PRINT VALUES OF THE W-ARRAY IN A FORMAT WHICH SHOWS            READW208
C     FULL ACCURACY AND THE EFFECTS OF ANY CONVERSIONS OR OVERRIDES.    READW209
C                                                                       READW210
C     GO TO NEXT PAGE, PUT OUT COPY OF INPUT DATA FOR THIS RUN SET      READW211
C     ASSUMING WE HAD A TEMPORARY FILE TO USE                           READW212
C                                                                       READW213
      IF(NDEVTMP.LE.0) GO TO 1065                                       READW214
      CALL NEWPAG(NPAG,INT(PAGLN),PC)                                   READW215
      LNSXPG=LINES+INT(PAGLN)                                           READW216
      CALL PUTHDR(3,PC,NPAG)                                            READW217
      CALL PUTDVR(3)                                                    READW218
      CALL PUTKBK(3,1)                                                  READW219
      CALL PUTKCT(3,'INPUT DATA FILE FOR RUN SET NUMBER'                READW220
     1  //NUMSTG(NSET,1,'(I5)'))                                        READW221
      CALL PUTKBK(3,1)                                                  READW222
      CALL PUTDVR(3)                                                    READW223
      CALL PUTKBK(3,1)                                                  READW224
      REWIND NDEVTMP                                                    READW225
C                                                                       READW226
1060  READ(NDEVTMP,'(A)',END=1065) LINEX                                READW227
      IF(LINES.GE.LNSXPG) THEN                                          READW228
         CALL NEWPAG(NPAG,INT(PAGLN),PC)                                READW229
         LNSXPG=LINES+INT(PAGLN)                                        READW230
         CALL PUTHDR(3,PC,NPAG)                                         READW231
         CALL PUTKBK(3,1)                                               READW232
      ENDIF                                                             READW233
      CALL PUTKST(3,' '//LINEX)                                         READW234
      GO TO 1060                                                        READW235
1065  CONTINUE                                                          READW236
C                                                                       READW237
C     GO TO NEXT PAGE, PUT OUT W-ELEMENTS SHOWING FULL PRECISION        READW238
C     USE A TWO COLUMN FORMAT                                           READW239
C                                                                       READW240
      CALL NEWPAG(NPAG,INT(PAGLN),PC)                                   READW241
      CALL PUTHDR(3,PC,NPAG)                                            READW242
      CALL PUTDVR(3)                                                    READW243
      CALL PUTKBK(3,1)                                                  READW244
      CALL PUTKCT(3,'INITIAL VALUES FOR THE W ARRAY')                   READW245
      CALL PUTKCT(3,'ONLY NONZERO VALUES PRINTED'                       READW246
     1  //' -- ALL ANGLES IN RADIANS')                                 READW247
      CALL PUTKBK(3,1)                                                  READW248
      CALL PUTDVR(3)                                                    READW249
      LINSPP=INT(PAGLN)-7                                               READW250
C                                                                       READW251
```

```
      WFRMT='(BZ,I3,E14.7,A)'                                          READW252
      IF(NFRMAT.EQ.0) WFRMT='(I4,E24.15,A)'                            READW253
C                                                                      READW254
      NWE=0                                                            READW255
C     ALLOW MAXIMUM OF 10 PAGES OF OUTPUT(1 IS ENOUGH)                 READW256
      DO 18 NPGS=1,10                                                  READW257
C     ALLOW 3 LINES FOR INSIDE HEADER(SEE BELOW)                       READW258
         LINSPP=LINSPP-3                                               READW259
C     NEXT ELEMENT TO SCAN IS ONE MORE THAN LAST ONE                   READW260
         LWE=NWE+1                                                     READW261
C                                                                      READW262
C     INITIALIZE SECOND COLUMN START INDEX                             READW263
         NXCL=0                                                        READW264
C     INITIALIZE TOTAL ELEMENT COUNTER                                 READW265
         NELS=0                                                        READW266
C     LOOP TO FIND BREAK POINTS FOR FIRST/SECOND COLUMNS               READW267
         DO 14 I=LWE,MAXW                                              READW268
            IF(W(I).EQ.0.0) GO TO 14                                   READW269
            NWE=I                                                      READW270
            NELS=NELS+1                                                READW271
            IF(NELS.EQ.LINSPP) NXCL=I                                  READW272
            IF(NELS.EQ.2*LINSPP) GO TO 15                              READW273
14       CONTINUE                                                      READW274
15    IF(NELS.EQ.0) GO TO 22                                           READW275
C                                                                      READW276
         IF(NPGS.GT.1) THEN                                            READW277
            CALL NEWPAG(NPAG,INT(PAGLN),PC)                            READW278
            CALL PUTHDR(3,PC,NPAG)                                     READW279
            LINSPP=INT(PAGLN)-1                                        READW280
         ENDIF                                                         READW281
C                                                                      READW282
C     INSERT 'INNER' HEADER                                            READW283
         CALL PUTKBK(3,2)                                              READW284
         STMP1=' N                  W(N)'                              READW285
         CALL PUTKST(3,STMP1(:65)//' '//STMP1)                         READW286
C                                                                      READW287
       NX=NXCL-1                                                       READW288
       IF(NX.LT.LWE) NX=NWE                                            READW289
       DO 17 NW=LWE,NX                                                 READW290
       NCOMT=MIN0(NW,MXCMTS)                                           READW291
       IF(W(NW).NE.0) THEN                                             READW292
         WRITE(STMP1,WFRMT) NW,W(NW),WNOTES(WCOMTS(NCOMT))             READW293
         STMP2=' '                                                     READW294
         IF(NXCL.EQ.0) GO TO 23                                        READW295
         DO 19 I=NXCL,MAXW                                             READW296
         IF(W(I).NE.0) THEN                                            READW297
           NCOMT=MIN0(I,MXCMTS)                                        READW298
           WRITE(STMP2,WFRMT) I,W(I),WNOTES(WCOMTS(NCOMT))             READW299
           NXCL=I+1                                                    READW300
           GO TO 23                                                    READW301
         ENDIF                                                         READW302
19       CONTINUE                                                      READW303
23       CALL PUTKST(3,STMP1(:65)//' '//STMP2)                         READW304
       ENDIF                                                           READW305
17     CONTINUE                                                        READW306
```

```
      IF(NELS.EQ.0) GO TO 22                                          READW307
18    CONTINUE                                                        READW308
C                                                                     READW309
22    CONTINUE                                                        READW310
      END                                                             READW311
```

```
      SUBROUTINE CLEAR(A,N)                                           CLEAR  2
C     SET N ELEMENTS OF ARRAY A TO ZERO                               CLEAR  3
      REAL A(N)                                                       CLEAR  4
      IF(N.LE.0) RETURN                                               CLEAR  5
      DO    10 I=1,N                                                  CLEAR  6
10    A(I)=0.0                                                        CLEAR  7
      RETURN                                                          CLEAR  8
      END                                                             CLEAR  9
```

```
      FUNCTION ND2B(INDEC)                                            ND2B   2
C                                                                     ND2B   3
C     CONVERT A NUMERIC DECIMAL DIGIT STRING TO A BIT STRING          ND2B   4
C     WITH EACH BIT SET BY A CORRESPONDING DECIMAL DIGIT.             ND2B   5
C                                                                     ND2B   6
      ND2B=0                                                          ND2B   7
      IF(INDEC.LE.0) RETURN                                           ND2B   8
      M=INDEC                                                         ND2B   9
      MB=1                                                            ND2B  10
C                                                                     ND2B  11
10    IF(MOD(M,10).NE.0) ND2B=ND2B+MB                                 ND2B  12
      MB=MB*2                                                         ND2B  13
      M=M/10                                                          ND2B  14
      IF(M.GT.0) GO TO 10                                             ND2B  15
      END                                                             ND2B  16
```

```
      LOGICAL FUNCTION UCON(JC1,U,CONV)                               UCON   2
      LOGICAL SETUCON                                                 UCON   3
C     PROVIDES KEYWORD UNITS CONVERSION FOR W-ARRAY INPUT.            UCON   4
C     UNITS SPECIFICATION MUST BE IN THE FORM 'DV UN' WHERE DV IS THE UCON   5
C     TYPE OF VARIABLE(SUCH AS AN FOR ANGLE) AND UN IS THE UNITS CHOICE UCON 6
C     SUCH AS RD FOR RADIANS). RETURN VALUE IS THE CONVERSION FACTOR. UCON   7
C     COMMON DECK "CUCON" INSERTED HERE                               CUCON  2
      COMMON/UCONV/CNVV(4,4)                                          CUCON  4
      CHARACTER PCV*3,CNVC*2                                          CUCON  5
      COMMON/UCONC/PCV(4),CNVC(4,4)                                   CUCON  6
C     COMMON DECK "CONST" INSERTED HERE                               CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                   CCONST 4
```

```
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                          CCONST 5
C     COMMON DECK "WWR" INSERTED HERE                                    CWWR   2
      PARAMETER (NWARSZ=1000)                                            CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                    CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                 CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),     CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),       CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),           CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),          CWW2   6
     8 (RCVRH,W(20)),                                                    CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                       CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                       CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                      CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),        CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))         CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),         CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))               CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                    CWW2  16
      CHARACTER U*(*),PU*3,PV*2                                          UCON  11
C                                                                        UCON  12
      DATA NPV,NPU/3,4/                                                  UCON  13
      UCON=.FALSE.                                                       UCON  14
      CONV=1.0                                                           UCON  15
C                                                                        UCON  16
      READ(U,100) PU,PV                                                  UCON  17
100   FORMAT(A,A)                                                        UCON  18
C                                                                        UCON  19
      DO 2010 J=1,NPV                                                    UCON  20
2010     IF(PU.EQ.PCV(J)) GO TO 2015                                     UCON  21
      JC1=4                                                              UCON  22
      RETURN                                                             UCON  23
2015  JC1=J                                                              UCON  24
      DO 2020 K=1,NPU                                                    UCON  25
2020     IF(PV.EQ.CNVC(J,K)) GO TO 2025                                  UCON  26
      JC1=4                                                              UCON  27
      RETURN                                                             UCON  28
2025  UCON=.TRUE.                                                        UCON  29
      CONV=CNVV(JC1,K)                                                   UCON  30
      RETURN                                                             UCON  31
C                                                                        UCON  32
C     INITIAL CONVERSION CONSTANTS                                       UCON  33
      ENTRY SETUCON(JC1,U,CONV)                                          UCON  34
      SETUCON=.TRUE.                                                     UCON  35
C                                                                        UCON  36
      CNVV(1,2) = RAD                                                    UCON  37
      CNVV(1,3) = 1.0/EARTHR                                             UCON  38
      CNVV(2,2) = 1.0E-3                                                 UCON  39
      CNVV(2,3) = 3.048006096E-4                                         UCON  40
      CNVV(2,4) = 1.852                                                  UCON  41
      CNVV(3,2) = PIT2                                                   UCON  42
      CNVV(3,3) = PIT2*1.0E3                                             UCON  43
      CNVV(3,4) = PIT2*RAD                                               UCON  44
      END                                                                UCON  45
```

```
      SUBROUTINE TRACE                                                  TRACE  3
C                                                  VERSION 3/4/86       TRACE  4
C     CALCULATES ONE RAYPATH FOR THE REQUESTED NUMBER OF HOPS           TRACE  5
C     (CROSSINGS OR CLOSEST APPROACH TO RECEIVER SURFACE; A CLOSEST     TRACE  6
C     APPROACH COUNTS AS TWO HOPS).                                     TRACE  7
C     THIS VERSION IS LIMITED TO USE WITH ATMOSPHERIC MODELS            TRACE  8
      REAL NORYST                                                       TRACE  9
      PARAMETER (NORYST=0.0,MXPRGS=200)                                 TRACE 10
C                                                                       TRACE 11
      COMMON /RK/ N,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART       TRACE 12
C     COMMON DECK "FLAG" INSERTED HERE                                  TRACE 13
      LOGICAL NEWWR,NEWWP,NEWTRC,PENET                                  TRACE 14
      COMMON /FLG/ NTYP,NEWWR,NEWWP,NEWTRC,PENET,LINES,IHOP,HPUNCH      TRACE 15
C     COMMON DECK "TRAC" INSERTED HERE                                  CTRAC  2
      LOGICAL GROUND,SURF,PERIGE,THERE,MINDIS,NEWRAY                    CTRAC  4
      COMMON /TRAC/ GROUND,SURF,PERIGE,THERE,MINDIS,NEWRAY,SMT,OSMT     CTRAC  5
      COMMON/TRAC/ROLD(20),DROLD(20),TOLD,ZDOT,D2Z,RAD,RAD1             CTRAC  6
C     COMMON DECK "RR" INSERTED HERE                                    TRACE 17
      REAL MODREC                                                       TRACE 18
      COMMON/RR/ MODREC(4)                                              TRACE 19
      COMMON/RR/F,PFR,PFRR,PFRTH,PFRPH                                  TRACE 20
      COMMON/RR/PFTH,PFPH,PFTHTH,PFPHPH,PFTHPH,FSELECT,FTIME            TRACE 21
C     COMMON DECK "GG" INSERTED HERE                                    TRACE 22
      REAL MODG                                                         TRACE 23
      COMMON/GG/MODG(4)                                                 TRACE 24
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                  TRACE 25
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME            TRACE 26
C     COMMON DECK "RKTIME" INSERTED HERE                                TRACE 27
      COMMON/CRKTIME/RKTIME                                             TRACE 28
C     COMMON DECK "RINPLEX" INSERTED HERE                               TRACE 29
      REAL KAY2,KAY2I                                                   TRACE 30
      COMPLEX PNP,POLAR,LPOLAR                                          TRACE 31
      LOGICAL SPACE                                                     TRACE 32
      COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                 TRACE 33
      COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I                             TRACE 34
      COMMON/RIN/PNP(10),POLAR,LPOLAR,SGN                               TRACE 35
      COMMON R(20),T,STP,DRDT(20)                                       TRACE 36
C     COMMON DECK "WWR" INSERTED HERE                                   TRACE 37
      PARAMETER (NWARSZ=1000)                                           TRACE 38
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   TRACE 39
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                TRACE 40
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    TRACE 41
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      TRACE 42
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          TRACE 43
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         TRACE 44
     8 (RCVRH,W(20)),                                                   TRACE 45
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))TRACE 46
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      TRACE 47
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      TRACE 48
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     TRACE 49
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       TRACE 50
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     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))          TRACE 51
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),          TRACE 52
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                TRACE 53
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                     TRACE 54
C    THE FOLLOWING IS A LOCAL COMMON ONLY                                 TRACE 55
C     COMMON DECK "TRLOCAL" INSERTED HERE                                 TRACE 56
      COMMON/TRLOCAL/RSIGN,HOME,FDOT,GDOT,GOLD,GDOLD                      TRACE 57
      LOGICAL PCROSS,HOME,WASNT                                           TRACE 58
      LOGICAL LAUNCH,APOGEE,PLTENB,EXTON                                  TRACE 59
      EQUIVALENCE (R(2),TH),(R(3),PHI)                                    TRACE 60
C                                                                         TRACE 61
      CHARACTER*10 XCOND,DEFCND                                           TRACE 62
      PARAMETER (DEFCND=' MAX HOPS')                                      TRACE 63
C                                                                         TRACE 64
      REAL PRGHST(3,MXPRGS)                                               TRACE 65
      EQUIVALENCE(RKTIME,IRKTIME), (APOG,PRIGEE,W(80))                    TRACE 66
      DATA GROUND/.FALSE./                                                TRACE 67
C                                                                         TRACE 68
C     INCREMENT EVENT COUNT                                               TRACE 69
      IRKTIME=IRKTIME+1                                                   TRACE 70
      PLTENB=APOG.EQ.0.0                                                  TRACE 71
C     ENABLE EXTINCTION TEST IF LIMIT IS SET AND VARIABLE IS BEING INTE   TRACE 72
      EXTON=(EXTINC.GT.0.0) .AND. (W(58).NE.0.0)                          TRACE 73
C     POINT INDEX TO ABSORTION VARIABLE                                   TRACE 74
      NR=7                                                                TRACE 75
      IF(W(57).NE.0.0) NR=8                                               TRACE 76
      RMAX=HMAX+EARTHR                                                    TRACE 77
      RMIN=HMIN+EARTHR                                                    TRACE 78
      NHOP=HOP                                                            TRACE 79
      MAX=MAXSTP                                                          TRACE 80
      NSKIP=SKIP                                                          TRACE 81
C********* INITIALIZE PARAMETERS FOR INTEGRATION SUBROUTINE RKAM          TRACE 82
      MODE=INTYP                                                          TRACE 83
      STEP=STEP1                                                          TRACE 84
      E1MAX=MAXERR                                                        TRACE 85
      E1MIN=MAXERR/ERATIO                                                 TRACE 86
      E2MAX=STPMAX                                                        TRACE 87
      E2MIN=STPMIN                                                        TRACE 88
      FACT=FACTR                                                          TRACE 89
      RSTART=1.                                                           TRACE 90
      CALL HAMLTN                                                         TRACE 91
      FDOT=DOT(F)                                                         TRACE 92
C                                                                         TRACE 93
C     CHECK FOR EQUALITY WITH RECEIVER HEIGHT WITHIN MACHINE PRECISION    TRACE 94
      THERE=F.EQ.0.0                                                      TRACE 95
C                                                                         TRACE 96
      HOME=FDOT*F.GE.0.                                                   TRACE 97
C********* IHOP=0 TELLS PRINTR TO PRINT HEADING AND PUNCH A TRANSMITTER   TRACE 98
C********* RAYSET AND NEWTRC=TRUE TELLS RAYPLT TO START A NEW RAY         TRACE 99
      NEWTRC=.TRUE.                                                       TRACE100
      IHOP=0                                                              TRACE101
C********* RESET PERIGEE PLOT COUNTER                                     TRACE102
      NPRGS=0                                                             TRACE103
C     USE CURRENT RELATIVE POSITION OF RAY TO PREDICT                     TRACE104
C     SIGN OF NEXT INTERSECTION OF RAY WITH RECEIVER HEIGHT               TRACE105
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C       (WILL SOON BE REVERSED).                                                TRACE106
        RSIGN=SIGN(1.0,F)                                                       TRACE107
C       IF RAY IS LAUNCHED FROM RECEIVER HEIGHT, USE DIRECTION INSTEAD          TRACE108
        IF(THERE) RSIGN=SIGN(1.0,FDOT)                                          TRACE109
        GDOT=DOT(G)                                                             TRACE110
C       TEST CASE FOR RECEIVER ON THE GROUND                                    TRACE111
        IF(F.EQ.G) RSIGN=1.0                                                    TRACE112
C       IF RECEIVER IS ON TERRAIN THEN DIRECTION OF FIRST                       TRACE113
C       RECEIVER CROSSING IS DOWNWARD                                           TRACE114
        CALL PRINTR('TXMTR',RAYSET)                                             TRACE115
        IF (PLTENB) CALL RAYPLT                                                 TRACE116
        NEWRAY=.TRUE.                                                           TRACE117
        STH0=SIN(TH)                                                            TRACE118
        CTH0=COS(TH)                                                            TRACE119
        PHI0=PHI                                                                TRACE120
C                                                                               TRACE121
C       SET DEFAULT RAY EVENTS FOR 'PRINTR'                                     TRACE122
        XCOND=DEFCND                                                            TRACE123
        XSET=NORYST                                                             TRACE124
C                                                                               TRACE125
C********* LOOP ON NUMBER OF HOPS                                              TRACE126
10      IHOP=IHOP+1                                                             TRACE127
C        REVERSE SIGN AT EACH CROSSING OF RECEIVER HEIGHT                       TRACE128
        RSIGN=-RSIGN                                                            TRACE129
        IF (IHOP.GT.NHOP) GO TO 100                                             TRACE130
        PENET=.FALSE.                                                           TRACE131
C********* LOOP ON MAXIMUM NUMBER OF STEPS PER HOP                             TRACE132
        DO 79 J=1,MAX                                                           TRACE133
C       LAUNCH=TRUE ONLY WHEN TRANSMITTER ON GROUND WITH DOWNWARD               TRACE134
C       TRANSMISSION(POSSIBLE ONLY ON 1ST STEP).                                TRACE135
        LAUNCH=G.EQ.0.0 .AND. GDOT.LT.0.0                                       TRACE136
C                                                                               TRACE137
C       SAVE CURRENT STATE VALUES FOR LATER COMPARISONS                         TRACE138
   12   DO 13 L=1,6                                                             TRACE139
        ROLD(L)=R(L)                                                            TRACE140
   13   DROLD(L)=DRDT(L)                                                        TRACE141
        FDOLD=FDOT                                                              TRACE142
        GDOLD=GDOT                                                              TRACE143
        FOLD=F                                                                  TRACE144
        GOLD=G                                                                  TRACE145
        TOLD=T                                                                  TRACE146
C                                                                               TRACE147
C       PROCESS NEXT RAY POINT                                                  TRACE148
        CALL RKAM                                                               TRACE149
        FDOT=DOT(F)                                                             TRACE150
        WASNT=.NOT.HOME                                                         TRACE151
        HOME=FDOT*F.GE.0.                                                       TRACE152
C                                                                               TRACE153
C                                                                               TRACE154
C       LOOK FOR DOWNGOING CROSSING OF RECEIVER SURFACE                         TRACE155
        IF(.NOT.LAUNCH.AND.F.LT.0.0.AND.RSIGN.LT.0.0) GO TO 50                  TRACE156
C       CHECK FOR CASE OF CLOSEST APPROACH                                      TRACE157
        IF (HOME.AND.WASNT) GO TO 30                                            TRACE158
C       DETERMINE IF A GROUND CROSSING HAS OCCURED                              TRACE159
        IF(PCROSS(G,GDOT)) GO TO 20                                             TRACE160
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C       LOOK FOR UPGOING CROSSING OF RECEIVER SURFACE                    TRACE161
        IF(.NOT.LAUNCH.AND.F.GT.0.0.AND.RSIGN.GT.0.0) GO TO 50           TRACE162
        GO TO 18                                                         TRACE163
C                                                                        TRACE164
C       CHECK FOR PERIGEE CONDITION                                      TRACE165
18      IF (DROLD(1).GE.0..OR.DRDT(1).LE.0.) GO TO 25                    TRACE166
        CALL PRINTR(' PERIGEE ',NORYST)                                  TRACE167
        IF(PRIGEE.EQ.0.0) GO TO 25                                       TRACE168
C                                                                        TRACE169
        IF(NPRGS.GE.MXPRGS) CALL STOPIT('PRG LIMIT')                     TRACE170
        NPRGS=NPRGS+1                                                    TRACE171
        CALL RMOVE(PRGHST(1,NPRGS),R,3)                                  TRACE172
C                                                                        TRACE173
25      APOGEE=DROLD(1).GT.0..AND.DRDT(1).LT.0.                          TRACE174
        PLTENB=APOG.EQ.0.0.OR.APOGEE                                     TRACE175
C                                                                        TRACE176
        IF(APOGEE) CALL PRINTR(' APOGEE  ',NORYST)                       TRACE177
        IF (DROLD(2)*DRDT(2).LT.0.) CALL PRINTR(' MAX LAT ',NORYST)      TRACE178
        IF (DROLD(3)*DRDT(3).LT.0.) CALL PRINTR(' MAX LONG',NORYST)      TRACE179
        DO 14 I=4,6                                                      TRACE180
        IF (ROLD(I)*R(I).LT.0.) CALL PRINTR(' WAVE REV',NORYST)          TRACE181
   14 CONTINUE                                                           TRACE182
        GO TO 75                                                         TRACE183
C********* RAY WENT UNDERGROUND                                         TRACE184
C       USE 'FULL' REGULAR PARABOLIC FIT(ENTRY 'FIT')                    TRACE185
20      CALL RCROSS(-1.,G,GDOT,'GGRND REF',GROUND)                       TRACE186
        GO TO 75                                                         TRACE187
C********* RAY MAY HAVE MADE A CLOSEST APPROACH                         TRACE188
C       USE 'FULL' REGULAR PARABOLIC FIT                                 TRACE189
30      CALL FIT(F,FOLD,FDOLD)                                           TRACE190
        IF(RAD.GE.0.0) GO TO 501                                         TRACE191
C       ESTIMATE TIME OF CLOSEST APPROACH                                TRACE192
        TP=T-ZDOT/D2Z                                                    TRACE193
        CALL GRAZE(F,RSIGN,TP)                                           TRACE194
        FDOT=ZDOT                                                        TRACE195
        IF (THERE) GO TO 51                                              TRACE196
C                                                                        TRACE197
C       SET DRDT(1)=0 TO AVOID INCORRECT APOGEE OR PERIGEE PRINTOUT, A NEWTRACE198
C       VALUE WILL BE COMPUTED BEFORE FURTHER ANALYSIS IS DONE           TRACE199
40      DRDT(1)=0.                                                       TRACE200
        HPUNCH=R(1)-EARTHR                                               TRACE201
        CALL PRINTR('MMIN DIST',RAYSET)                                  TRACE202
        IF(PLTENB) CALL RAYPLT                                           TRACE203
        IF (IHOP.GE.NHOP) GO TO 100                                      TRACE204
        IHOP=IHOP+1                                                      TRACE205
        RSIGN=-RSIGN                                                     TRACE206
        CALL PRINTR ('MMIN DIST',RAYSET)                                 TRACE207
        GO TO 89                                                         TRACE208
C********* RAY CROSSED RECEIVER HEIGHT                                  TRACE209
50      CALL FIT(F,FOLD,FDOLD)                                           TRACE210
C       ESTIMATE GROUP TIME WHEN RAY CROSSES RECEIVER HEIGHT             TRACE211
C       (IN THE CORRECT DIRECTION).                                      TRACE212
501     TC=T-2.0*F/(ZDOT+SIGN(RAD1,RSIGN))                               TRACE213
        CALL BACKUP(F,RSIGN,TC)                                          TRACE214
        FDOT=ZDOT                                                        TRACE215
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      IF(.NOT.THERE) GO TO 40                                          TRACE216
51    HPUNCH=R(1)-EARTHR                                               TRACE217
      CALL PRINTR('RRCVR    ',RAYSET)                                  TRACE218
      IF (PLTENB) CALL RAYPLT                                          TRACE219
      IF (GET(F).NE.GET(G)) GO TO 89                                   TRACE220
C     RECEIVER IS ON TERRAINE                                          TRACE221
      IF (IHOP.GE.NHOP) GO TO 100                                      TRACE222
      IHOP=IHOP+1                                                      TRACE223
      RSIGN=-RSIGN                                                     TRACE224
C********* GROUND REFLECT                                             TRACE225
      CALL REFLECT(G)                                                  TRACE226
      CALL HAMLTN                                                      TRACE227
      FDOT=DOT(F)                                                      TRACE228
      RSTART=1.                                                        TRACE229
      HPUNCH=R(1)-EARTHR                                               TRACE230
      CALL PRINTR('GGRND REF',RAYSET)                                  TRACE231
      THERE=.TRUE.                                                     TRACE232
      HPUNCH=R(1)-EARTHR                                               TRACE233
      CALL PRINTR ('RRCVR    ',RAYSET)                                 TRACE234
      GO TO 89                                                         TRACE235
C*********                                                             TRACE236
75    IF (PLTENB) CALL RAYPLT                                          TRACE237
      PLTENB=APOG.EQ.0.0                                               TRACE238
      IF(EXTON) THEN                                                   TRACE239
         IF (R(NR).GE.EXTINC) XCOND='EEXTINC'                          TRACE240
      ENDIF                                                            TRACE241
      IF (R(1).GT.RMAX.AND.F.GT.0.0.AND.FDOT.GT.0.) XCOND='UMAX HT'    TRACE242
      IF (R(1).LT.RMIN.AND.F.LT.0.0.AND.FDOT.LT.0.) XCOND='DMIN HT'    TRACE243
      RANGE=EARTHR*ACOS(COS(TH)*CTH0+SIN(TH)*STH0*COS(PHI-PHI0))       TRACE244
      IF(RGMAX.GT.0.0.AND.RGMAX.LT.RANGE) XCOND='FMAX RANGE'           TRACE245
      IF(XCOND.NE.DEFCND) GO TO 90                                     TRACE246
C                                                                      TRACE247
      IF (MOD(J,NSKIP).EQ.0) CALL PRINTR('        ',NORYST)            TRACE248
   79 CONTINUE                                                         TRACE249
C********* EXCEEDED MAXIMUM NUMBER OF STEPS                           TRACE250
      HPUNCH=R(1)-EARTHR                                               TRACE251
      CALL PRINTR('SSTEP MAX',RAYSET)                                  TRACE252
      GO TO 100                                                        TRACE253
C*********                                                             TRACE254
   89 HOME=.TRUE.                                                      TRACE255
      GDOT=DOT(G)                                                      TRACE256
      GO TO 10                                                         TRACE257
C********* RAY PENETRATED COMPUTATIONAL AREA BOUNDARY AND WAS HEADING OUTRACE258
90    PENET=.TRUE.                                                     TRACE259
      HPUNCH=R(1)-EARTHR                                               TRACE260
      XSET=RAYSET                                                      TRACE261
C                                                                      TRACE262
C     NORMAL EXIT                                                      TRACE263
100   CALL PRINTR(XCOND,XSET)                                          TRACE264
      IF(NPRGS.LE.0) RETURN                                            TRACE265
C                                                                      TRACE266
      CALL DASH                                                        TRACE267
      NEWTRC=.TRUE.                                                    TRACE268
      DO 110 I=1,NPRGS                                                 TRACE269
      CALL RMOVE(R,PRGHST(1,I),3)                                      TRACE270
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110   CALL RAYPLT                                                        TRACE271
C                                                                        TRACE272
      CALL RESET('DASH')                                                 TRACE273
      END                                                                TRACE274



      LOGICAL FUNCTION PCROSS(Z,ZDT)                                     TRACE275
C     RETURNS 'TRUE' IF PARABOLIC 'FIT2'(SEE 'FIT' ROUTINE)              TRACE276
C     INDICATES CROSSING OF SURFACE 'Z'.                                 TRACE277
      REAL ZDT(3)                                                        TRACE278
C     COMMON DECK "TRAC" INSERTED HERE                                   CTRAC  2
      LOGICAL GROUND,SURF,PERIGE,THERE,MINDIS,NEWRAY                     CTRAC  4
      COMMON /TRAC/ GROUND,SURF,PERIGE,THERE,MINDIS,NEWRAY,SMT,OSMT      CTRAC  5
      COMMON/TRAC/ROLD(20),DROLD(20),TOLD,ZDOT,D2Z,RAD,RAD1              CTRAC  6
C                                                                        TRACE280
C     USE SPECIAL PARABOLIC FIT GIVING 'SMT' AND 'OSMT'                  TRACE281
      ZDT(1)=DOT(Z)                                                      TRACE282
      PCROSS=.TRUE.                                                      TRACE283
      IF(Z.LT.0.0) GO TO 20                                              TRACE284
      IF(ZDT(1).LE.0.0.OR.ZDT(3).GE.0.0) GO TO 15                        TRACE285
      CALL FIT2(Z,ZDT(2),ZDT(3))                                         TRACE286
      IF(SMT.GT.Z.OR.OSMT.GT.ZDT(2)) GO TO 20                            TRACE287
C                                                                        TRACE288
15    PCROSS=.FALSE.                                                     TRACE289
20    RETURN                                                             TRACE290
      END                                                                TRACE291



      SUBROUTINE RCROSS(S,Z,ZDT,EVENT,QMODE)                             TRACE292
C     FIND ESTIMATED CROSSING POINT OF SURFACE 'Z' THEN USE              TRACE293
C     ROUTINE 'BACKUP' TO GO THERE AND PERFORM A RAY REFLECTION          TRACE294
C     WITH ROUTINE 'REFLECT'.                                            TRACE295
C     EXTENDS RAY PROPAGATION TO INTERSECTION WITH REFLECTING SURFACE    TRACE296
C     Z AND CALLS 'REFLECT' TO OBTAIN VECTOR COMPONENTS.                 TRACE297
C                                                                        TRACE298
      CHARACTER EVENT*8                                                  TRACE299
      REAL ZDT(3)                                                        TRACE300
      LOGICAL QMODE                                                      TRACE301
C     COMMON DECK "TRAC" INSERTED HERE                                   CTRAC  2
      LOGICAL GROUND,SURF,PERIGE,THERE,MINDIS,NEWRAY                     CTRAC  4
      COMMON /TRAC/ GROUND,SURF,PERIGE,THERE,MINDIS,NEWRAY,SMT,OSMT      CTRAC  5
      COMMON/TRAC/ROLD(20),DROLD(20),TOLD,ZDOT,D2Z,RAD,RAD1              CTRAC  6
C     COMMON DECK "RR" INSERTED HERE                                     TRACE303
      REAL MODREC                                                        TRACE304
      COMMON/RR/ MODREC(4)                                               TRACE305
      COMMON/RR/F,PFR,PFRR,PFRTH,PFRPH                                   TRACE306
      COMMON/RR/PFTH,PFPH,PFTHTH,PFPHPH,PFTHPH,FSELECT,FTIME             TRACE307
C     COMMON DECK "WWR" INSERTED HERE                                    TRACE308
      PARAMETER (NWARSZ=1000)                                            TRACE309
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      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                    TRACE310
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                 TRACE311
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),     TRACE312
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),       TRACE313
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),           TRACE314
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),          TRACE315
     8 (RCVRH,W(20)),                                                    TRACE316
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))TRACE317
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                       TRACE318
     6 (HMIN,W(27)),(RGMAX,W(28)),                                       TRACE319
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                      TRACE320
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),        TRACE321
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))         TRACE322
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),         TRACE323
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))               TRACE324
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                    TRACE325
C      COMMON DECK "FLAG" INSERTED HERE                                  TRACE326
       LOGICAL NEWWR,NEWWP,NEWTRC,PENET                                  TRACE327
       COMMON /FLG/ NTYP,NEWWR,NEWWP,NEWTRC,PENET,LINES,IHOP,HPUNCH      TRACE328
       COMMON R(20),T,STP,DRDT(20)                                       TRACE329
       COMMON /RK/ N,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART       TRACE330
       LOGICAL HOME                                                      TRACE331
C      COMMON DECK "TRLOCAL" INSERTED HERE                               TRACE332
       COMMON/TRLOCAL/RSIGN,HOME,FDOT,GDOT,GOLD,GDOLD                    TRACE333
C                                                                        TRACE334
       IF(QMODE) GO TO 60                                                TRACE335
       CALL FIT(Z,ZDT(2),ZDT(3))                                         TRACE336
       TC=T-2.0*Z/(ZDOT-RAD1)                                            TRACE337
       CALL BACKUP(Z,-1.,TC)                                             TRACE338
C********* GROUND REFLECT                                               TRACE339
60     CALL REFLECT(Z)                                                   TRACE340
       CALL HAMLTN                                                       TRACE341
       ZDT(1)=DOT(Z)                                                     TRACE342
       FDOT=DOT(F)                                                       TRACE343
       HOME=FDOT*F.GE.0.0                                                TRACE344
       RSTART=1.                                                         TRACE345
       HPUNCH=R(1)-EARTHR                                                TRACE346
       CALL PRINTR(EVENT,RAYSET)                                         TRACE347
       IF(F.NE.Z) RETURN                                                 TRACE348
C      AVOID RECEIVER CROSSING AT THE TRANSMITTER IF RECEIVER ON TERRAIN TRACE349
       RSIGN=S                                                           TRACE350
       HOME=.TRUE.                                                       TRACE351
       END                                                               TRACE352



       SUBROUTINE HAMLTN                                                 HAMLTN 2
C********* CALCULATES HAMILTONS EQUATIONS FOR RAY TRACING                HAMLTN 3
C      AND OTHER QUANTITIES TO BE INTEGRATED                             HAMLTN 4
C      COMMON DECK "GG" INSERTED HERE                                    CGG    2
       REAL MODG                                                         CGG    4
       COMMON/GG/MODG(4)                                                 CGG    5
       COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                  CGG    6
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      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME                CGG    7
C     COMMON DECK "CONST" INSERTED HERE                                    CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                        CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                            CCONST 5
C     COMMON DECK "RINREAL" INSERTED HERE                                  CRINREA2
      LOGICAL SPACE                                                        CRINREA4
      REAL LPOLAR,LPOLRI,KPHK,KPHKI,KAY2,KAY2I                             CRINREA5
      CHARACTER DISPM*6                                                    CRINREA6
      COMMON/RINPL/DISPM                                                   CRINREA7
      COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                    CRINREA8
      COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I,                               CRINREA9
     1             H,HI,PHT,PHTI,PHR,PHRI,PHTH,PHTHI,PHPH,PHPHI          CRINRE10
     2, PHOW,PHOWI,PHKR,PHKRI,PHKTH,PHKTI, PHKPH,PHKPI                     CRINRE11
     3 ,KPHK,KPHKI,POLAR,POLARI,LPOLAR,LPOLRI,SGN                          CRINRE12
      COMMON R(20),T,STP,DRDT(20)                                          HAMLTN 8
      PARAMETER (NWARSZ=1000)                                              CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                      CWW1   4
      EQUIVALENCE (TH,R(2)),(PH,R(3)),(KR,R(4)),(KTH,R(5)),(KPH,R(6)),     HAMLTN10
     1 (DTHDT,DRDT(2)),(DPHDT,DRDT(3)),(DKRDT,DRDT(4)),(DKTHDT,DRDT(5)),   HAMLTN11
     2 (DKPHDT,DRDT(6)),(HMAX,W(26)),(OW,W(6))                             HAMLTN12
      REAL KR,KTH,KPH                                                      HAMLTN13
      STH=SIN(TH)                                                          HAMLTN14
      CTH=SIN(PID2-TH)                                                     HAMLTN15
      RSTH=R(1)*STH                                                        HAMLTN16
      RCTH=R(1)*CTH                                                        HAMLTN17
      CALL DISPER                                                          HAMLTN18
      DENPHC=1.0/(PHOW*CREF)                                               HAMLTN19
      DRDT(1)=-PHKR*DENPHC                                                 HAMLTN20
      DTHDT=-PHKTH*DENPHC/R(1)                                             HAMLTN21
      DPHDT=-PHKPH*DENPHC/RSTH                                             HAMLTN22
      DKRDT=PHR*DENPHC+KTH*DTHDT+KPH*STH*DPHDT                             HAMLTN23
      DKTHDT=(PHTH*DENPHC-KTH*DRDT(1)+KPH*RCTH*DPHDT)/R(1)                 HAMLTN24
      DKPHDT=(PHPH*DENPHC-KPH*STH*DRDT(1)-KPH*RCTH*DTHDT)/RSTH             HAMLTN25
      NR=6                                                                 HAMLTN26
C********* PHASE PATH                                                      HAMLTN27
      IF (W(57).EQ.0.) GO TO 10                                            HAMLTN28
      NR=NR+1                                                              HAMLTN29
      DRDT(NR)=-     KPHK/PHOW/OW                                          HAMLTN30
C********* ABSORPTION                                                      HAMLTN31
   10 IF (W(58).EQ.0.) GO TO 15                                            HAMLTN32
      NR=NR+1                                                              HAMLTN33
      DRDT(NR)= 10./ALN10*KPHK*KAY2I/(KR*KR+KTH*KTH+KPH*KPH)*DENPHC        HAMLTN34
C********* DOPPLER SHIFT                                                   HAMLTN35
   15 IF (W(59).EQ.0.) GO TO 20                                            HAMLTN36
      NR=NR+1                                                              HAMLTN37
      DRDT(NR)=-PHT*DENPHC/PIT2                                            HAMLTN38
C********* GEOMETRICAL PATH LENGTH                                         HAMLTN39
   20 IF (W(60).EQ.0.) GO TO 25                                            HAMLTN40
      NR=NR+1                                                              HAMLTN41
      DRDT(NR)=SQRT(PHKR**2+PHKTH**2+PHKPH**2)*ABS(DENPHC)                 HAMLTN42
C********* TERRAIN FUNCTION AS COMPLETE INTEGRAL                           HAMLTN43
25    IF(ABS(W(61))+ABS(W(62))+ABS(W(63))+ABS(W(64)).EQ.0.0) GO TO 45      HAMLTN44
      CALL TOPOG                                                           HAMLTN45
C                                                                          HAMLTN46
      IF(W(61).EQ.0.) GO TO 30                                             HAMLTN47
```

```
      NR=NR+1                                                          HAMLTN48
      DRDT(NR)=PGR*DRDT(1)+PGTH*DTHDT+PGPH*DPHDT                       HAMLTN49
C********* TERRAIN TIME DERIVATIVES AS COMPLETE INTEGRALS              HAMLTN50
   30 IF(W(62).EQ.0.) GO TO 35                                         HAMLTN51
      NR=NR+1                                                          HAMLTN52
C     DERIVATIVE WITH RESPECT TO R                                     HAMLTN53
      DRDT(NR)=PGRR*DRDT(1)+PGRTH*DTHDT+PGRPH*DPHDT                    HAMLTN54
   35 IF(W(63).EQ.0.) GO TO 40                                         HAMLTN55
      NR=NR+1                                                          HAMLTN56
C     DERIVATIVE WITH RESPECT TO THETA                                 HAMLTN57
      DRDT(NR)=PGRTH*DRDT(1)+PGTHTH*DTHDT+PGTHPH*DPHDT                 HAMLTN58
   40 IF(W(64).EQ.0.) GO TO 45                                         HAMLTN59
      NR=NR+1                                                          HAMLTN60
C     DERIVATIVE WITH RESPECT TO PHI                                   HAMLTN61
      DRDT(NR)=PGRPH*DRDT(1)+PGTHPH*DTHDT+PGPHPH*DPHDT                 HAMLTN62
C********* OTHER CALCULATIONS                                         HAMLTN63
45    CONTINUE                                                         HAMLTN64
      RETURN                                                           HAMLTN65
         END                                                           HAMLTN66
```

```
      SUBROUTINE RKAM                                                  RKAM   2
C     KEEPS TRACK OF INTERNAL INTEGRATION STEPS PERFORMED BY THE RKAM1  RKAM   3
C     ROUTINE AND MAKES THEM AVAILABLE TO CALLING ROUTINES.            RKAM   4
      COMMON/RKAMS/XV(5),FV(4,20),YU(5,20),EPM,ALPHA,MM                RKAM   5
C     COMMON DECK "RK" INSERTED HERE                                   CRK    2
C     DEFINE SIZE REQUIRED FOR RAY STATE SAVE ARRAY                    CRK    4
      PARAMETER (LRKAMS=87+2*100,NXRKMS=12+LRKAMS,MXEQPT=21)           CRK    5
      PARAMETER (NRKSAV=NXRKMS+MXEQPT-1)                               CRK    6
      COMMON /RK/ NEQS,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART   CRK    7
C     COMMON DECK "RKTIME" INSERTED HERE                               CRKTIME2
      COMMON/CRKTIME/RKTIME                                            CRKTIME4
      COMMON Y(20),T,SPACE,DYDT(20)                                    RKAM   8
      REAL RV(1)                                                       RKAM   9
      DOUBLE PRECISION YU                                              RKAM  10
      EQUIVALENCE(RKTIME,IRKTIME),(RV,R)                               RKAM  11
C                                                                      RKAM  12
      REAL SVBUF(NRKSAV)                                               RKAM  13
      LOGICAL SAVED                                                    RKAM  14
C                                                                      RKAM  15
      DATA SAVED/.FALSE./                                              RKAM  16
C     PERFORM CLOCK ADVANCE(SEE 'GET' ROUTINE)                         RKAM  17
      IRKTIME=IRKTIME+1                                                RKAM  18
C                                                                      RKAM  19
      IF(RSTART.NE.0.0 .OR. MODE.LE.2) GO TO 250                       RKAM  20
C                                                                      RKAM  21
      NV=NV+1                                                          RKAM  22
      IF(NV.LE.4) GO TO 300                                            RKAM  23
C                                                                      RKAM  24
250   TOLD=T                                                           RKAM  25
C     PERFORM NUMERICAL INTEGRATION TO TIME 'T'                        RKAM  26
      CALL RKAM1                                                       RKAM  27
```

```
      IF(MODE.LE.2) GO TO 400                                          RKAM  28
      IF(RSTART.NE.0.0) GO TO 260                                      RKAM  29
C     SEARCH FOR REQUESTED VALUE IN PIPELINE                           RKAM  30
C     TAKING SIGN OF 'STEP' INTO ACCOUNT.                              RKAM  31
      TUP=TOLD+.25*STEP                                                RKAM  32
      DO 150 NV=1,3                                                    RKAM  33
      IF(SPACE.GT.0.0.AND.TUP.LT.XV(NV)) GO TO 300                     RKAM  34
      IF(SPACE.LT.0.0.AND.TUP.GT.XV(NV)) GO TO 300                     RKAM  35
150   CONTINUE                                                         RKAM  36
C     GOT IT ALREADY, RETURN                                           RKAM  37
      GO TO 400                                                        RKAM  38
C                                                                      RKAM  39
260   NV=1                                                             RKAM  40
C     RETRIEVE REQUESTED VALUES FROM PIPELINE                          RKAM  41
300   T=XV(NV)                                                         RKAM  42
      DO 350 I=1,NEQS                                                  RKAM  43
      Y(I)=YU(NV,I)                                                    RKAM  44
350   DYDT(I)=FV(NV,I)                                                 RKAM  45
C                                                                      RKAM  46
C     STANDARD EXIT SEQUENCE                                           RKAM  47
400   RETURN                                                           RKAM  48
C                                                                      RKAM  49
      ENTRY RKSAVE(SVBUF)                                              RKAM  50
C                                                                      RKAM  51
      SVBUF(1)=NV                                                      RKAM  52
      SVBUF(2)=NEQS                                                    RKAM  53
      SVBUF(3)=MM                                                      RKAM  54
      SVBUF(4)=SPACE                                                   RKAM  55
      SVBUF(5)=MODE                                                    RKAM  56
      CALL RMOVE(SVBUF(6),E1MAX,6)                                     RKAM  57
      CALL RMOVE(SVBUF(12),XV,LRKAMS)                                  RKAM  58
      CALL RMOVE(SVBUF(NXRKMS),Y,MXEQPT)                               RKAM  59
C                                                                      RKAM  60
      SAVED=.TRUE.                                                     RKAM  61
      RETURN                                                           RKAM  62
      ENTRY RKRSTR(SVBUF)                                              RKAM  63
C                                                                      RKAM  64
      IF(.NOT.SAVED) RETURN                                            RKAM  65
C                                                                      RKAM  66
      NV=SVBUF(1)                                                      RKAM  67
      NEQS=SVBUF(2)                                                    RKAM  68
      MM=SVBUF(3)                                                      RKAM  69
      SPACE=SVBUF(4)                                                   RKAM  70
      MODE=SVBUF(5)                                                    RKAM  71
      CALL RMOVE(E1MAX,SVBUF(6),6)                                     RKAM  72
      CALL RMOVE(XV,SVBUF(12),LRKAMS)                                  RKAM  73
      CALL RMOVE(Y,SVBUF(NXRKMS),MXEQPT)                               RKAM  74
C                                                                      RKAM  75
      WRITE(3,*) 'RESTORING NV,NEQS,MM,ALPHA,T='                       RKAM  76
     1   ,NV,NEQS,MM,ALPHA,T                                           RKAM  77
      RETURN                                                           RKAM  78
      END                                                              RKAM  79
```

```
      SUBROUTINE RKAM1                                                      RKAM1  2
C        NUMERICAL INTEGRATION OF DIFFERENTIAL EQUATIONS                    RKAM1  3
C     THIS ROUTINE IS A MODIFICATION OF RKAMSUB, WHICH WAS WRITTEN          RKAM1  4
C     BY G.J. LASTMAN AND IS AVAILABLE THROUGH THE CDC CO-OP LIBRARY        RKAM1  5
C     AS 'D2 UTEX RKAMSUB'.                                                 RKAM1  6
      COMMON /RK/ NN,SPACE,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART         RKAM1  7
      COMMON Y(20),T,STEP,DYDT(20)                                          RKAM1  8
      COMMON/RKAMS/XV(5),FV(4,20),YU(5,20),EPM,ALPHA,MM                     RKAM1  9
      DIMENSION DELY(4,20),BET(4)                                           RKAM1 10
      DOUBLE PRECISION YU                                                   RKAM1 11
C                                                                           RKAM1 12
      IF (RSTART.EQ.0.) GO TO 1000                                          RKAM1 13
      LL=1                                                                  RKAM1 14
      MM=1                                                                  RKAM1 15
      IF (MODE.EQ.1) MM=4                                                   RKAM1 16
      ALPHA=T                                                               RKAM1 17
      EPM=0.0                                                               RKAM1 18
      BET(1)=0.5                                                            RKAM1 19
      BET(2)=0.5                                                            RKAM1 20
      BET(3)=1.0                                                            RKAM1 21
      BET(4)=0.0                                                            RKAM1 22
      STEP=SPACE                                                            RKAM1 23
      R=19.0/270.0                                                          RKAM1 24
      XV(MM)=T                                                              RKAM1 25
      IF (E1MIN.LE.0.) E1MIN=E1MAX/50.                                      RKAM1 26
      IF (FACT.LE.0.) FACT=0.5                                              RKAM1 27
      CALL HAMLTN                                                           RKAM1 28
      DO 320 I=1,NN                                                         RKAM1 29
      FV(MM,I)=DYDT(I)                                                      RKAM1 30
  320 YU(MM,I)=Y(I)                                                         RKAM1 31
      RSTART=0.                                                             RKAM1 32
      GO TO 1001                                                            RKAM1 33
 1000 IF (MODE.NE.1) GO TO 2000                                             RKAM1 34
C                                                                           RKAM1 35
C           RUNGE-KUTTA                                                     RKAM1 36
 1001 DO 1034 K=1,4                                                         RKAM1 37
      DO 1350 I=1,NN                                                        RKAM1 38
      DELY(K,I)=STEP*FV(MM,I)                                               RKAM1 39
      Z=YU(MM,I)                                                            RKAM1 40
 1350 Y(I)=Z+BET(K)*DELY(K,I)                                               RKAM1 41
      T=BET(K)*STEP+XV(MM)                                                  RKAM1 42
      CALL HAMLTN                                                           RKAM1 43
      DO 1034 I=1,NN                                                        RKAM1 44
 1034 FV(MM,I)=DYDT(I)                                                      RKAM1 45
      DO 1039 I=1,NN                                                        RKAM1 46
      DEL=(DELY(1,I)+2.0*DELY(2,I)+2.0*DELY(3,I)+DELY(4,I))/6.0             RKAM1 47
 1039 YU(MM+1,I)=YU(MM,I)+DEL                                               RKAM1 48
      MM=MM+1                                                               RKAM1 49
      XV(MM)=XV(MM-1)+STEP                                                  RKAM1 50
      DO 1400 I=1,NN                                                        RKAM1 51
 1400 Y(I)=YU(MM,I)                                                         RKAM1 52
      T=XV(MM)                                                              RKAM1 53
      CALL HAMLTN                                                           RKAM1 54
```

```
      IF (MODE.EQ.1) GO TO 42                                                  RKAM1 55
      DO 150 I=1,NN                                                            RKAM1 56
  150 FV(MM,I)=DYDT(I)                                                         RKAM1 57
      IF (MM.LE.3) GO TO 1001                                                  RKAM1 58
C                                                                              RKAM1 59
C          ADAMS-MOULTON                                                       RKAM1 60
 2000 DO 2048 I=1,NN                                                           RKAM1 61
      DEL=STEP*(55.*FV(4,I)-59.*FV(3,I)+37.*FV(2,I)-9.*FV(1,I))/24.            RKAM1 62
      Y(I)=YU(4,I)+DEL                                                         RKAM1 63
 2048 DELY(1,I)=Y(I)                                                           RKAM1 64
      T=XV(4)+STEP                                                             RKAM1 65
      CALL HAMLTN                                                              RKAM1 66
      XV(5)=T                                                                  RKAM1 67
      DO 2051 I=1,NN                                                           RKAM1 68
      DEL=STEP*(9.*DYDT(I)+19.*FV(4,I)-5.*FV(3,I)+FV(2,I))/24.                 RKAM1 69
      YU(5,I)=YU(4,I)+DEL                                                      RKAM1 70
 2051 Y(I)=YU(5,I)                                                             RKAM1 71
      CALL HAMLTN                                                              RKAM1 72
      IF (MODE.LE.2) GO TO 42                                                  RKAM1 73
C                                                                              RKAM1 74
C          ERROR ANALYSIS                                                      RKAM1 75
      SSE=0.0                                                                  RKAM1 76
      DO 3033 I=1,NN                                                           RKAM1 77
      EPSIL=R*ABS(Y(I)-DELY(1,I))                                              RKAM1 78
      IF (MODE.EQ.3.AND.Y(I).NE.0.) EPSIL=EPSIL/ABS(Y(I))                      RKAM1 79
      IF (SSE.LT.EPSIL) SSE=EPSIL                                              RKAM1 80
 3033 CONTINUE                                                                 RKAM1 81
      IF (E1MAX.GT.SSE) GO TO 3035                                             RKAM1 82
      IF (ABS(STEP).LE.E2MIN) GO TO 42                                         RKAM1 83
      LL=1                                                                     RKAM1 84
      MM=1                                                                     RKAM1 85
      STEP=STEP*FACT                                                           RKAM1 86
      GO TO 1001                                                               RKAM1 87
 3035 IF (LL.LE.1.OR.SSE.GE.E1MIN.OR.E2MAX.LE.ABS(STEP)) GO TO 42              RKAM1 88
      LL=2                                                                     RKAM1 89
      MM=3                                                                     RKAM1 90
      XV(2)=XV(3)                                                              RKAM1 91
      XV(3)=XV(5)                                                              RKAM1 92
      DO 5363 I=1,NN                                                           RKAM1 93
      FV(2,I)=FV(3,I)                                                          RKAM1 94
      FV(3,I)=DYDT(I)                                                          RKAM1 95
      YU(2,I)=YU(3,I)                                                          RKAM1 96
 5363 YU(3,I)=YU(5,I)                                                          RKAM1 97
      STEP=2.0*STEP                                                            RKAM1 98
      GO TO 1001                                                               RKAM1 99
C                                                                              RKAM1100
C          EXIT ROUTINE                                                        RKAM1101
   42 LL=2                                                                     RKAM1102
      MM=4                                                                     RKAM1103
      DO 12 K=1,3                                                              RKAM1104
      XV(K)=XV(K+1)                                                            RKAM1105
      DO 12 I=1,NN                                                             RKAM1106
      FV(K,I)=FV(K+1,I)                                                        RKAM1107
   12 YU(K,I)=YU(K+1,I)                                                        RKAM1108
      XV(4)=XV(5)                                                              RKAM1109
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      DO 52 I=1,NN                                                      RKAM1110
      FV(4,I)=DYDT(I)                                                   RKAM1111
   52 YU(4,I)=YU(5,I)                                                   RKAM1112
      IF (MODE.LE.2) RETURN                                             RKAM1113
      E=ABS(XV(4)-ALPHA)                                                RKAM1114
      IF (E.LE.EPM+.25*STEP) GO TO 2000                                 RKAM1115
      EPM=E                                                             RKAM1116
      RETURN                                                            RKAM1117
         END                                                            RKAM1118
```

```
      SUBROUTINE BACKUP(Z,RSIGN,TC)                                     BACKUP 2
C     MOVES THE RAY TO THE CLOSEST INTERSECTION WITH THE RECEIVER       BACKUP 3
C     OR TERRAIN SURFACE(VARIABLES 'FSELECT' OR 'GSELECT' IN LABELED    BACKUP 4
C     COMMONS /RR/ OR /GG/, RESPECTIVELY, TELL WHICH KIND OF SURFACE).  BACKUP 5
C                                                                       BACKUP 6
      CHARACTER*9 NBAK,NGRAZ,NTRY                                       BACKUP 7
C                                                                       BACKUP 8
      PARAMETER (PRNZTL=0.5E-4,PRNDZTL=1.E-6)                           BACKUP 9
C                                                                       BACKUP10
      COMMON /RK/ N,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART       BACKUP11
C     COMMON DECK "TRAC" INSERTED HERE                                  CTRAC  2
      LOGICAL GROUND,SURF,PERIGE,THERE,MINDIS,NEWRAY                    CTRAC  4
      COMMON /TRAC/ GROUND,SURF,PERIGE,THERE,MINDIS,NEWRAY,SMT,OSMT     CTRAC  5
      COMMON/TRAC/ROLD(20),DROLD(20),TOLD,ZDOT,D2Z,RAD,RAD1             CTRAC  6
      COMMON R(20),T,STP,DRDT(20)                                       BACKUP13
      PARAMETER (NWARSZ=1000)                                           CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   CWW1   4
      EQUIVALENCE (EARTHR,W(1)),(INTYP,W(41)),(STEP1,W(44))             BACKUP15
      REAL KR                                                           BACKUP16
      EQUIVALENCE (KR,R(4)),(DKRDT,DRDT(4))                             BACKUP17
      REAL INTYP                                                        BACKUP18
      LOGICAL PCNTRL                                                    BACKUP19
      DATA NBAK,NGRAZ/' BACK UP0', ' GRAZE 1'/                          BACKUP20
C                                                                       BACKUP21
      NTRY=NBAK                                                         BACKUP22
      GO TO 100                                                         BACKUP23
C                                                                       BACKUP24
      ENTRY GRAZE(Z,RSIGN,TC)                                           BACKUP25
      NTRY=NGRAZ                                                        BACKUP26
C                                                                       BACKUP27
C     DEFINE BASE STEP SIZE                                             BACKUP28
  100 STPB=STP                                                          BACKUP29
C                                                                       BACKUP30
C     DEFINE BACKUP LOCATION TOLERANCES BASED ON INTEGRATION MODE       BACKUP31
C                                                                       BACKUP32
      IF(MODE.LT.3) THEN                                                BACKUP33
         TOL=STEP1                                                      BACKUP34
      ELSEIF(MODE.EQ.3) THEN                                            BACKUP35
         TOL=ABS(E1MAX*STPB)                                            BACKUP36
      ELSE                                                              BACKUP37
         TOL=E1MAX                                                      BACKUP38
```

```
      ENDIF                                                             BACKUP39
C     USE THIS OR MINIMUM STEP SIZE WHICHEVER IS LESS                   BACKUP40
      TOL=AMIN1(TOL,FACT*E2MIN)                                         BACKUP41
C                                                                       BACKUP42
      PCNTRL=W(73).NE.0.0                                               BACKUP43
      THERE=.TRUE.                                                      BACKUP44
C      STEP TO ESTIMATED CROSSING AT TC.                                BACKUP45
C********* DIAGNOSTIC PRINTOUT                                         BACKUP46
      IF(PCNTRL) CALL PRINTR (NTRY,0.)                                  BACKUP47
      STEP=TC-T                                                         BACKUP48
      STEP=SIGN(AMIN1(ABS(STPB),ABS(STEP)),STEP)                        BACKUP49
      MODE=1                                                            BACKUP50
      RSTART=1                                                          BACKUP51
      TOLD=T                                                            BACKUP52
      CALL RMOVE(DROLD,DRDT,3)                                          BACKUP53
      ZDOLD=DOT(Z)                                                      BACKUP54
      CALL RKAM                                                         BACKUP55
      RSTART=1.0                                                        BACKUP56
      ZDOT=DOT(Z)                                                       BACKUP57
      IF(NTRY.EQ.NGRAZ .OR. RSIGN*ZDOT.LE.0.0) GO TO 12                 BACKUP58
C                                                                       BACKUP59
C********* FIND NEAREST INTERSECTION OF RAY WITH THE HEIGHT HS          BACKUP60
      DO 10 I=1,10                                                      BACKUP61
      STEP=-Z/ZDOT                                                      BACKUP62
      STEP=SIGN(AMIN1(ABS(STPB),ABS(STEP)),STEP)                        BACKUP63
      IF (ABS(Z).LT.PRNZTL .AND. ABS(STEP).LT.TOL) GO TO 60             BACKUP64
C********* DIAGNOSTIC PRINTOUT                                         BACKUP65
      IF(PCNTRL) CALL PRINTR(' BACK UP1',0.)                            BACKUP66
      MODE=1                                                            BACKUP67
      RSTART=1.                                                         BACKUP68
      TOLD=T                                                            BACKUP69
      CALL RMOVE(DROLD,DRDT,3)                                          BACKUP70
      ZDOLD=ZDOT                                                        BACKUP71
      CALL RKAM                                                         BACKUP72
      ZDOT=DOT(Z)                                                       BACKUP73
   10 RSTART=1.                                                         BACKUP74
C                                                                       BACKUP75
C********* FIND NEAREST CLOSEST APPROACH OF RAY TO THE HEIGHT HS        BACKUP76
12    THERE=.FALSE.                                                     BACKUP77
      DO 20 I=1,10                                                      BACKUP78
C     DO 'LOCAL' PARABOLIC FIT                                          BACKUP79
      CALL FIT3(Z,ZOLD,ZDOLD)                                           BACKUP80
      STEP=-ZDOT/D2Z                                                    BACKUP81
      STEP=SIGN(AMIN1(ABS(STPB),ABS(STEP)),STEP)                        BACKUP82
      IF (ABS(ZDOT).LE.PRNDZTL .AND. ABS(STEP).LT.TOL) GO TO 60         BACKUP83
C********* DIAGNOSTIC PRINTOUT                                         BACKUP84
      IF(PCNTRL) CALL PRINTR (' GRAZE 1 ',0.)                           BACKUP85
      MODE=1                                                            BACKUP86
      RSTART=1.                                                         BACKUP87
      TOLD=T                                                            BACKUP88
      CALL RMOVE(DROLD,DRDT,3)                                          BACKUP89
      ZOLD=Z                                                            BACKUP90
      ZDOLD=ZDOT                                                        BACKUP91
      CALL RKAM                                                         BACKUP92
      RSTART=1.                                                         BACKUP93
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      IF (D2Z*Z.LT.0.) GO TO 30                                          BACKUP94
      IF(KPARLEL(Z).EQ.0.0) GO TO 60                                     BACKUP95
   20 CONTINUE                                                           BACKUP96
      WRITE(3,350)                                                       BACKUP97
350   FORMAT(' ****** COULDN''T FIND CLOSEST APPROACH IN 10 STEPS')      BACKUP98
      GO TO 60                                                           BACKUP99
C                                                                        BACKU100
   30 CONTINUE                                                           BACKU101
C********* DIAGNOSTIC PRINTOUT                                         BACKU102
      IF(PCNTRL) CALL PRINTR (' BACK UP2',0.)                            BACKU103
      MODE=1                                                             BACKU104
C********* ESTIMATE DISTANCE TO NEAREST INTERSECTION GOING THE RIGHT    BACKU105
C********* DIRECTION OF RAY WITH HEIGHT HS                              BACKU106
      CALL FIT3(Z,ZOLD,ZDOLD)                                            BACKU107
      STEP=(-ZDOT+RSIGN*RAD1)/D2Z                                        BACKU108
      RSTART=1.                                                          BACKU109
      CALL RKAM                                                          BACKU110
      RSTART=1.                                                          BACKU111
C********* FIND NEAREST INTERSECTION OF RAY WITH HEIGHT HS              BACKU112
      DO 40 I=1,10                                                       BACKU113
      ZDOT=DOT(Z)                                                        BACKU114
      STEP=-Z/ZDOT                                                       BACKU115
      STEP=SIGN(AMIN1(ABS(STPB),ABS(STEP)),STEP)                         BACKU116
      IF (ABS(Z).LT.PRNZTL .AND. ABS(STEP).LT.TOL) GO TO 50              BACKU117
C********* DIAGNOSTIC PRINTOUT                                         BACKU118
      IF(PCNTRL) CALL PRINTR (' BACK UP3',0.)                            BACKU119
      MODE=1                                                             BACKU120
      RSTART=1.                                                          BACKU121
      CALL RKAM                                                          BACKU122
   40 RSTART=1.                                                          BACKU123
   50 THERE=.TRUE.                                                       BACKU124
C********* RESET STANDARD MODE AND INTEGRATION TYPE                     BACKU125
   60 MODE=INTYP                                                         BACKU126
      STEP=STPB                                                          BACKU127
      RETURN                                                             BACKU128
         END                                                             BACKU129
```

```
      FUNCTION REFLECT(Z)                                                REFLECT2
C     COMPUTES NORMAL AND PARALLEL COMPONENTS OF THE K-VECTOR AT          REFLECT3
C     REFLECTION POINTS TO A SURFACE. WIND EFFECTS ARE INCLUDED.         REFLECT4
C                                                                        REFLECT5
      REAL Z(12),KPARLEL,KNORM                                           REFLECT6
C     COMMON DECK "CC" INSERTED HERE                                     CCC    2
      REAL MODC                                                          CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                         CCC    5
C     COMMON DECK "WWR" INSERTED HERE                                    CWWR   2
      PARAMETER (NWARSZ=1000)                                            CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                    CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                 CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),     CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),       CWW2   4
```

```
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                CWW2    5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),               CWW2    6
                                                                              CWW2    7
     8 (RCVRH,W(20)),
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))      CWW2    8
                                                                              CWW2    9
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                            CWW2   10
     6 (HMIN,W(27)),(RGMAX,W(28)),                                            CWW2   11
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                           CWW2   12
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),             CWW2   13
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))              CWW2   14
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),              CWW2   15
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                    CWW2   16
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                         CWW2   16
C      COMMON DECK "RKAM" INSERTED HERE                                       RKAMCOM2
       REAL KR,KTH,KPH                                                        RKAMCOM4
       COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)            RKAMCOM5
C      COMMON DECK "UU" INSERTED HERE                                         CUU     2
       REAL MODU                                                              CUU     4
       COMMON/UU/MODU(4)                                                      CUU     5
     1   ,V   ,PVT   ,PVR   ,PVTH   ,PVPH                                    CUU     6
     2   ,VR  ,PVRT  ,PVRR  ,PVRTH  ,PVRPH                                   CUU     7
     3   ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                      CUU     8
     4   ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                      CUU     9
C      COMMON DECK "FNDER" INSERTED HERE                                      CFNDER  2
       COMMON/FNDER/NZ,NPZR,NPZRR,NPZRTH,NPZRPH,NPZTH,NPZPH,NPZTHTH           CFNDER  4
       COMMON/FNDER/NPZPHPH,NPZTHPH,NSELECT,NTIME                             CFNDER  5
C                                                                             REFLEC12
       REAL NR,NTH,NPH,KRNR,KPARR,KPARTH,KPARPH                               REFLEC13
C                                                                             REFLEC14
       IENTRY=1                                                               REFLEC15
       REFLECT=0.0                                                            REFLEC16
       GO TO 5                                                                REFLEC17
C                                                                             REFLEC18
       ENTRY KPARLEL(Z)                                                       REFLEC19
       KPARLEL=0.0                                                            REFLEC20
       IENTRY=2                                                               REFLEC21
       GO TO 5                                                                REFLEC22
C                                                                             REFLEC23
       ENTRY KNORM(Z)                                                         REFLEC24
       KNORM=0.0                                                              REFLEC25
       IENTRY=3                                                               REFLEC26
C                                                                             REFLEC27
5      Z(1)=GET(Z)                                                            REFLEC28
       NR=Z(NPZR)                                                             REFLEC29
       NTH=Z(NPZTH)/R                                                         REFLEC30
       NPH=Z(NPZPH)/(R*SIN(TH))                                               REFLEC31
C                                                                             REFLEC32
       CALL RENORM(NR,1.0,3)                                                  REFLEC33
C      COMPUTE THE NORMAL COMPONENT OF K-VECTOR TO SURFACE                    REFLEC34
       KRNR=KR*NR+KTH*NTH+KPH*NPH                                             REFLEC35
       IF(IENTRY.NE.3) GO TO 8                                                REFLEC36
C      IF ENTRY 3 THEN WE ARE DONE                                            REFLEC37
       REFLECT=KRNR                                                           REFLEC38
       RETURN                                                                 REFLEC39
C                                                                             REFLEC40
C      COMPUTE THE PARALLEL VECTOR COMPONENT                                  REFLEC41
```

```
8       KPARR=KR-KRNR*NR                                                    REFLEC42
        KPARTH=KTH-KRNR*NTH                                                 REFLEC43
        KPARPH=KPH-KRNR*NPH                                                 REFLEC44
C                                                                           REFLEC45
        IF(IENTRY.NE.2) GO TO 10                                            REFLEC46
        REFLECT=ABS(KPARR)+ABS(KPARTH)+ABS(KPARPH)                          REFLEC47
        RETURN                                                              REFLEC48
C                                                                           REFLEC49
10      OWIPAR=OW-KPARR*VR-KPARTH*VTH-KPARPH*VPH                            REFLEC50
        VNR=VR*NR+VTH*NTH+VPH*NPH                                           REFLEC51
C                                                                           REFLEC52
        FCTR=2.0*(KRNR+OWIPAR*VNR/(CS-VNR*VNR))                            REFLEC53
        KR=KR-FCTR*NR                                                       REFLEC54
        KTH=KTH-FCTR*NTH                                                    REFLEC55
        KPH=KPH-FCTR*NPH                                                    REFLEC56
        END                                                                 REFLEC57
```

```
        SUBROUTINE FIT(Z,ZOLD,ZDOLD)                                        FIT     2
C       COMPUTES THREE TYPES OF PARABOLIC FITS TO RAY PATH RELATIVE          FIT     3
C       TO TERRAIN.                                                         FIT     4
C                                                                           FIT     5
        REAL Z(12)                                                          FIT     6
C       COMMON DECK "RKAM" INSERTED HERE                                    RKAMCOM2
        REAL KR,KTH,KPH                                                     RKAMCOM4
        COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)         RKAMCOM5
C       COMMON DECK "TRAC" INSERTED HERE                                    CTRAC   2
        LOGICAL GROUND,SURF,PERIGE,THERE,MINDIS,NEWRAY                      CTRAC   4
        COMMON /TRAC/ GROUND,SURF,PERIGE,THERE,MINDIS,NEWRAY,SMT,OSMT       CTRAC   5
        COMMON/TRAC/ROLD(20),DROLD(20),TOLD,ZDOT,D2Z,RAD,RAD1               CTRAC   6
C       COMMON DECK "FNDER" INSERTED HERE                                   CFNDER  2
        COMMON/FNDER/NZ,NPZR,NPZRR,NPZRTH,NPZRPH,NPZTH,NPZPH,NPZTHTH        CFNDER  4
        COMMON/FNDER/NPZPHPH,NPZTHPH,NSELECT,NTIME                          CFNDER  5
C                                                                           FIT    10
        REAL D2(3)                                                          FIT    11
C                                                                           FIT    12
C       USE FIT OF APPENDIX 'J' OF REPORT 'WPL-103' WHICH USES              FIT    13
C       WEIGHTED ESTIMATE OF 1ST DERIVATIVE.                                FIT    14
C                                                                           FIT    15
        IENTRY=1                                                            FIT    16
        GO TO 5                                                             FIT    17
C                                                                           FIT    18
C       USE MODIFIED FIT REQUIRING HEIGHTS OF PARABOLA VERTICES FROM        FIT    19
C       CURRENT AND PREVIOUS RAY POINTS.                                    FIT    20
        ENTRY FIT2(Z,ZOLD,ZDOLD)                                            FIT    21
        IENTRY=2                                                            FIT    22
        GO TO 5                                                             FIT    23
C                                                                           FIT    24
C       USE FIT OF APPENDIX U(LOCAL VALUE OF 1ST DERIVATIVE)                FIT    25
        ENTRY FIT3(Z,ZOLD,ZDOLD)                                            FIT    26
        IENTRY=3                                                            FIT    27
C                                                                           FIT    28
```

```
5       ZDOT=DOT(Z)                                                          FIT   29
C                                                                            FIT   30
        DTI=1.0/(TPULSE-TOLD)                                                FIT   31
        DO 10 I=1,3                                                          FIT   32
10      D2(I)=(DRDT(I)-DROLD(I))*DTI                                         FIT   33
C                                                                            FIT   34
        D2Z=Z(NPZR)*D2(1)+Z(NPZTH)*D2(2)+Z(NPZPH)*D2(3)                      FIT   35
     1         +Z(NPZRR)*DRDT(1)*DRDT(1)                                     FIT   36
     1         +Z(NPZTHTH)*DRDT(2)*DRDT(2)                                   FIT   37
     1         +Z(NPZPHPH)*DRDT(3)*DRDT(3)                                   FIT   38
     1    +2.0*(Z(NPZRTH)*DRDT(1)*DRDT(2)                                    FIT   39
     1         +Z(NPZRPH)*DRDT(1)*DRDT(3)                                    FIT   40
     1         +Z(NPZTHPH)*DRDT(2)*DRDT(3) )                                 FIT   41
C                                                                            FIT   42
C       THE STATEMENTS FROM HERE TO 'END FIT' IMPLEMENT THE                  FIT   43
C       PARABOLIC FITS IN EQUATIONS J.1 AND U.3 OF THE TEXT.                 FIT   44
C                                                                            FIT   45
        IF(IENTRY.NE.2) GO TO 30                                             FIT   46
        SMT=0.                                                               FIT   47
        IF (D2Z.NE.0.) SMT=0.5*ZDOT*ZDOT/D2Z                                 FIT   48
C       USE FIT U.3 AT THE PREVIOUS POINT OF RAY PATH                        FIT   49
        OSMT=0.                                                              FIT   50
        IF (D2Z.NE.0.) OSMT=0.5*ZDOLD*ZDOLD/D2Z                              FIT   51
        GO TO 2000                                                           FIT   52
C                                                                            FIT   53
C       IMPLEMENTATION OF FIT FOR EQUATION J.1                               FIT   54
C                                                                            FIT   55
30      IF(IENTRY.EQ.3) GO TO 1000                                           FIT   56
        ZDOTM=.5*(ZDOT+ZDOLD)                                                FIT   57
C       IMPLEMENT TESTS OF EQUATIONS J.2 AND J.3                             FIT   58
        IF(ABS(ZDOTM).LE..05*ABS(ZDOT)) GO TO 1000                           FIT   59
        FCTR=(Z(NZ)-ZOLD)*DTI/ZDOTM                                          FIT   60
        D2Z=FCTR*D2Z                                                         FIT   61
        ZDOT=FCTR*ZDOT                                                       FIT   62
C       END FIT                                                              FIT   63
C                                                                            FIT   64
C       COMMON CODE FOR FIT AND FIT3                                         FIT   65
1000    RAD=ZDOT*ZDOT-2.0*Z(NZ)*D2Z                                          FIT   66
        RAD1=SQRT(AMAX1(RAD,0.0))                                            FIT   67
C                                                                            FIT   68
2000    CONTINUE                                                             FIT   69
C                                                                            FIT   70
        END                                                                  FIT   71
```

```
        FUNCTION GET1(Z)                                                     GET   14
C       FUNCTIONALLY THE SAME AS 'GET' PROGRAM, SEE DOCUMENTATION THERE      GET   15
C       NEEDED BECAUSE RECEIVER MODELS WILL CALL GET TO OBTAIN TERRAIN VA    GET   16
C       BUT THEY THEMSELVES ARE CALLED VIA GET. HENCE HAVE RE-ENTRANCE       GET   17
C       PROBLEM.                                                             GET   18
C                                                                            GET   19
        REAL Z(*)                                                            GET   20
```

```
      REAL PF(10),PG(10)                                                    GET   21
C     COMMON DECK "RKAM" INSERTED HERE                                      RKAMCOM2
      REAL KR,KTH,KPH                                                       RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)           RKAMCOM5
C     COMMON DECK "FNDER" INSERTED HERE                                     CFNDER 2
      COMMON/FNDER/NZ,NPZR,NPZRR,NPZRTH,NPZRPH,NPZTH,NPZPH,NPZTHTH          CFNDER 4
      COMMON/FNDER/NPZPHPH,NPZTHPH,NSELECT,NTIME                            CFNDER 5
C     COMMON DECK "RR" INSERTED HERE                                        CRR    2
      REAL MODREC                                                           CRR    4
      COMMON/RR/ MODREC(4)                                                  CRR    5
      COMMON/RR/F,PFR,PFRR,PFRTH,PFRPH                                      CRR    6
      COMMON/RR/PFTH,PFPH,PFTHTH,PFPHPH,PFTHPH,FSELECT,FTIME                CRR    7
C     COMMON DECK "GG" INSERTED HERE                                        CGG    2
      REAL MODG                                                             CGG    4
      COMMON/GG/MODG(4)                                                     CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                      CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME                CGG    7
C     COMMON DECK "RKTIME" INSERTED HERE                                    CRKTIME2
      COMMON/CRKTIME/RKTIME                                                 CRKTIME4
C                                                                           GET   27
C     COMMON DECK "RMACH" INSERTED HERE                                     CRMACH 2
      COMMON/CRMACH/RMACH(5)                                                CRMACH 4
      EQUIVALENCE(RKTIME,IRKTIME)                                           GET   29
C     COMMON DECK "WWR" INSERTED HERE                                       CWWR   2
      PARAMETER (NWARSZ=1000)                                               CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                       CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                    CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),        CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),          CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),              CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),             CWW2   6
     8 (RCVRH,W(20)),                                                       CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))    CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                          CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                          CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                         CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),           CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))            CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),            CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                  CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                       CWW2  16
C                                                                           GET   31
      COMMON/CGET/ZERO                                                      GET   32
C                                                                           GET   33
      IENTRY=1                                                              GET   34
      GO TO 5                                                               GET   35
C                                                                           GET   36
      ENTRY DOT1(Z)                                                         GET   37
      IENTRY=2                                                              GET   38
5     CONTINUE                                                              GET   39
      IF(ZERO.EQ.0.0) ZERO=EARTHR*RMACH(3)*2.0                              GET   40
C                                                                           GET   41
      IF(ITEST(Z(NTIME)).EQ.IRKTIME) GO TO 10                               GET   42
C                                                                           GET   43
      IF(Z(NSELECT).EQ.FSELECT) CALL RECEVER                                GET   44
```

```
      IF(Z(NSELECT).EQ.GSELECT) CALL TOPOG                                  GET   45
      Z(NTIME)=RKTIME                                                       GET   46
C     REMOVE MACHINE ROUND OFF NOISE FROM EXACT RECEIVER LOCATIONS          GET   47
      IF(ABS(Z(NZ)).LE.ZERO) Z(NZ)=0.0                                      GET   48
C                                                                           GET   49
10    IF(IENTRY.NE.1) GO TO 20                                              GET   50
      GET1=Z(NZ)                                                            GET   51
      RETURN                                                                GET   52
C                                                                           GET   53
20    GET1=Z(NPZR)*DRDT(1)+Z(NPZTH)*DRDT(2)+Z(NPZPH)*DRDT(3)                GET   54
      RETURN                                                                GET   55
      ENTRY GETST1(Z)                                                       GET   56
C                                                                           GET   57
C     FORCE LOAD THE GET ROUTINE                                            GET   58
      CALL GET                                                              GET   59
      END                                                                   GET   60
```

```
      FUNCTION GET(Z)                                                       GET   61
C     'GET' AND ENTRY 'DOT' PROVIDE A CONTROL METHOD FOR AVOIDING           GET   62
C     REDUNDANT CALLS TO THE TERRAIN AND RECEIVER MODELS. THE VALUES        GET   63
C     RETURNED ARE THE FUNCTION VALUES FOR 'F' OR 'G' OR THEIR DERIVATI     GET   64
C     (VIA 'DOT' ENTRY). UNNECESSARY CALLS ARE ELIMINATED THROUGH USE       GET   65
C     OF 'TIME OF CALL' VARIABLES WHICH ARE COMPARED WITH THE CURRENT       GET   66
C     LAST CALL TIME MAINTAINED BY THE 'RKAM' PROGRAM. WHEN VALUES ARE      GET   67
C     NOT CURRENT THEY ARE UPDATED BY CALLS TO THE APPROPRIATE ROUTINES     GET   68
C                                                                           GET   69
      REAL Z(*),PF(10),PG(10)                                               GET   70
C     COMMON DECK "RKAM" INSERTED HERE                                      RKAMCOM2
      REAL KR,KTH,KPH                                                       RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)           RKAMCOM5
C     COMMON DECK "FNDER" INSERTED HERE                                     CFNDER 2
      COMMON/FNDER/NZ,NPZR,NPZRR,NPZRTH,NPZRPH,NPZTH,NPZPH,NPZTHTH          CFNDER 4
      COMMON/FNDER/NPZPHPH,NPZTHPH,NSELECT,NTIME                            CFNDER 5
C     COMMON DECK "RR" INSERTED HERE                                        CRR    2
      REAL MODREC                                                           CRR    4
      COMMON/RR/ MODREC(4)                                                  CRR    5
      COMMON/RR/F,PFR,PFRR,PFRTH,PFRPH                                      CRR    6
      COMMON/RR/PFTH,PFPH,PFTHTH,PFPHPH,PFTHPH,FSELECT,FTIME                CRR    7
C     COMMON DECK "GG" INSERTED HERE                                        CGG    2
      REAL MODG                                                             CGG    4
      COMMON/GG/MODG(4)                                                     CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                      CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME                CGG    7
C     COMMON DECK "RKTIME" INSERTED HERE                                    CRKTIME2
      COMMON/CRKTIME/RKTIME                                                 CRKTIME4
C                                                                           GET   76
C     COMMON DECK "RMACH" INSERTED HERE                                     CRMACH 2
      COMMON/CRMACH/RMACH(5)                                                CRMACH 4
      EQUIVALENCE(RKTIME,IRKTIME)                                           GET   78
C                                                                           GET   79
C     COMMON DECK "WWR" INSERTED HERE                                       CWWR   2
```

```
      PARAMETER (NWARSZ=1000)                                                    CWW1    3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                            CWW1    4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                         CWW2    2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),             CWW2    3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),               CWW2    4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                   CWW2    5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),                  CWW2    6
     8 (RCVRH,W(20)),                                                           CWW2    7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))        CWW2    8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                              CWW2    9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                              CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                             CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),               CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))                CWW2   13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),                CWW2   14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                      CWW2   15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                           CWW2   16
C                                                                               GET    81
      COMMON/CGET/ZERO                                                          GET    82
C                                                                               GET    83
      EQUIVALENCE (PF,PFR), (PG,PGR)                                            GBL     2
      DATA PF,PG/1.0,9*0.0,1.0,9*0.0/                                           GBL     3
      DATA NZ,NPZR,NPZRR,NPZRTH,NPZRPH,NPZTH,NPZPH,NPZTHTH                      GBL     4
     1    ,NPZPHPH,NPZTHPH,NSELECT,NTIME                                        GBL     5
     2  /1,2,3,4,5,6,7,8,9,10,11,12/                                            GBL     6
      DATA FTIME,GTIME,FSELECT,GSELECT/2*-1.0,8HRECEIVER ,7HTERRAIN /           GBL     7
      DATA ZERO/0.0/                                                            GBL     8
C                                                                               GET    86
      IENTRY=1                                                                  GET    87
      GO TO 5                                                                   GET    88
C                                                                               GET    89
      ENTRY DOT(Z)                                                              GET    90
      IENTRY=2                                                                  GET    91
5     CONTINUE                                                                  GET    92
      IF(ZERO.EQ.0.0) ZERO=EARTHR*RMACH(3)*2.0                                  GET    93
C                                                                               GET    94
      IF(ITEST(Z(NTIME)).EQ.IRKTIME) GO TO 10                                   GET    95
C                                                                               GET    96
      IF(Z(NSELECT).EQ.FSELECT) CALL RECEVER                                    GET    97
      IF(Z(NSELECT).EQ.GSELECT) CALL TOPOG                                      GET    98
      Z(NTIME)=RKTIME                                                           GET    99
C     REMOVE MACHINE ROUND OFF NOISE FROM EXACT RECEIVER LOCATIONS              GET   100
      IF(ABS(Z(NZ)).LE.ZERO) Z(NZ)=0.0                                          GET   101
C                                                                               GET   102
10    IF(IENTRY.NE.1) GO TO 20                                                  GET   103
      GET=Z(NZ)                                                                 GET   104
      RETURN                                                                    GET   105
C                                                                               GET   106
20    GET=Z(NPZR)*DRDT(1)+Z(NPZTH)*DRDT(2)+Z(NPZPH)*DRDT(3)                     GET   107
      RETURN                                                                    GET   108
      ENTRY DFCNCL(Z)                                                           GET   109
C                                                                               GET   110
C     FORCE LOAD THE MACHINE DEPENDENT CONSTANTS(SEE MODULE 'DFCNST')           GET   111
C                                                                               GET   112
      CALL DFCNST                                                               GET   113
```

```
      END                                                                    GET  114



      FUNCTION ITEST(I)                                                      ITEST  2
C     USED TO PASS INTEGER VALUES THROUGH FOR VARIABLES TYPED REAL           ITEST  3
C     (AS IN MIXED REAL/INTEGER ARRAYS)                                      ITEST  4
      ITEST=I                                                                ITEST  5
      END                                                                    ITEST  6



      SUBROUTINE CONBLK                                                      CONBLK 3
C     DATA INITIALIZATION AND FILE OPENING SERVICE ROUTINE                   CONBLK 4
C                                                                            CONBLK 5
C     COMMON DECK "HDR" INSERTED HERE                                        CHDR   2
      CHARACTER*10 INITID*80,DAT,TOD                                         CHDR   4
      COMMON/HDR/SEC                                                         CHDR   5
      COMMON/HDRC/INITID,DAT,TOD                                             CHDR   6
C                                                                            CONBLK 9
C     COMMON DECK "CPROCFL" INSERTED HERE                                    CPROCFL2
      INTEGER PMX,PNTBL,PITBL,PFRMTBL,IDSP(10)                               CPROCFL4
C     PARAMETER DECK "PGROUPS"                                               PGROUPS2
      PARAMETER (NCHPG1=11,NWPV=250,NSPGP=NCHPG1+2*NWPV+1)                   PGROUPS3
      PARAMETER (MNGRP=9,MXGRP=69,MXLIST=MXGRP-MNGRP+2)                      PGROUPS4
      COMMON/PROCFL/LIST(MXLIST)                                             CPROCFL6
      COMMON/PROCFL/PMX,PNTBL(10),PITBL(10),PFRMTBL(10),PGP(NSPGP)           CPROCFL7
      EQUIVALENCE (PGP,IDSP)                                                 CPROCFL8
C     COMMON DECK "CC" INSERTED HERE                                         CCC    2
      REAL MODC                                                              CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                             CCC    5
C     COMMON DECK "GG" INSERTED HERE                                         CGG    2
      REAL MODG                                                              CGG    4
      COMMON/GG/MODG(4)                                                      CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                       CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME                 CGG    7
C     COMMON DECK "RR" INSERTED HERE                                         CRR    2
      REAL MODREC                                                            CRR    4
      COMMON/RR/ MODREC(4)                                                   CRR    5
      COMMON/RR/F,PFR,PFRR,PFRTH,PFRPH                                       CRR    6
      COMMON/RR/PFTH,PFPH,PFTHTH,PFPHPH,PFTHPH,FSELECT,FTIME                 CRR    7
C     COMMON DECK "TT" INSERTED HERE                                         CTT    2
      REAL MODT                                                              CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                                 CTT    5
C     COMMON DECK "UU" INSERTED HERE                                         CUU    2
      REAL MODU                                                              CUU    4
      COMMON/UU/MODU(4)                                                      CUU    5
     1  ,V  ,PVT  ,PVR  ,PVTH  ,PVPH                                         CUU    6
     2  ,VR ,PVRT ,PVRR ,PVRTH ,PVRPH                                        CUU    7
     3  ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                       CUU    8
     4  ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                       CUU    9
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C                                                                       CONBLK16
C       COMMON DECK "RAYDEV" INSERTED HERE                              CRAYDEV2
C       DEVICE ASSIGNED TO RAYTRC INPUT FILE                            CRAYDEV4
        COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN             CRAYDEV5
C       COMMON DECK "CUCON" INSERTED HERE                               CUCON  2
        COMMON/UCONV/CNVV(4,4)                                          CUCON  4
        CHARACTER PCV*3,CNVC*2                                          CUCON  5
        COMMON/UCONC/PCV(4),CNVC(4,4)                                   CUCON  6
C                                                                       CONBLK19
C       COMMON DECK "SS" INSERTED HERE                                  CSS    2
        REAL MODSURF                                                    CSS    4
        COMMON/SS/ MODSURF(4)                                           CSS    5
        COMMON/SS/U,PUR,PURR,PURTH,PURPH                                CSS    6
        COMMON/SS/PUTH,PUPH,PUTHTH,PUPHPH,PUTHPH,USELECT,UTIME          CSS    7
C       COMMON DECK "CONST" INSERTED HERE                               CCONST 2
        COMMON/PCONST/CREF,RGAS,GAMMA                                   CCONST 4
        COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                       CCONST 5
C       COMMON DECK "WWR" INSERTED HERE                                 CWWR   2
        PARAMETER (NWARSZ=1000)                                         CWW1   3
        COMMON/WW/ID(10),MAXW,W(NWARSZ)                                 CWW1   4
        REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                              CWW2   2
        EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),  CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         CWW2   6
     8 (RCVRH,W(20)),                                                   CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))        CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),        CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))              CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                   CWW2  16
C       COMMON DECK "B9" INSERTED HERE                                  CB8    2
        INTEGER GMX,GNTBL,GITBL,GFRMTBL,IDSG(10)                        CB8    4
        COMMON/B9/GMX,GNTBL(10),GITBL(10),GFRMTBL(10),GGP(113)          CB8    5
        EQUIVALENCE (GGP,IDSG),(ANG,GGP(11))                            CB8    6
C       COMMON DECK "B2" INSERTED HERE                                  CB2    2
        INTEGER DUMX,DUNTBL,DUITBL,DUFRMTB,IDSDU(10)                    CB2    4
        COMMON/B2/DUMX,DUNTBL(10),DUITBL(10),DUFRMTB(10),DUGP(10)       CB2    5
        EQUIVALENCE (DUGP,IDSDU)                                        CB2    6
C       COMMON DECK "B4" INSERTED HERE                                  CB4    2
        INTEGER DCMX,DCNTBL,DCITBL,DCFRMTB,IDSDC(10)                    CB4    4
        COMMON/B4/DCMX,DCNTBL(10),DCITBL(10),DCFRMTB(10),DCGP(10)       CB4    5
        EQUIVALENCE (DCGP,IDSDC)                                        CB4    6
C       COMMON DECK "B6" INSERTED HERE                                  CB6    2
        INTEGER DTMX,DTNTBL,DTITBL,DTFRMTB,IDSDT(10)                    CB6    4
        COMMON/B6/DTMX,DTNTBL(10),DTITBL(10),DTFRMTB(10),DTGP(10)       CB6    5
        EQUIVALENCE (DTGP,IDSDT)                                        CB6    6
C       COMMON DECK "B1" INSERTED HERE                                  CB1    2
        INTEGER UMX,UNTBL,UITBL,UFRMTBL,IDSU(10)                        CB1    4
        COMMON/B1/UMX,UNTBL(10),UITBL(10),UFRMTBL(10),UGP(10)           CB1    5
        EQUIVALENCE (UGP,IDSU)                                          CB1    6
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C       COMMON DECK "B3" INSERTED HERE                                          CB3     2
        INTEGER CMX,CNTBL,CITBL,CFRMTBL,IDSC(10)                                CB3     4
        COMMON/B3/CMX,CNTBL(10),CITBL(10),CFRMTBL(10),CGP(512)                  CB3     5
        EQUIVALENCE (CGP,IDSC),(ANC,CGP(11))                                    CB3     6
C       COMMON DECK "B5" INSERTED HERE                                          CB5     2
        INTEGER TMX,TNTBL,TITBL,TFRMTBL,IDST(10)                                CB5     4
        COMMON/B5/TMX,TNTBL(10),TITBL(10),TFRMTBL(10),TGP(262)                  CB5     5
        EQUIVALENCE (TGP,IDST),(ANT,TGP(11))                                    CB5     6
C       COMMON DECK "B7" INSERTED HERE                                          CB7     2
        INTEGER MMX,MNTBL,MITBL,MFRMTBL,IDSM(10)                                CB7     4
        REAL MGP                                                                CB7     5
        COMMON/B7/MMX,MNTBL(10),MITBL(10),MFRMTBL(10),MGP(10)                   CB7     6
        EQUIVALENCE (MGP,IDSM)                                                  CB7     7
C       COMMON DECK "RINPLEX" INSERTED HERE                                     CRINPLE2
        REAL KAY2,KAY2I                                                         CRINPLE4
        COMPLEX PNP,POLAR,LPOLAR                                                CRINPLE5
        LOGICAL SPACE                                                           CRINPLE6
        CHARACTER DISPM*6                                                       CRINPLE7
        COMMON/RINPL/DISPM                                                      CRINPLE8
        COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                       CRINPLE9
        COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I                                   CRINPL10
        COMMON/RIN/PNP(10),POLAR,LPOLAR,SGN                                     CRINPL11
C       COMMON DECK "MM" INSERTED HERE                                          CMM     2
        REAL M,MODM                                                             CMM     4
        COMMON/MM/MODM(4),M,PMT,PMR,PMTH,PMPH                                   CMM     5
C       COMMON DECK "PP" INSERTED HERE                                          CPP     2
        REAL MODP                                                               CPP     4
        COMMON/PP/MODP(4),P,PPT,PPR,PPTH,PPPH                                   CPP     5
C       COMMON DECK "AA" INSERTED HERE                                          CAA     2
        REAL MODA                                                               CAA     4
        REAL MU,MUPT,MUPR,MUPTH,MUPPH                                           CAA     5
        REAL KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                                      CAA     6
        COMMON/AA/MODA(4),MU,MUPT,MUPR,MUPTH,MUPPH                              CAA     7
        COMMON/AA/KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                                 CAA     8
C       COMMON DECK "FLAG" INSERTED HERE                                        CFLAG   2
        LOGICAL NEWWR,NEWWP,NEWTRC,PENET                                        CFLAG   4
        COMMON /FLG/ NTYP,NEWWR,NEWWP,NEWTRC,PENET,LINES,IHOP,HPUNCH            CFLAG   5
        COMMON/FLGP/NSET                                                        CFLAG   6
C       COMMON DECK "RKTIME" INSERTED HERE                                      CRKTIME2
        COMMON/CRKTIME/RKTIME                                                   CRKTIME4
C                                                                               CONBLK37
        COMMON/RAYCON/MCONP                                                     CONBLK38
C                                                                               CONBLK39
        EQUIVALENCE(RKTIME,IRKTIME)                                             CONBLK40
C                                                                               CONBLK41
C       COMMON DECK "B10" INSERTED HERE                                         CB9     2
        INTEGER DGMX,DGNTBL,DGITBL,DGFRMTB,IDSDG(10)                            CB9     4
        COMMON/B10/DGMX,DGNTBL(10),DGITBL(10),DGFRMTB(10),DGGP(10)              CB9     5
        EQUIVALENCE (DGGP,IDSDG)                                                CB9     6
C       COMMON DECK "B8" INSERTED HERE                                          CB10    2
        INTEGER RMX,RNTBL,RITBL,RFRMTBL,IDSR(10)                                CB10    4
        COMMON/B8/RMX,RNTBL(10),RITBL(10),RFRMTBL(10),RGP(10)                   CB10    5
        EQUIVALENCE (RGP,IDSR)                                                  CB10    6
C       COMMON DECK "CB17" INSERTED HERE                                        CB17    2
        INTEGER VMX,VNTBL,VITBL,VFRMTBL,IDSV(10)                                CB17    4
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      COMMON/B17/VMX,VNTBL(10),VITBL(10),VFRMTBL(10),VGP(53)                CB17   5
      EQUIVALENCE (VGP,IDSV),(ANV,VGP(11))                                 CB17   6
C     COMMON DECK "CB18" INSERTED HERE                                     CB18   2
      INTEGER DVMX,DVNTBL,DVITBL,DVFRMTB,IDSDV(10)                         CB18   4
      COMMON/B18/DVMX,DVNTBL(10),DVITBL(10),DVFRMTB(10),DVGP(11)           CB18   5
      EQUIVALENCE (DVGP,IDSDV),(ANDV,DVGP(11))                             CB18   6
C     COMMON DECK "CB19" INSERTED HERE                                     CB19   2
      INTEGER PRMX,PRNTBL,PRITBL,PRFRMTB,IDSPR(10)                         CB19   4
      COMMON/B19/PRMX,PRNTBL(10),PRITBL(10),PRFRMTB(10),PRGP(11)           CB19   5
      EQUIVALENCE (PRGP,IDSPR),(ANP,PRGP(11))                              CB19   6
C     COMMON DECK "CB20" INSERTED HERE                                     CB20   2
      INTEGER DPMX,DPNTBL,DPITBL,DPFRMTB,IDSDP(10)                         CB20   4
      COMMON/B20/DPMX,DPNTBL(10),DPITBL(10),DPFRMTB(10),DPGP(11)           CB20   5
      EQUIVALENCE (DPGP,IDSDP),(ANDP,DPGP(11))                             CB20   6
      REAL KVECT(22)                                                       CONBLK48
      REAL VSET(20)                                                        CONBLK49
      EQUIVALENCE(KVECT,KAY2),(VSET,V)                                     CONBLK50
C                                                                          CONBLK51
      DATA KVECT/22*0.0/                                                   CONBLK52
      DATA RAYNAME/6*1H /                                                  CONBLK53
      DATA VSET/20*0.0/                                                    CONBLK54
      DATA OMEGMIN,OMEGMAX/0.0,0.0/                                        CONBLK55
      DATA POLAR,LPOLAR/(0.0,0.0),(1.0,0.0)/                               CONBLK56
C                                                                          CONBLK57
      DATA IRKTIME/0/                                                      CONBLK58
      DATA MCONP/0/                                                        CONBLK59
      DATA CREF,GAMMA,RGAS/1.0,1.4,8.31436E-3/                             CONBLK60
      DATA NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN/8,4,0,10,11/              CONBLK61
      DATA PCV/'AN','LN','FQ',' '/                                         CONBLK62
      DATA CNVC/'RD' ,'KM' ,'RD' ,' '                                      CONBLK63
     1         ,'DG' ,' M' ,'HZ' ,' '                                      CONBLK64
     2         ,'KM' ,'FT' ,'KH' ,' '                                      CONBLK65
     3         ,'  ' ,'NM' ,'DG' ,' '/                                     CONBLK66
      DATA CNVV /16*1.0 /                                                  CONBLK67
C                                                                          CONBLK68
      DATA IDSDC,IDSDT,IDSDU,IDSC,IDSM,IDST,IDSU,IDSG/80*1H /              CONBLK69
      DATA IDSDG,IDSV,IDSDV,IDSPR,IDSDP,IDSR/60*1H /                       CONBLK70
      DATA MODG/7HNO MODL,0.0,7HNO MODL,0.0/                               CONBLK71
      DATA MODREC/7HNO MODL,0.0,7HNO MODL,0.0/                             CONBLK72
      DATA MODC/7HNO MODL,0.0,7HNO MODL,0.0/                               CONBLK73
      DATA MODM/7HNO MODL,0.0,7HNO MODL,0.0/                               CONBLK74
      DATA MODT/7HNO MODL,0.0,7HNO MODL,0.0/                               CONBLK75
      DATA MODU/7HNO MODL,0.0,7HNO MODL,0.0/                               CONBLK76
      DATA MODC/7HNO MODL,0.0,7HNO MODL,0.0/                               CONBLK77
      DATA MODT/7HNO MODL,0.0,7HNO MODL,0.0/                               CONBLK78
      DATA MODM/7HNO MODL,0.0,7HNO MODL,0.0/                               CONBLK79
      DATA MODP/7HNO MODL,0.0,7HNO MODL,0.0/                               CONBLK80
      DATA MODA/7HNO MODL,0.0,7HNO MODL,0.0/                               CONBLK81
C                                                                          CONBLK82
      RETURN                                                               CONBLK91
C                                                                          CONBLK92
      ENTRY STDINI                                                         CONBLK93
      CALL OPNREP(NDEVTMP,'TAPE4')                                         CONBLK94
      CALL OPNURP(NDEVBIN,'TAPE6')                                         CONBLK95
      CALL OPNREP(9,'PUNCH')                                               CONBLK96
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C                                                                       CONBLK97
      ENTRY STDINT                                                      CONBLK98
      OPEN(UNIT=NRYIND,FILE='DINP',STATUS='OLD',ERR=1000)               CONBLK99
      REWIND NRYIND                                                     CONBL100
      CALL OPNREP(2,'OUTPUT')                                           CONBL101
      CALL OPNREP(3,'DOUTP')                                            CONBL102
      CALL OPNURP(NDEVGRP,'TAPE5')                                      CONBL103
C                                                                       CONBL104
C     TEMPORARY WE HOPE, TO MAKE CRAY VERSION WORK                      CONBL105
      FSELECT=8HRECEIVER                                                CONBL106
      GSELECT=7HTERRAIN                                                 CONBL107
C  INITIALIZE RAYSET FILE                                               CONBL108
      READ(NRYIND,'(A)',END=1000) INITID                                CONBL109
      CALL SETW                                                         CONBL110
      CALL SYSDAT(DAT)                                                  CONBL111
      CALL SYSTIM(TOD)                                                  CONBL112
      CALL SYSSEC(SEC)                                                  CONBL113
C     INITIALIZE POINT MODEL LIST                                       CONBL114
      LIST(1)=1                                                         CONBL115
      LIST(2)=0                                                         CONBL116
C     FILL FORMAT CONTROL ARRAYS                                        CONBL117
      PNTBL(1)=1                                                        CONBL118
C     ALLOW FOR AN 80 CHARACTER IDENT STRING(A8)                        CONBL119
      PNTBL(2)=NCHPG1                                                   CONBL120
C     ALLOW MAXIMUM 250 WORD PER VARIABLE                               CONBL121
      PITBL(2)=NWPV                                                     CONBL122
C     FOR BOTH X AND Y PLUS 1 FOR NUMBER OF VARIABLES                   CONBL123
      PNTBL(3)=NSPGP                                                    CONBL124
      RETURN                                                            CONBL125
1000  STOP 'DINP FORMAT ERROR'                                          CONBL126
      END                                                               CONBL127
```

```
      LOGICAL FUNCTION WCHANGE(W1,W2)                                   WCHANGE2
      REAL W1(400),W2(400)                                              WCHANGE3
C                                                                       WCHANGE4
C WCHANGE PROVIDES A TEST AGAINST TWO W-ARRAYS                          WCHANGE5
C     IF BOTH WOULD PRODUCE THE SAME SET OF RAYS BY RAYTRC THEN RESULT   WCHANGE6
C     IS <FALSE>.                                                       WCHANGE7
C                                                                       WCHANGE8
      INTEGER NDX(8)                                                    WCHANGE9
C                                                                       WCHANG10
      DATA NGRPS,NDX/8, 1,17, 21,26, 41,47, 100,399/                    WCHANG11
C                                                                       WCHANG12
      WCHANGE=.FALSE.                                                   WCHANG13
      DO 20 N=1,NGRPS,2                                                 WCHANG14
         N1=NDX(N)                                                      WCHANG15
         N2=NDX(N+1)                                                    WCHANG16
      DO 20 I=N1,N2                                                     WCHANG17
          WCHANGE=W1(I).NE.W2(I)                                        WCHANG18
          IF(WCHANGE) RETURN                                            WCHANG19
20    CONTINUE                                                          WCHANG20
```

```
      END                                                                WCHANG21



      FUNCTION RENORM(VECTOR,NNORM,NCOMPS)                               RENORM 2
C     NORMALIZES 'NCOMPS' COMPONENT VECTOR 'VECTOR' TO MAGNITUDE         RENORM 3
C     'NNORM' AND RETURNS SQUARE ROOT OF FACTOR NEEDED.                  RENORM 4
      REAL NNORM,VECTOR(*)                                               RENORM 5
C                                                                        RENORM 6
      RENORM=0.0                                                         RENORM 7
      IF(NNORM.LE.0.0) RETURN                                            RENORM 8
C                                                                        RENORM 9
      RENORM=0.0                                                         RENORM10
      DO 10 I=1,NCOMPS                                                   RENORM11
10    RENORM=RENORM+VECTOR(I)*VECTOR(I)                                  RENORM12
      IF(RENORM.EQ.0.0) RETURN                                           RENORM13
C                                                                        RENORM14
      RENORM=SQRT(NNORM/RENORM)                                          RENORM15
      DO 20 I=1,NCOMPS                                                   RENORM16
20    VECTOR(I)=VECTOR(I)*RENORM                                         RENORM17
C                                                                        RENORM18
      RETURN                                                             RENORM19
      END                                                                RENORM20



      SUBROUTINE SET2(A,V,N)                                             SET2   2
C     SETS N COMPONENTS OF VECTER TO SINGLE VALUE V                      SET2   3
C                                                                        SET2   4
      REAL A(N)                                                          SET2   5
C                                                                        SET2   6
      DO 100 I=1,N                                                       SET2   7
100   A(I)=V                                                             SET2   8
      END                                                                SET2   9



      SUBROUTINE PRINTR(EVENT,CARD)                                      PRINTR 2
C                                                                        PRINTR 3
      CHARACTER EVENT*9,NWHY*8,CC*1,PC*1,TMP*9                           PRINTR 4
C                                                                        PRINTR 5
C     PRINTS OUTPUT AND OUTPUTS RAYSETS(MACHINE READABLE OUTPUT)         PRINTR 6
C     WHEN 'CARD' ARGUMENT NONZERO.                                      PRINTR 7
      REAL KNORM                                                         PRINTR 8
      DIMENSION G0(3,3),G1(3,3)                                          PRINTR 9
      CHARACTER*12 HEADRS(20),HEAD(20),UNITS(20),UNIT(20)                PRINTR10
      DIMENSION RPRINT(20),NPR(20)                                       PRINTR11
C     COMMON DECK "RK" INSERTED HERE                                     CRK    2
C     DEFINE SIZE REQUIRED FOR RAY STATE SAVE ARRAY                      CRK    4
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      PARAMETER (LRKAMS=87+2*100,NXRKMS=12+LRKAMS,MXEQPT=21)                CRK     5
      PARAMETER (NRKSAV=NXRKMS+MXEQPT-1)                                   CRK     6
      COMMON /RK/ NEQS,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART       CRK     7
C     COMMON DECK "CERR" INSERTED HERE                                     CERR    2
      COMMON/ERR/NERG,NERR,NERT,NERP                                       CERR    3
C     COMMON DECK "GG" INSERTED HERE                                       CGG     2
      REAL MODG                                                            CGG     4
      COMMON/GG/MODG(4)                                                    CGG     5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                     CGG     6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME               CGG     7
C     COMMON DECK "CONST" INSERTED HERE                                    CCONST  2
      COMMON/PCONST/CREF,RGAS,GAMMA                                        CCONST  4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                            CCONST  5
C     COMMON DECK "FLAG" INSERTED HERE                                     CFLAG   2
      LOGICAL NEWWR,NEWWP,NEWTRC,PENET                                     CFLAG   4
      COMMON /FLG/ NTYP,NEWWR,NEWWP,NEWTRC,PENET,LINES,IHOP,HPUNCH         CFLAG   5
      COMMON/FLGP/NSET                                                     CFLAG   6
C     COMMON DECK "RINPLEX" INSERTED HERE                                  CRINPLE2
      REAL KAY2,KAY2I                                                      CRINPLE4
      COMPLEX PNP,POLAR,LPOLAR                                             CRINPLE5
      LOGICAL SPACE                                                        CRINPLE6
      CHARACTER DISPM*6                                                    CRINPLE7
      COMMON/RINPL/DISPM                                                   CRINPLE8
      COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                    CRINPLE9
      COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I                                CRINPL10
      COMMON/RIN/PNP(10),POLAR,LPOLAR,SGN                                  CRINPL11
C     COMMON DECK "RKAM" INSERTED HERE                                     RKAMCOM2
      REAL KR,KTH,KPH                                                      RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)          RKAMCOM5
C     COMMON DECK "WW" INSERTED HERE                                       CWW     2
      PARAMETER (NWARSZ=1000)                                              CWW1    3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                      CWW1    4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                   CWW2    2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),       CWW2    3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),         CWW2    4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),             CWW2    5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),            CWW2    6
     8 (RCVRH,W(20)),                                                      CWW2    7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))   CWW2    8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                         CWW2    9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                         CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                        CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),          CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))           CWW2   13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),           CWW2   14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                 CWW2   15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                      CWW2   16
      REAL MMODEL,MFORM,MID                                                CWW3    2
C                                                                          CWW3    3
C     WIND         100-124                                                 CWW3    4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)              CWW3    5
C                                                                          CWW3    6
C     DELTA WIND         125-149                                           CWW3    7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)           CWW3    8
C                                                                          CWW3    9
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C       SOUND SPEED 150-174                                                     CWW3   10
        EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                 CWW3   11
        EQUIVALENCE (W(153),REFC)                                               CWW3   12
C                                                                               CWW3   13
C       DELTA SOUND SPEED 175-199                                               CWW3   14
        EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)              CWW3   15
C                                                                               CWW3   16
C       TEMPERATURE    200-224                                                  CWW3   17
        EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                 CWW3   18
C                                                                               CWW3   19
C       DELTA TEMPERATURE    225-249                                            CWW3   20
        EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)              CWW3   21
C                                                                               CWW3   22
C       MOLECULAR   250-274                                                     CWW3   23
        EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                 CWW3   24
C                                                                               CWW3   25
C       RECEIVER HEIGHT   275-299                                               CWW3   26
        EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                 CWW3   27
C                                                                               CWW3   28
C       TOPOGRAPHY    300-324                                                   CWW3   29
        EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)                 CWW3   30
C                                                                               CWW3   31
C       DELTA TOPOGRAPHY    325-349                                             CWW3   32
        EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)              CWW3   33
C                                                                               CWW3   34
C       UPPER SURFACE TOPOGRAPHY    350-374                                     CWW3   35
        EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)                 CWW3   36
C       PLOT ENHANCEMENTS CONTROL PARAMETERS                                    CWW3   37
C                                                                               CWW3   38
        EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                             CWW3   39
C       ABSORPTION          500-524                                             CWW3   40
        EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)                 CWW3   41
C                                                                               CWW3   42
C       DELTA ABSORPTION          525-549                                       CWW3   43
        EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)              CWW3   44
C                                                                               CWW3   45
C       PRESSURE          550-574                                               CWW3   46
        EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)                 CWW3   47
C                                                                               CWW3   48
C       DELTA PRESSURE          575-599                                         CWW3   49
        EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)              CWW3   50
C                                                                               CWW3   51
        EQUIVALENCE(T,TPULSE),(PHI,PH),(TH,THETA)                               PRINTR20
        DATA                                                                    PRINTR21
     2  HEADRS(7)/'   PHASE TIME'/,UNITS(7)/'    SEC'/                         PRINTR22
     3 ,HEADRS(8)/'   ABSORPTION'/,UNITS(8)/'    DB '/                        PRINTR23
     4 ,HEADRS(9)/'    DOPPLER   '/,UNITS(9)/'   C/,S '/                       PRINTR24
     5 ,HEADRS(10)/' PATH LENGTH'/,UNITS(10)/'     KM '/                       PRINTR25
     6 ,HEADRS(11)/' TERRAIN'/,UNITS(11)/' '/                                   PRINTR26
     7 ,HEADRS(12)/' TERRAIN PGR'/,UNITS(12)/' '/                               PRINTR27
     8 ,HEADRS(13)/' TERRAIN PGT'/,UNITS(13)/' '/                               PRINTR28
     9 ,HEADRS(14)/' TERRAIN PGP'/,UNITS(14)/' '/                               PRINTR29
C                                                                               PRINTR30
C        ROUND-OFF FUNCTION                                                     PRINTR31
        ROUND(X)=SIGN(ABS(X)+0.5,X)                                             PRINTR32
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C                                                                       PRINTR33
      NWHY=EVENT(2:)                                                    PRINTR34
      GO TO 10                                                          PRINTR35
C                                                                       PRINTR36
C     INITIALIZATION ENTRY POINT FOR PRINTR. CALLED FOR EACH NEW        PRINTR37
C     W-ARRAY.                                                          PRINTR38
      ENTRY IPRINTR                                                     PRINTR39
C                                                                       PRINTR40
C********* NEW W ARRAY -- REINITIALIZE                                  PRINTR41
      NEWWP=.FALSE.                                                     PRINTR42
      SPL=SIN (PLON-TLON)                                               PRINTR43
      CPL=SIN (PID2-(PLON-TLON))                                        PRINTR44
      SP=SIN (PLAT)                                                     PRINTR45
      CP=SIN (PID2-PLAT)                                                PRINTR46
      SL=SIN (TLAT)                                                     PRINTR47
      CL=SIN (PID2-TLAT)                                                PRINTR48
C********* MATRIX TO ROTATE COORDINATES                                 PRINTR49
      G0(1,1)=CPL*SP*CL-CP*SL                                           PRINTR50
      G0(1,2)=SPL*SP                                                    PRINTR51
      G0(1,3)=-SL*SP*CPL-CL*CP                                          PRINTR52
      G0(2,1)=-SPL*CL                                                   PRINTR53
      G0(2,2)=CPL                                                       PRINTR54
      G0(2,3)=SL*SPL                                                    PRINTR55
      G0(3,1)=CL*CP*CPL+SP*SL                                           PRINTR56
      G0(3,2)=CP*SPL                                                    PRINTR57
      G0(3,3)=-SL*CP*CPL+SP*CL                                          PRINTR58
      DENM=G0(1,1)*G0(2,2)*G0(3,3)+G0(1,2)*G0(3,1)*G0(2,3)              PRINTR59
     1   +G0(2,1)*G0(3,2)*G0(1,3)-G0(2,2)*G0(3,1)*G0(1,3)               PRINTR60
     2   -G0(1,2)*G0(2,1)*G0(3,3)-G0(1,1)*G0(3,2)*G0(2,3)               PRINTR61
C********* THE MATRIX G1 IS THE INVERSE OF THE MATRIX G                 PRINTR62
      G1(1,1)=(G0(2,2)*G0(3,3)-G0(3,2)*G0(2,3))/DENM                    PRINTR63
      G1(1,2)=(G0(3,2)*G0(1,3)-G0(1,2)*G0(3,3))/DENM                    PRINTR64
      G1(1,3)=(G0(1,2)*G0(2,3)-G0(2,2)*G0(1,3))/DENM                    PRINTR65
      G1(2,1)=(G0(3,1)*G0(2,3)-G0(2,1)*G0(3,3))/DENM                    PRINTR66
      G1(2,2)=(G0(1,1)*G0(3,3)-G0(3,1)*G0(1,3))/DENM                    PRINTR67
      G1(2,3)=(G0(2,1)*G0(1,3)-G0(1,1)*G0(2,3))/DENM                    PRINTR68
      G1(3,1)=(G0(2,1)*G0(3,2)-G0(3,1)*G0(2,2))/DENM                    PRINTR69
      G1(3,2)=(G0(3,1)*G0(1,2)-G0(1,1)*G0(3,2))/DENM                    PRINTR70
      G1(3,3)=(G0(1,1)*G0(2,2)-G0(2,1)*G0(1,2))/DENM                    PRINTR71
      R0=EARTHR+XMTRH                                                   PRINTR72
C********* CARTESIAN COORDINATES OF TRANSMITTER                         PRINTR73
      XR=R0*G0(1,1)                                                     PRINTR74
      YR=R0*G0(2,1)                                                     PRINTR75
      ZR=R0*G0(3,1)                                                     PRINTR76
      CTHR=G0(3,1)                                                      PRINTR77
      STHR=SIN (ACOS (CTHR))                                            PRINTR78
      PHIR=ATAN2(YR,XR)                                                 PRINTR79
      ALPH=ATAN2(G0(3,2),G0(3,3))                                       PRINTR80
C*********                                                             PRINTR81
      NR=0                                                              PRINTR82
      NP=0                                                              PRINTR83
      NERG=0                                                            PRINTR84
      NERR=0                                                            PRINTR85
      NERT=0                                                            PRINTR86
      NERP=0                                                            PRINTR87
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C      INSURE NO GARBLE IN HEADERS                                          PRINTR88
       HEAD(1)=' '                                                          PRINTR89
       UNIT(1)=' '                                                          PRINTR90
C                                                                           PRINTR91
       DO 7 NN=7,20                                                         PRINTR92
       IF (W(NN+50).EQ.0.) GO TO 7                                          PRINTR93
C********* DEPENDENT VARIABLE NUMBER NN IS BEING INTEGRATED                 PRINTR94
C********* NR IS THE NUMBER OF DEPENDENT VARIABLES BEING INTEGRATED         PRINTR95
       NR=NR+1                                                              PRINTR96
C      ENABLE SELECTED RELATIVE ERROR PRINTOUTS FOR TERRAIN(G) OR           PRINTR97
C      ITS DERIVATIVES WITH RESPECT TO (R)ANGE, (T)HETA OR (P)HI.           PRINTR98
       IF(NN.EQ.11) NERG=NR                                                 PRINTR99
       IF(NN.EQ.12) NERR=NR                                                 PRINT100
       IF(NN.EQ.13) NERT=NR                                                 PRINT101
       IF(NN.EQ.14) NERP=NR                                                 PRINT102
       IF (W(NN+50).NE.2.) GO TO 7                                          PRINT103
C********* DEPENDENT VARIABLE NUMBER NN IS BEING INTEGRATED AND PRINTED.    PRINT104
C********* NP IS THE NUMBER OF DEPENDENT VARIABLES BEING INTEGRATED AND     PRINT105
C********* PRINTED                                                          PRINT106
       NP=NP+1                                                              PRINT107
C********* SAVE THE INDEX OF THE DEPENDENT VARIABLE TO PRINT                PRINT108
       NPR(NP)=NR                                                           PRINT109
       HEAD(NP)=HEADRS(NN)                                                  PRINT110
       HEAD(NP)=HEADRS(NN)                                                  PRINT111
       UNIT(NP)=UNITS(NN)                                                   PRINT112
     7 CONTINUE                                                             PRINT113
       NPM=MIN0(NP,3)                                                       PRINT114
       NP1=NPM+1                                                            PRINT115
       P=0.0                                                                PRINT116
       ABSORB=0.0                                                           PRINT117
       DOPP=0.0                                                             PRINT118
       NEQS=NR+6                                                            PRINT119
       RETURN                                                               PRINT120
C                                                                           PRINT121
       ENTRY PRNHD1(CC)                                                     PRINT122
C      PRINT PRINTR HEADER 1                                                PRINT123
C    IF NO OUTPUT NEEDED EXIT NOW                                           PRINT124
       IF(PRTSRP.NE.0.0) RETURN                                             PRINT125
C                                                                           PRINT126
C      ADD NUMBER OF LINES NEEDED FOR THIS HEADER                           PRINT127
       PC=CC                                                                PRINT128
       IF(CC.EQ.'1') CALL NEWPAG(NPAG,INT(PAGLN),PC)                        PRINT129
       LINES=LINES+3                                                        PRINT130
C********* PRINT COLUMN HEADINGS                                            PRINT131
C                                                                           PRINT132
       WRITE(3,1100) PC,(HEAD(NN),NN=1,NPM)                                 PRINT133
C                                                                           PRINT134
1100   FORMAT (   A,T25,'ELEVATION',T54,'AZIMUTH',T71,'ELEVATION'/          PRINT135
     3 ,T20,2('ABOVE',6X),T53,'DEVIATION',T72,'ANGLE'/'  ERROR   EVENT'     PRINT136
     4  ,T20,'SEA LEVEL  TERRAIN     RANGE',4X,2('XMTR   LOCAL',5X),       PRINT137
     5  'PULSE TIME',3A12)                                                 PRINT138
C                                                                           PRINT139
       WRITE(3,1150) (UNIT(NN),NN=1,NPM)                                    PRINT140
 1150 FORMAT(13X,3(8X,'KM'),2X,2(6X,'DEG',5X,'DEG'),T88                     PRINT141
     1 ,'SEC',3X,3(3X,A7,2X))                                               PRINT142
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C                                                                       PRINT143
      RETURN                                                            PRINT144
C                                                                       PRINT145
      ENTRY PRNHD2(CC)                                                  PRINT146
C     PRINT PRINTR HEADER 1                                             PRINT147
C   IF NO OUTPUT NEEDED EXIT NOW                                        PRINT148
      IF(PRTSRP.NE.0.0) RETURN                                          PRINT149
C     PAGE BY HALF LENGTH                                               PRINT150
      LINSPP=PAGLN/2                                                    PRINT151
      IF(LINSPP.LT.40) LINSPP=PAGLN                                     PRINT152
      PC=CC                                                             PRINT153
      IF(CC.EQ.'1') CALL NEWPAG(NPAG,LINSPP,PC)                         PRINT154
C     ADD NUMBER OF LINES NEEDED FOR THIS SUBHEADER                     PRINT155
      LINES=LINES+1                                                     PRINT156
C                                                                       PRINT157
      IF(ELEND.GE.ELBEG+ELSTEP) THEN                                    PRINT158
         WRITE(3,'(A,''ELEVATION ANGLE OF TRANSMISSION ='' '            PRINT159
     1    ,F10.4,'' DEG'')') PC,BETA*DEGS                              PRINT160
      ELSEIF(AZEND.GE.AZBEG+AZSTEP) THEN                                PRINT161
         WRITE(3,'(A,''AZIMUTH ANGLE OF TRANSMISSION ='' '              PRINT162
     1    ,F10.4,'' DEG'')') PC,AZ1*DEGS                               PRINT163
      ENDIF                                                             PRINT164
      RETURN                                                            PRINT165
C                                                                       PRINT166
C     IF PRINTING SUPPRESSED AND RAYSETS OFF NOTHING TO DO              PRINT167
10    IF(PRTSRP.NE.0.0 .AND. CARD.EQ.0.0) RETURN                        PRINT168
      CALL DISPER                                                       PRINT169
      IF (CARD.EQ.0.0 .OR. IHOP.NE.0) GO TO 12                          PRINT170
C********* OUTPUT A TRANSMITTER RAYSET                                 PRINT171
C        NOTE: THIS IS A SPECIAL CASE, ALL OTHER RAY EVENTS ARE         PRINT172
C           OUTPUT AT CODE 'PUNCH A RAYSET' BELOW.                      PRINT173
C                                                                       PRINT174
      TLOND=TLON*DEGS                                                   PRINT175
      IF (TLOND.LT.0.) TLOND=TLOND+360.                                 PRINT176
      TLATD=TLAT*DEGS                                                   PRINT177
      IF (TLATD.LT.0.) TLATD=TLATD+360.                                 PRINT178
      AZ=AZ1*DEGS                                                       PRINT179
      EL=BETA*DEGS                                                      PRINT180
      NHOP=HOP                                                          PRINT181
      NXMTRH=ROUND(XMTRH*1.E4)                                          PRINT182
      NTLATD=ROUND(TLATD*1.E3)                                          PRINT183
       NTLOND=ROUND(TLOND*1.E3)                                         PRINT184
      NRCVRH=ROUND(RCVRH*1.E4)                                          PRINT185
       NF=ROUND(OW*1.E4)                                                PRINT186
      NAZ=ROUND(AZ*1.E5)                                                PRINT187
       NEL=ROUND(EL*1.E5)                                               PRINT188
      NPOLAR1=ROUND(REAL(POLAR)*1.E2)                                   PRINT189
       NPOLAR2=ROUND(AIMAG(POLAR)*1.E2)                                 PRINT190
      WRITE(9,1201) ID(1),TYPE(NTYP),NXMTRH,NTLATD,NTLOND,NRCVRH,NF,NAZ PRINT191
     1 ,NEL,NPOLAR1,NPOLAR2,NHOP,'T'                                    PRINT192
 1201 FORMAT(A3,A1,I9,2I6,2I9,2I10,5X,I5,I4,I2,A1)                      PRINT193
C*********                                                              PRINT194
12    V=1.E10                                                           PRINT195
C     OBTAIN THE WORST ERROR OF THOSE ENABLED.                          PRINT196
      IF (KAY2.NE.0.) V=(KR**2+KTH**2+KPH**2)/KAY2-1.                   PRINT197
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      ERT=1HK                                                          PRINT198
      V=RERR(V,ERT,'G',NERG,G)                                         PRINT199
      V=RERR(V,ERT,'R',NERR,PGR)                                       PRINT200
      V=RERR(V,ERT,'T',NERT,PGTH)                                      PRINT201
      V=RERR(V,ERT,'P',NERP,PGPH)                                      PRINT202
C                                                                      PRINT203
      H=R-EARTHR                                                       PRINT204
      STH=SIN (THETA)                                                  PRINT205
      CTH=SIN (PID2-THETA)                                             PRINT206
C********* CARTESIAN COORDINATES OF RAY POINT, ORIGIN AT TRANSMITTER    PRINT207
      XP=R*STH*SIN (PID2-PHI)-XR                                       PRINT208
      YP=R*STH*SIN (PHI)-YR                                            PRINT209
      ZP=R*CTH-ZR                                                      PRINT210
C********* CARTESIAN COORDINATES OF RAY POINT, ORIGIN AT TRANSMITTER ANDPRINT211
C********* ROTATED                                                     PRINT212
      EPS=XP*G1(1,1)+YP*G1(1,2)+ZP*G1(1,3)                             PRINT213
      ETA=XP*G1(2,1)+YP*G1(2,2)+ZP*G1(2,3)                             PRINT214
      ZETA=XP*G1(3,1)+YP*G1(3,2)+ZP*G1(3,3)                            PRINT215
      RCE2=ETA**2+ZETA**2                                              PRINT216
      RCE=SQRT (RCE2)                                                  PRINT217
C********* GROUND RANGE                                               PRINT218
      RANGE=EARTHR*ATAN2(RCE,EARTHR+EPS+XMTRH)                         PRINT219
C********* ANGLE OF WAVE NORMAL WITH LOCAL HORIZONTAL                  PRINT220
      ELL=ATAN2(KR,SQRT (KTH**2+KPH**2))*DEGS                          PRINT221
C********* STRAIGHT LINE DISTANCE FROM TRANSMITTER TO RAY POINT        PRINT222
      SR=SQRT (RCE2+EPS**2)                                            PRINT223
C********* TERRAIN RELATIVE HEIGHT                                    PRINT224
      GRH=GET(G)/PGR                                                   PRINT225
C     REPORT GROUP TIME AS FIRST 'OPTION'                              PRINT226
      RPRINT(1)=T                                                      PRINT227
      IF (NP1.LT.2) GO TO 16                                           PRINT228
C     ADD MORE OPTIONS IF REQUESTED                                    PRINT229
      DO 15 I=2,NP1                                                    PRINT230
      NN=NPR(I-1)                                                      PRINT231
   15 RPRINT(I)=RKVARS(NN)                                             PRINT232
C                                                                      PRINT233
16    IF(V.GE.0.0) THEN                                                PRINT234
         WRITE(TMP,'(A1,E7.2)') ERT,V                                  PRINT235
      ELSE                                                             PRINT236
         WRITE(TMP,'(A1,E7.1)') ERT,V                                  PRINT237
      ENDIF                                                            PRINT238
C     DETERMINE WHERE TO PUT A SPACE                                   PRINT239
C     AT BEGINNING OR END OF 1ST 2 VALUES                              PRINT240
      KT=1                                                             PRINT241
      IF(TMP(1:1).EQ.'K') KT=2                                         PRINT242
C                                                                      PRINT243
      IF (SR.GE.1.E-6) GO TO 20                                        PRINT244
C********* TOO CLOSE TO TRANSMITTER TO CALCULATE DIRECTION FROM        PRINT245
C********* TRANSMITTER                                                PRINT246
      IF(PRTSRP.EQ.0.0)                                                PRINT247
     1 WRITE(3,1500)TMP(KT:9),NWHY,H,GRH,RANGE,ELL,(RPRINT(NN),NN=1,NP1)PRINT248
 1500 FORMAT (1X,A8,A8,2F10.4,F11.4,26X,F8.3,4F12.4)                   PRINT249
C     SET RAYSET VARIABLES TO UNDEFINDED VALUES FOR FLAGS              PRINT250
      AZDEV=999.0                                                      PRINT251
      AZA=999.0                                                        PRINT252
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      GO TO 40                                                                  PRINT253
C********* ELEVATION ANGLE OF RAY POINT FROM TRANSMITTER                        PRINT254
   20 EL=ATAN2(EPS,RCE)*DEGS                                                    PRINT255
      IF (RCE.GE.1.E-6) GO TO 30                                                PRINT256
C********* NEARLY DIRECTLY ABOVE OR BELOW TRANSMITTER. CAN NOT CALCULATEPRINT257
C********* AZIMUTH DIRECTION FROM TRANSMITTER ACCURATELY                       PRINT258
      IF(PRTSRP.EQ.0.0)                                                         PRINT259
     1   WRITE(3,2500)TMP(KT:9),NWHY,H,GRH,RANGE,EL,ELL                        PRINT260
     2  ,(RPRINT(NN),NN=1,NP1)                                                 PRINT261
 2500 FORMAT (1X,A8,A8,2F10.4,F11.4,17X,F9.3,F8.3,                              PRINT262
     1 4F12.4)                                                                  PRINT263
      GO TO 40                                                                  PRINT264
C********* AZIMUTH ANGLE OF RAY POINT FROM TRANSMITTER                         PRINT265
   30 ANGA=ATAN2(ETA,ZETA)                                                      PRINT266
      AZDEV=180.-AMOD(540.-(AZ1-ANGA)*DEGS,360.)                                PRINT267
      IF (KTH.NE.0..OR.KPH.NE.0.) GO TO 34                                      PRINT268
C********* WAVE NORMAL IS VERTICAL, SO AZIMUTH DIRECTION CANNOT BE             PRINT269
C********* CALCULATED                                                          PRINT270
      IF(PRTSRP.EQ.0.0)                                                         PRINT271
     1 WRITE(3,3000)TMP(KT:9),NWHY,H,GRH,RANGE,AZDEV,EL,ELL,(RPRINT(NN),PRINT272
     1 NN=1,NP1)                                                                PRINT273
 3000 FORMAT (1X,A8,A8,2F10.4,F11.4,F9.3,8X,F9.3,F8.3,                          PRINT274
     1 4F12.4)                                                                  PRINT275
      GO TO 40                                                                  PRINT276
   34 ANA=ANGA-ALPH                                                             PRINT277
      SANA=SIN (ANA)                                                            PRINT278
      SPHI=SANA*STHR/STH                                                        PRINT279
      CPHI=-SIN (PID2-ANA)*SIN (PID2-(PHI-PHIR))+SANA*SIN (PHI-PHIR)            PRINT280
     1 *CTHR                                                                    PRINT281
      AZA=180.-AMOD (540.-(ATAN2(SPHI,CPHI)-ATAN2(KPH,KTH))*DEGS,360.)          PRINT282
      IF(PRTSRP.EQ.0.0)                                                         PRINT283
     1  WRITE(3,3500)TMP(KT:9),NWHY,H,GRH,RANGE,AZDEV,AZA,EL,ELL               PRINT284
     2  ,(RPRINT(NN),NN=1,NP1)                                                 PRINT285
 3500 FORMAT (1X,A8,A8,2F10.4,F11.4,2(F9.3,F8.3),                               PRINT286
     1 4F12.4)                                                                  PRINT287
C*********                                                                     PRINT288
   40 LINES=LINES+1                                                             PRINT289
      IF (NP.LE.3) GO TO 45                                                     PRINT290
C********* ADDITIONAL LINE TO PRINT REMAINING DEPENDENT INTEGRATION            PRINT291
C********* VARIABLES                                                          PRINT292
      IF(PRTSRP.EQ.0.0)                                                         PRINT293
     1   WRITE(3,4000) (RPRINT(NN),NN=4,NP)                                     PRINT294
 4000 FORMAT (99X,3F12.4)                                                       PRINT295
      LINES=LINES+1                                                             PRINT296
C                                                                               PRINT297
C     IF NO 'CARDS' WANTED OR AT TRANSMITTER, NO RAYSET OUTPUT                  PRINT298
C                                                                               PRINT299
45    IF (CARD.EQ.0.0 .OR. IHOP.LT.1) RETURN                                    PRINT300
C                                                                               PRINT301
C********* PUNCH A RAYSET                                                     PRINT302
      IF (AZDEV.LT.-90.) AZDEV=AZDEV+360.                                       PRINT303
      IF (AZA.LT.-90.) AZA=AZA+360.                                             PRINT304
      NR=0                                                                      PRINT305
      IF (W(57).EQ.0.) GO TO 47                                                 PRINT306
C********* PHASE PATH                                                         PRINT307
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      NR=NR+1                                                          PRINT308
      P=RKVARS(NR)                                                     PRINT309
   47 IF (W(58).EQ.0.) GO TO 48                                        PRINT310
C********* ABSORPTION                                                  PRINT311
      NR=NR+1                                                          PRINT312
      ABSORB=RKVARS(NR)                                                PRINT313
C********* DOPPLER SHIFT                                              PRINT314
   48 IF (W(59).NE.0.) DOPP=RKVARS(NR+1)                               PRINT315
      NHPUNCH=ROUND(HPUNCH*1.E4)                                       PRINT316
       NRANGE=ROUND(RANGE*1.E4)                                        PRINT317
      NAZDEV=ROUND(AZDEV*1.E3)                                         PRINT318
       NAZA=ROUND(AZA*1.E3)                                            PRINT319
       NELL=ROUND(ELL*1.E3)                                            PRINT320
      IF(NWHY.EQ.'GRND REF') NELL =                                    PRINT321
     1 ROUND((PID2 - ACOS(KNORM(G)/SQRT(KR*KR+KTH*KTH+KPH*KPH))))      PRINT322
     2   *DEGS*1.E3)                                                   PRINT323
       NABSORB=AMIN1(999999.0,ROUND(ABSORB*1.E3))                      PRINT324
       NDOPP=ROUND(DOPP*1.E3)                                          PRINT325
       NPOLAR1=ROUND(REAL(POLAR)*1.E2)                                 PRINT326
       NPOLAR2=ROUND(AIMAG(POLAR)*1.E2)                                PRINT327
       JP=ROUND(P*1.E5)                                                PRINT328
       JT=ROUND(T*1.E5)                                                PRINT329
       WRITE(9,4501) NHPUNCH,NRANGE,NAZDEV,NAZA,NELL,JT,JP,NABSORB     PRINT330
     1 ,NDOPP,NPOLAR1,NPOLAR2,IHOP,EVENT(1:1)                          PRINT331
 4501 FORMAT(2I9,3I6,2I10,2I6,I5,I4,I2,A1)                           PRINT332
       RETURN                                                          PRINT333
       END                                                             PRINT334
```

```
      SUBROUTINE ATMOSHD                                               ATMOSHD2
C     PRINTS PAGE HEADINGS                                             ATMOSHD3
C     IF W(72) IS NEGATIVE, ONLY ONE HEADER OUTPUT IS INCLUDED IN RAYSE ATMOSHD4
      CHARACTER PCC*1,PC*1,BLANKS*100,DIVIDR*132,BANNER(8)*80          ATMOSHD5
      CHARACTER NUMSTG*80,STMP*80                                      ATMOSHD6
      LOGICAL NOPUNCH                                                  ATMOSHD7
      INTEGER STRIM                                                    ATMOSHD8
C                                                                      ATMOSHD9
C     TWO ENTRY POINTS ARE PROVIDED. ONE FOR THE FIRST PAGE HEADER     ATMOSH10
C     OF THE COMPUTATIONAL PRINTOUT AND FOR THE RAYSET FILE. THE       ATMOSH11
C     SECOND ENTRY IS FOR ALL SUBSEQUENT PAGES OF THE COMPUTATIONAL    ATMOSH12
C     PRINTOUT.                                                        ATMOSH13
C                                                                      ATMOSH14
C     COMMON DECK "AA" INSERTED HERE                                   CAA    2
      REAL MODA                                                        CAA    4
      REAL MU,MUPT,MUPR,MUPTH,MUPPH                                    CAA    5
      REAL KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                               CAA    6
      COMMON/AA/MODA(4),MU,MUPT,MUPR,MUPTH,MUPPH                       CAA    7
      COMMON/AA/KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                          CAA    8
C     COMMON DECK "PP" INSERTED HERE                                   CPP    2
      REAL MODP                                                        CPP    4
      COMMON/PP/MODP(4),P,PPT,PPR,PPTH,PPPH                            CPP    5
C                                                                      ATMOSH17
```

```
C     COMMON DECK "SS" INSERTED HERE                                          CSS    2
      REAL MODSURF                                                            CSS    4
      COMMON/SS/ MODSURF(4)                                                   CSS    5
      COMMON/SS/U,PUR,PURR,PURTH,PURPH                                        CSS    6
      COMMON/SS/PUTH,PUPH,PUTHTH,PUPHPH,PUTHPH,USELECT,UTIME                  CSS    7
C     COMMON DECK "CONST" INSERTED HERE                                       CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                           CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                               CCONST 5
C     COMMON DECK "WWR" INSERTED HERE                                         CWWR   2
      PARAMETER (NWARSZ=1000)                                                 CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                         CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                      CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),          CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),            CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),               CWW2   6
     8 (RCVRH,W(20)),                                                         CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))      CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                            CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                            CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                           CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),             CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))              CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),              CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                    CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                         CWW2  16
C     COMMON DECK "GG" INSERTED HERE                                          CGG    2
      REAL MODG                                                               CGG    4
      COMMON/GG/MODG(4)                                                       CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                        CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME                  CGG    7
C     COMMON DECK "RR" INSERTED HERE                                          CRR    2
      REAL MODREC                                                             CRR    4
      COMMON/RR/ MODREC(4)                                                    CRR    5
      COMMON/RR/F,PFR,PFRR,PFRTH,PFRPH                                        CRR    6
      COMMON/RR/PFTH,PFPH,PFTHTH,PFPHPH,PFTHPH,FSELECT,FTIME                  CRR    7
C     COMMON DECK "B9" INSERTED HERE                                          CB8    2
      INTEGER GMX,GNTBL,GITBL,GFRMTBL,IDSG(10)                                CB8    4
      COMMON/B9/GMX,GNTBL(10),GITBL(10),GFRMTBL(10),GGP(113)                  CB8    5
      EQUIVALENCE (GGP,IDSG),(ANG,GGP(11))                                    CB8    6
C     COMMON DECK "B2" INSERTED HERE                                          CB2    2
      INTEGER DUMX,DUNTBL,DUITBL,DUFRMTB,IDSDU(10)                            CB2    4
      COMMON/B2/DUMX,DUNTBL(10),DUITBL(10),DUFRMTB(10),DUGP(10)               CB2    5
      EQUIVALENCE (DUGP,IDSDU)                                                CB2    6
C     COMMON DECK "B4" INSERTED HERE                                          CB4    2
      INTEGER DCMX,DCNTBL,DCITBL,DCFRMTB,IDSDC(10)                            CB4    4
      COMMON/B4/DCMX,DCNTBL(10),DCITBL(10),DCFRMTB(10),DCGP(10)               CB4    5
      EQUIVALENCE (DCGP,IDSDC)                                                CB4    6
C     COMMON DECK "B6" INSERTED HERE                                          CB6    2
      INTEGER DTMX,DTNTBL,DTITBL,DTFRMTB,IDSDT(10)                            CB6    4
      COMMON/B6/DTMX,DTNTBL(10),DTITBL(10),DTFRMTB(10),DTGP(10)               CB6    5
      EQUIVALENCE (DTGP,IDSDT)                                                CB6    6
C     COMMON DECK "B1" INSERTED HERE                                          CB1    2
      INTEGER UMX,UNTBL,UITBL,UFRMTBL,IDSU(10)                                CB1    4
      COMMON/B1/UMX,UNTBL(10),UITBL(10),UFRMTBL(10),UGP(10)                   CB1    5
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      EQUIVALENCE (UGP,IDSU)                                                CB1    6
C     COMMON DECK "B3" INSERTED HERE                                        CB3    2
      INTEGER CMX,CNTBL,CITBL,CFRMTBL,IDSC(10)                              CB3    4
      COMMON/B3/CMX,CNTBL(10),CITBL(10),CFRMTBL(10),CGP(512)                CB3    5
      EQUIVALENCE (CGP,IDSC),(ANC,CGP(11))                                  CB3    6
C     COMMON DECK "B5" INSERTED HERE                                        CB5    2
      INTEGER TMX,TNTBL,TITBL,TFRMTBL,IDST(10)                              CB5    4
      COMMON/B5/TMX,TNTBL(10),TITBL(10),TFRMTBL(10),TGP(262)                CB5    5
      EQUIVALENCE (TGP,IDST),(ANT,TGP(11))                                  CB5    6
C     COMMON DECK "B7" INSERTED HERE                                        CB7    2
      INTEGER MMX,MNTBL,MITBL,MFRMTBL,IDSM(10)                              CB7    4
      REAL MGP                                                              CB7    5
      COMMON/B7/MMX,MNTBL(10),MITBL(10),MFRMTBL(10),MGP(10)                 CB7    6
      EQUIVALENCE (MGP,IDSM)                                                CB7    7
C     COMMON DECK "HDR" INSERTED HERE                                       CHDR   2
      CHARACTER*10 INITID*80,DAT,TOD                                        CHDR   4
      COMMON/HDR/SEC                                                        CHDR   5
      COMMON/HDRC/INITID,DAT,TOD                                            CHDR   6
C     COMMON DECK "RINPLEX" INSERTED HERE                                   CRINPLE2
      REAL KAY2,KAY2I                                                       CRINPLE4
      COMPLEX PNP,POLAR,LPOLAR                                              CRINPLE5
      LOGICAL SPACE                                                         CRINPLE6
      CHARACTER DISPM*6                                                     CRINPLE7
      COMMON/RINPL/DISPM                                                    CRINPLE8
      COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                     CRINPLE9
      COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I                                 CRINPL10
      COMMON/RIN/PNP(10),POLAR,LPOLAR,SGN                                   CRINPL11
C     COMMON DECK "CC" INSERTED HERE                                        CCC    2
      REAL MODC                                                             CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                            CCC    5
C     COMMON DECK "MM" INSERTED HERE                                        CMM    2
      REAL M,MODM                                                           CMM    4
      COMMON/MM/MODM(4),M,PMT,PMR,PMTH,PMPH                                 CMM    5
C     COMMON DECK "FLAG" INSERTED HERE                                      CFLAG  2
      LOGICAL NEWWR,NEWWP,NEWTRC,PENET                                      CFLAG  4
      COMMON /FLG/ NTYP,NEWWR,NEWWP,NEWTRC,PENET,LINES,IHOP,HPUNCH          CFLAG  5
      COMMON/FLGP/NSET                                                      CFLAG  6
C     COMMON DECK "TT" INSERTED HERE                                        CTT    2
      REAL MODT                                                             CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                                CTT    5
C     COMMON DECK "UU" INSERTED HERE                                        CUU    2
      REAL MODU                                                             CUU    4
      COMMON/UU/MODU(4)                                                     CUU    5
     1  ,V  ,PVT  ,PVR  ,PVTH  ,PVPH                                        CUU    6
     2  ,VR ,PVRT ,PVRR ,PVRTH ,PVRPH                                       CUU    7
     3  ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                      CUU    8
     4  ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                      CUU    9
C                                                                           ATMOSH38
C     COMMON DECK "B10" INSERTED HERE                                       CB9    2
      INTEGER DGMX,DGNTBL,DGITBL,DGFRMTB,IDSDG(10)                          CB9    4
      COMMON/B10/DGMX,DGNTBL(10),DGITBL(10),DGFRMTB(10),DGGP(10)            CB9    5
      EQUIVALENCE (DGGP,IDSDG)                                              CB9    6
C     COMMON DECK "B8" INSERTED HERE                                        CB10   2
      INTEGER RMX,RNTBL,RITBL,RFRMTBL,IDSR(10)                              CB10   4
      COMMON/B8/RMX,RNTBL(10),RITBL(10),RFRMTBL(10),RGP(10)                 CB10   5
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      EQUIVALENCE (RGP,IDSR)                                                 CB10   6
C     COMMON DECK "CB17" INSERTED HERE                                       CB17   2
      INTEGER VMX,VNTBL,VITBL,VFRMTBL,IDSV(10)                               CB17   4
      COMMON/B17/VMX,VNTBL(10),VITBL(10),VFRMTBL(10),VGP(53)                 CB17   5
      EQUIVALENCE (VGP,IDSV),(ANV,VGP(11))                                   CB17   6
C     COMMON DECK "CB18" INSERTED HERE                                       CB18   2
      INTEGER DVMX,DVNTBL,DVITBL,DVFRMTB,IDSDV(10)                           CB18   4
      COMMON/B18/DVMX,DVNTBL(10),DVITBL(10),DVFRMTB(10),DVGP(11)             CB18   5
      EQUIVALENCE (DVGP,IDSDV),(ANDV,DVGP(11))                               CB18   6
C     COMMON DECK "CB19" INSERTED HERE                                       CB19   2
      INTEGER PRMX,PRNTBL,PRITBL,PRFRMTB,IDSPR(10)                           CB19   4
      COMMON/B19/PRMX,PRNTBL(10),PRITBL(10),PRFRMTB(10),PRGP(11)             CB19   5
      EQUIVALENCE (PRGP,IDSPR),(ANP,PRGP(11))                                CB19   6
C     COMMON DECK "CB20" INSERTED HERE                                       CB20   2
      INTEGER DPMX,DPNTBL,DPITBL,DPFRMTB,IDSDP(10)                           CB20   4
      COMMON/B20/DPMX,DPNTBL(10),DPITBL(10),DPFRMTB(10),DPGP(11)             CB20   5
      EQUIVALENCE (DPGP,IDSDP),(ANDP,DPGP(11))                               CB20   6
C                                                                            ATMOSH45
      PARAMETER (NBNRLS=8,NBLNS=8)                                           ATMOSH46
C                                                                            ATMOSH47
      DATA BLANKS/' '/                                                       ATMOSH48
      DATA BANNER/                                                           ATMOSH49
     1  '***** H A R P A *****'                                             ATMOSH50
     2 ,'HAMILTONIAN ACOUSTIC RAY-TRACING PROGRAM FOR THE ATMOSPHERE'       ATMOSH51
     3 ,' '                                                                 ATMOSH52
     4 ,'BY'                                                                ATMOSH53
     5 ,'R. M. JONES,  J. P. RILEY  AND  T. M. GEORGES'                     ATMOSH54
     6 ,'WAVE PROPAGATION LABORATORY'                                       ATMOSH55
     7 ,'NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION'                   ATMOSH56
     8 ,'BOULDER, COLORADO 80303'/                                          ATMOSH57
      DATA NOPUNCH/.FALSE./                                                 ATMOSH58
      DATA IBLK/1H /                                                        ATMOSH59
C                                                                           ATMOSH60
      ENTRY HEADER1                                                         ATMOSH61
C                                                                           ATMOSH62
C     COMPUTE EFFECTIVE LINES COUNT BASED ON FIXED PAGE SIZE                ATMOSH63
      CALL NEWPAG(NPAG,INT(PAGLN),PC)                                       ATMOSH64
      CALL SFILL(DIVIDR,LEN(DIVIDR),'-')                                    ATMOSH65
      DIVIDR(1:1)=' '                                                       ATMOSH66
      NTYP=2                                                                ATMOSH67
      IF(RAY.NE.0.0) NTYP=2.0+SIGN(1.0,RAY)                                 ATMOSH68
C                                                                           ATMOSH69
1600  FORMAT(2(2(A8,F7.1,1X),2X))                                           ATMOSH70
      CALL PUTKST(3,'1'                                                     ATMOSH71
     1  //DAT//TOD//BLANKS(:100)//'PAGE'//NUMSTG(NPAG,1,'(I5)'))           ATMOSH72
      CALL PUTKST(3,DIVIDR)                                                 ATMOSH73
      CALL PUTKBK(3,1)                                                      ATMOSH74
      DO 15 I=1,NBNRLS                                                      ATMOSH75
15    CALL PUTKCT(3,BANNER(I))                                              ATMOSH76
      CALL PUTKBK(3,1)                                                      ATMOSH77
      CALL PUTKST(3,DIVIDR)                                                 ATMOSH78
      CALL PUTKBK(3,NBLNS)                                                  ATMOSH79
C                                                                           ATMOSH80
      CALL PUTKST(3,BLANKS(:57)//'RUN SET NUMBER'                           ATMOSH81
     1  //NUMSTG(NSET,1,'(I5)'))                                           ATMOSH82
```

```
      CALL PUTKBK(3,1)                                                      ATMOSH83
      WRITE(STMP,'(10A8)') ID                                               ATMOSH84
      CALL PUTKST(3,BLANKS(:52)//'ATMOSPHERIC MODEL ID -- '//STMP(:3))      ATMOSH85
      CALL PUTKBK(3,1)                                                      ATMOSH86
      CALL PUTKST(3,                                                        ATMOSH87
     1 BLANKS(:25)//'ATMOSPHERIC MODEL DESCRIPTION -- '//STMP(7:))          ATMOSH88
      CALL PUTKBK(3,1)                                                      ATMOSH89
C                                                                           ATMOSH90
      WRITE(STMP,'(2A8)') (RAYNAME(I,NTYP),I=1,2)                           ATMOSH91
      CALL PUTKST(3,STMP)                                                   ATMOSH92
      CALL PUTKBK(3,1)                                                      ATMOSH93
      CALL PUTKST(3,DIVIDR)                                                 ATMOSH94
      CALL PUTKBK(3,1)                                                      ATMOSH95
      CALL PUTKST(3,                                                        ATMOSH96
     1  BLANKS(:8)//'MODEL                    SUBROUTINE     DATA SET'     ATMOSH97
     1  //'       DESCRIPTION')                                            ATMOSH98
      CALL PUTKST(3,                                                        ATMOSH99
     1  BLANKS(:8)//'TYPE                       NAME          ID')         ATMOS100
      CALL PUTKBK(3,1)                                                      ATMOS101
      CALL PUTKST(3,DIVIDR)                                                 ATMOS102
      CALL PUTKBK(3,1)                                                      ATMOS103
      CALL PUTKST(3,' DISPERSION RELATION           '//DISPM                ATMOS104
     1  //BLANKS(:16)//NUMSTG(MODRIN,8,'(8A8)'))                           ATMOS105
      CALL PUTDES(3,'BACKGROUND WIND VELOCITY',MODU,IDSU)                   ATMOS106
      CALL PUTDES(3,'WIND VELOCITY PERTURBATION',MODU(3),IDSDU)             ATMOS107
      CALL PUTDES(3,'BACKGROUND SOUND SPEED',MODC,IDSC)                     ATMOS108
      CALL PUTDES(3,'SOUND SPEED PERTURBATION',MODC(3),IDSDC)               ATMOS109
      CALL PUTDES(3,'BACKGROUND TEMPERATURE',MODT,IDST)                     ATMOS110
      CALL PUTDES(3,'TEMPERATURE PERTURBATION',MODT(3),IDSDT)               ATMOS111
      CALL PUTDES(3,'MOLECULAR WEIGHT',MODM,IDSM)                           ATMOS112
      CALL PUTDES(3,'BACKGROUND TERRAIN',MODG,IDSG)                         ATMOS113
      CALL PUTDES(3,'TERRAIN PERTURBATION',MODG(3),IDSDG)                   ATMOS114
      CALL PUTKST(3,' BACKGROUND VISCOSITY/')                               ATMOS115
      CALL PUTDES(3,'  THERMAL CONDUCTIVITY',MODA,IDSV)                     ATMOS116
      CALL PUTKST(3,' VISCOSITY/THERMAL')                                   ATMOS117
      CALL PUTDES(3,'  CONDUCTIVITY PERTURBATION',MODA(3),IDSDV)            ATMOS118
      CALL PUTDES(3,'BACKGROUND PRESSURE',MODP,IDSPR)                       ATMOS119
      CALL PUTDES(3,'PRESSURE PERTURBATION',MODP(3),IDSDP)                  ATMOS120
      CALL PUTDES(3,'RECEIVER SURFACE',MODREC,IDSR)                         ATMOS121
      CALL PUTKST(3,DIVIDR)                                                 ATMOS122
C                                                                           ATMOS123
      NOPUNCH=NOPUNCH.AND.RAYSET.LT.0.0                                     ATMOS124
      IF(NOPUNCH) RETURN                                                    ATMOS125
      NOPUNCH=RAYSET.LT.0.0                                                 ATMOS126
C                                                                           ATMOS127
      WRITE(9,1200) ID,DAT,TOD                                              ATMOS128
      WRITE(9,1600) MODU,MODC,MODT,MODM,MODP,MODA                           ATMOS129
     1    ,MODG,MODREC                                                      ATMOS130
      IF(IDSU(1) .NE. IBLK) WRITE(9,1200) IDSU                              ATMOS131
      IF(IDSDU(1) .NE. IBLK) WRITE(9,1200) IDSDU                            ATMOS132
      IF(IDSC(1) .NE. IBLK) WRITE(9,1200) IDSC                              ATMOS133
      IF(IDSDC(1) .NE. IBLK) WRITE(9,1200) IDSDC                            ATMOS134
      IF(IDST(1) .NE. IBLK) WRITE(9,1200) IDST                              ATMOS135
      IF(IDSDT(1) .NE. IBLK) WRITE(9,1200) IDSDT                            ATMOS136
      IF(IDSM(1) .NE. IBLK) WRITE(9,1200) IDSM                              ATMOS137
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```
      IF(IDSG(1) .NE. IBLK) WRITE(9,1200) IDSG                          ATMOS138
C                                                                       ATMOS139
 1000 FORMAT (A1,10A8,24X,2A,' PAGE',I4)                                ATMOS140
1200  FORMAT(10A8,2(A8,2X))                                             ATMOS141
C                                                                       ATMOS142
      RETURN                                                            ATMOS143
C                                                                       ATMOS144
      ENTRY HEADER2                                                     ATMOS145
C                                                                       ATMOS146
C     COMPUTE EFFECTIVE LINES COUNT BASED ON FIXED PAGE SIZE            ATMOS147
      CALL NEWPAG(NPAG,INT(PAGLN),PC)                                   ATMOS148
      LINES=LINES+5                                                     ATMOS149
C                                                                       ATMOS150
      WRITE(3,1000) PC,ID,DAT,TOD,NPAG                                  ATMOS151
      WRITE(3,2400) AZ1*DEGS,TLAT*DEGS,OW/PIT2,BETA*DEGS                ATMOS152
     1        ,TLON*DEGS,MAXERR                                         ATMOS153
 2400 FORMAT (                                                          ATMOS154
     1  /' AZIMUTH ANGLE OF TRANSMISSION   =',F12.6,' DEG'              ATMOS155
     2  ,'      TRANSMITTER  LATITUDE  =',F12.6,' DEG'                  ATMOS156
     3  ,'    FREQUENCY =',F12.6,' HZ'                                  ATMOS157
     4  /' ELEVATION ANGLE OF TRANSMISSION =',F12.6,' DEG'              ATMOS158
     5  ,'      TRANSMITTER  LONGITUDE =',F12.6,' DEG'                  ATMOS159
     6  ,'    SINGLE STEP ERROR =',1PG13.6/)                            ATMOS160
C                                                                       ATMOS161
      RETURN                                                            ATMOS162
C                                                                       ATMOS163
      ENTRY PUTDVR(NUNIT)                                               ATMOS164
      CALL PUTKST(NUNIT,DIVIDR)                                         ATMOS165
      RETURN                                                            ATMOS166
C                                                                       ATMOS167
      ENTRY PUTHDR(NUNIT,PCC,NP)                                        ATMOS168
      CALL PUTKST(NUNIT,                                                ATMOS169
     1  PCC//DAT//TOD//BLANKS(:100)//'PAGE'//NUMSTG(NP,1,'(I5)'))       ATMOS170
      RETURN                                                            ATMOS171
      END                                                               ATMOS172
```

```
      SUBROUTINE PUTDES(NUNIT,DES,MOD,ID)                               PUTDES 2
      CHARACTER DES*(*),TITLE*30,SMODL*20,NUMSTG*80                     PUTDES 3
      REAL MOD(2),ID(10)                                                PUTDES 4
      TITLE=DES                                                         PUTDES 5
      WRITE(SMODL,'(A8,F10.2)') MOD                                     PUTDES 6
      CALL PUTKST(NUNIT, ' '//TITLE//SMODL//NUMSTG(ID,10,'(10A8)'))     PUTDES 7
      END                                                               PUTDES 8
```

```
      CHARACTER*80 FUNCTION NUMSTG(V,N,FRM)                             NUMSTG 2
      INTEGER V(N)                                                      NUMSTG 3
      CHARACTER FRM*(*)                                                 NUMSTG 4
```

```
      NUMSTG=' '                                                        NUMSTG 5
      WRITE(NUMSTG,FRM) V                                               NUMSTG 6
      RETURN                                                            NUMSTG 7
      END                                                               NUMSTG 8



      SUBROUTINE SFILL(STG,LN,C)                                        SFILL  2
      CHARACTER STG*(*),C*1                                             SFILL  3
C                                                                       SFILL  4
      DO 10 I=1,LN                                                      SFILL  5
10    STG(I:I)=C                                                        SFILL  6
      RETURN                                                            SFILL  7
      END                                                               SFILL  8



      INTEGER FUNCTION STRIM(C)                                         STRIM  2
      CHARACTER*(*) C                                                   STRIM  3
C                                                                       STRIM  4
     . L=LEN(C)                                                         STRIM  5
      DO 100 I=L,1,-1                                                   STRIM  6
100   IF(C(I:I) .NE. ' ') GO TO 200                                     STRIM  7
      I=0                                                               STRIM  8
200   STRIM=I                                                           STRIM  9
      END                                                               STRIM 10



      FUNCTION RERR(V,ERT,ELAB,NKV,PREF)                                RERR   2
C     RETURNS RELATIVE ERROR OF VARIABLE RKVAR(NKV) IF PREF<>0 AND      RERR   3
C     THE ERROR IS GREATER THAN PREVIOUS ERROR 'V'.                     RERR   4
C     COMMON DECK "RKAM" INSERTED HERE                                  RKAMCOM2
      REAL KR,KTH,KPH                                                   RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)       RKAMCOM5
C                                                                       RERR   6
      RERR=V                                                            RERR   7
      IF(NKV.LE.0) RETURN                                               RERR   8
      IF(PREF.EQ.0.) RETURN                                             RERR   9
      V1=RKVARS(NKV)/PREF-1.                                            RERR  10
      IF(ABS(V1).LT.ABS(V)) RETURN                                      RERR  11
C                                                                       RERR  12
      ERT=ELAB                                                          RERR  13
      RERR=V1                                                           RERR  14
      END                                                               RERR  15
```

```
      SUBROUTINE RERROR(ROUTIN,STR,VAL)                                 RERROR 2
C     REPORTS ERROR CONDITIONS AND STOPS PROGRAM.                       RERROR 3
C                                                                       RERROR 4
      PRINT 10,ROUTIN,STR,VAL                                           RERROR 5
10    FORMAT(39H ERROR CONDITION IN RAYTRACE ROUTINE <                  RERROR 6
     1  ,A8,10H> DUE TO " ,A10,9H", VALUE=   ,F8.2)                    RERROR 7
      STOP                                                              RERROR 8
      END                                                               RERROR 9
```

```
      SUBROUTINE STOPIT(A)                                              STOPIT 2
C     PRINTS CONDITION AND STOPS PROGRAM                                STOPIT 3
C     AFTER CALLING THE SYSTEM POST MORTEM DUMP.                        STOPIT 4
C                                                                       STOPIT 5
      CHARACTER A*(*)                                                   STOPIT 6
C                                                                       STOPIT 7
      PRINT 100, A                                                      STOPIT 8
      CALL MORTEM                                                       STOPIT 9
100   FORMAT('*** STOPIT WITH CONDITION <',A,'>')                       STOPIT10
      STOP                                                              STOPIT11
      END                                                               STOPIT12
```

```
      SUBROUTINE PUTKST(NUNIT,STRG)                                     PUTKST 2
C     WRITE LINE OF OUTPUT TO PRINTER UNIT ADDING TO LINE COUNT         PUTKST 3
C                                                                       PUTKST 4
      CHARACTER STRG*(*)                                                PUTKST 5
      CHARACTER BLANKS*100,STMP*80                                      PUTKST 6
      INTEGER STRIM                                                     PUTKST 7
      CHARACTER PC*1                                                    PUTKST 8
C                                                                       PUTKST 9
C     COMMON DECK "FLAG" INSERTED HERE                                  CFLAG  2
      LOGICAL NEWWR,NEWWP,NEWTRC,PENET                                  CFLAG  4
      COMMON /FLG/ NTYP,NEWWR,NEWWP,NEWTRC,PENET,LINES,IHOP,HPUNCH      CFLAG  5
      COMMON/FLGP/NSET                                                  CFLAG  6
C                                                                       PUTKST11
      DATA BLANKS/' '/                                                  PUTKST12
C                                                                       PUTKST13
C     PUT OUT A STRING WITH LINE COUNT INCREMENT                        PUTKST14
      LINES=LINES+1                                                     PUTKST15
      LN=MIN0(LEN(STRG),132)                                            PUTKST16
      WRITE(NUNIT,'(A)') STRG(:LN)                                      PUTKST17
      RETURN                                                            PUTKST18
C                                                                       PUTKST19
      ENTRY PUTKCT(NUNIT,STRG)                                          PUTKST20
C     PUT OUT A CENTERED LINE AND COUNT                                 PUTKST21
      NTRM=MAX0(1,STRIM(STRG))                                          PUTKST22
      NBLKS=66-(NTRM+1)/2                                               PUTKST23
```

```
      LINES=LINES+1                                                      PUTKST24
      LN=MIN0(NTRM,132-NBLKS)                                            PUTKST25
      STMP=STRG                                                          PUTKST26
      WRITE(NUNIT,'(A)') BLANKS(:NBLKS)//STMP(:LN)                       PUTKST27
      RETURN                                                             PUTKST28
      ENTRY PUTKBK(NUNIT,NBKS)                                           PUTKST29
C     PUT A BLANK LINE TO PRINTER                                        PUTKST30
C                                                                        PUTKST31
      LINES=LINES+1                                                      PUTKST32
      DO 100 I=1,NBKS                                                    PUTKST33
100      WRITE(NUNIT,'(1X)')                                             PUTKST34
      RETURN                                                             PUTKST35
C                                                                        PUTKST36
      ENTRY NEWPAG(NP,LINSPP,PC)                                         PUTKST37
C     THE LOGIC HERE ASSUMES THAT A FORM FEED IS ALWAYS NEEDED           PUTKST38
      PC='1'                                                             PUTKST39
C     COMPUTE EFFECTIVE LINES COUNT AFTER NEXT FORM FEED                 PUTKST40
      NPAG=(LINES+LINSPP-1)/LINSPP                                       PUTKST41
      LINES=NPAG*LINSPP                                                  PUTKST42
      NP=NPAG+1                                                          PUTKST43
      RETURN                                                             PUTKST44
      END                                                                PUTKST45
```

```
      SUBROUTINE OPNREP(IUN,FNAME)                                       OPNREP 2
C     CYBER VERSION OF OPEN FOR REPLACE                                  OPNREP 3
C     SINCE THIS OPERATION SEEMS TO BE COMPILER DEPENDENT                OPNREP 4
C     WE MAKE A SUBROUTINE OUT OF IT.                                    OPNREP 5
C     THIS OPEN OPERATION ALLOWS FOR AN EXISTING VERSION OF              OPNREP 6
C     A FILE. IF THE FILE EXISTS IT IS OVERWRITTEN.                      OPNREP 7
      CHARACTER*(*) FNAME                                                OPNREP 8
      OPEN(IUN,FILE=FNAME)                                               OPNREP 9
      REWIND IUN                                                         OPNREP10
      RETURN                                                             OPNREP11
      ENTRY OPNURP(IUN,FNAME)                                            OPNREP12
      OPEN(IUN,FILE=FNAME,FORM='UNFORMATTED')                            OPNREP13
      REWIND IUN                                                         OPNREP14
      END                                                                OPNREP15
```

```
      SUBROUTINE OVERRD(VAR,TST,DEFT,NFLG,NFVLEQ,NFVLNE)                 OVERRD 2
C                                                                        OVERRD 3
C     OVERRIDE SUPPORT ROUTINE                                           OVERRD 4
C     TEST 'VAR' AGAINST 'TST', IF EQUAL SET TO DEFAULT 'DEFT'           OVERRD 5
C     AND ALSO SET INTEGER FLAG 'NFLG' TO VALUE 'NFVLEQ' ELSE 'NFVLNE'   OVERRD 6
C                                                                        OVERRD 7
      IF(VAR.EQ.TST) THEN                                                OVERRD 8
         VAR=DEFT                                                        OVERRD 9
         NFLG=NFVLEQ                                                     OVERRD10
```

```
      ELSE                                                              OVERRD11
         NFLG=NFVLNE                                                    OVERRD12
      ENDIF                                                             OVERRD13
      RETURN                                                            OVERRD14
      END                                                               OVERRD15
```

```
      SUBROUTINE SFILTR(C,S,KSET)                                       SFILTR 2
      CHARACTER*(*) C,S,KSET                                            SFILTR 3
C                                                                       SFILTR 4
      LN=LEN(C)                                                         SFILTR 5
      J=0                                                               SFILTR 6
      DO 10 I=1,LN                                                      SFILTR 7
        IF(INDEX(KSET,C(I:I)).EQ.0) THEN                                SFILTR 8
           J=J+1                                                        SFILTR 9
           S(J:J)=C(I:I)                                                SFILTR10
        ENDIF                                                           SFILTR11
10    CONTINUE                                                          SFILTR12
      RETURN                                                            SFILTR13
      END                                                               SFILTR14
```

```
      FUNCTION ALCOSH(X)                                                ALCOSH 2
C     COMPUTE LOG(COSH(X)) AND USE LARGE ARGUMENT APPROXIMATION         ALCOSH 3
C     WHEN POSSIBLE.                                                    ALCOSH 4
      DATA ALOG2/.6931471806/                                           ALCOSH 5
C                                                                       ALCOSH 6
      IF(ABS(X).GT.50.0) GO TO 10                                       ALCOSH 7
      EX=EXP(X)                                                         ALCOSH 8
      ALCOSH=ALOG((EX+1.0/EX)*.5)                                       ALCOSH 9
      RETURN                                                            ALCOSH10
10    ALCOSH=ABS(X)-ALOG2                                               ALCOSH11
      END                                                               ALCOSH12
```

```
      SUBROUTINE GAUSEL (C,NRD,NRR,NCC,NSF)                             GAUSEL 2
C     MATRIX INVERSION BY METHOD OF GAUSSIAN PIVOT                      GAUSEL 3
C     SOLVES NCC-NRR SETS OF NRR EQUATIONS                              GAUSEL 4
C********* SAME AS SUBROUTINE GAUSSEL WRITTEN BY L. DAVID LEWIS ********GAUSEL 5
      DIMENSION C(NRD,NCC),L(128,2)                                     GAUSEL 6
C          BITS = 2.**-18                                               GAUSEL 7
      DATA BITS/3.8146972656E-6/                                        GAUSEL 8
      NR=NRR                                                            GAUSEL 9
      NC=NCC                                                            GAUSEL10
      IF(NC.LT.NR.OR.NR.GT.128.OR.NR.LE.0) CALL EXIT                    GAUSEL11
C                                                                       GAUSEL12
```

```
C           INITIALIZE.                                                    GAUSEL13
      NSF=0                                                                GAUSEL14
      NRM=NR-1                                                             GAUSEL15
      NRP=NR+1                                                             GAUSEL16
      D=1.                                                                 GAUSEL17
      LSD=1                                                                GAUSEL18
      DO 1 KR=1,NR                                                         GAUSEL19
      L(KR,1)=KR                                                           GAUSEL20
1     L(KR,2)=0                                                            GAUSEL21
      IF(NR.EQ.1) GO TO 42                                                 GAUSEL22
C                                                                          GAUSEL23
C           ELIMINATION PHASE.                                             GAUSEL24
      DO 41 KP=1,NRM                                                       GAUSEL25
      KPP=KP+1                                                             GAUSEL26
      PM=0.                                                                GAUSEL27
      MPN=0                                                                GAUSEL28
C                                                                          GAUSEL29
C           SEARCH COLUMN KP FROM DIAGONAL DOWN FOR MAX PIVOT.             GAUSEL30
      DO 2 KR=KP,NR                                                        GAUSEL31
      LKR=L(KR,1)                                                          GAUSEL32
      PT=ABS(C(LKR,KP))                                                    GAUSEL33
      IF(PT.LE.PM) GO TO 2                                                 GAUSEL34
      PM=PT                                                                GAUSEL35
      MPN=KR                                                               GAUSEL36
      LMP=LKR                                                              GAUSEL37
2     CONTINUE                                                             GAUSEL38
C                                                                          GAUSEL39
C           IF MAX PIVOT IS ZERO, MATRIX IS SINGULAR.                      GAUSEL40
      IF(MPN.EQ.0) GO TO 9                                                 GAUSEL41
      NSF=NSF+1                                                            GAUSEL42
      IF(MPN.EQ.KP) GO TO 3                                                GAUSEL43
C                                                                          GAUSEL44
C           NEW ROW NUMBER KP HAS MAX PIVOT.                               GAUSEL45
      LSD=-LSD                                                             GAUSEL46
      L(KP,2)=L(KP,1)                                                      GAUSEL47
      L(MPN,1)=L(KP,1)                                                     GAUSEL48
      L(KP,1)=LMP                                                          GAUSEL49
C                                                                          GAUSEL50
C           ROW OPERATIONS TO ZERO COLUMN KP BELOW DIAGONAL.               GAUSEL51
3     MKP=L(KP,1)                                                          GAUSEL52
      P=C(MKP,KP)                                                          GAUSEL53
      D=D*P                                                                GAUSEL54
      DO 41 KR=KPP,NR                                                      GAUSEL55
      MKR=L(KR,1)                                                          GAUSEL56
      Q=C(MKR,KP)/P                                                        GAUSEL57
      IF(Q.EQ.0.) GO TO 41                                                 GAUSEL58
C                                                                          GAUSEL59
C           SUBTRACT Q * PIVOT ROW FROM ROW KR.                            GAUSEL60
      DO 4 LC=KPP,NC                                                       GAUSEL61
      R=Q*C(MKP,LC)                                                        GAUSEL62
      C(MKR,LC)=C(MKR,LC)-R                                                GAUSEL63
4     IF(ABS(C(MKR,LC)).LT.ABS(R)*BITS) C(MKR,LC)=0.                       GAUSEL64
41    CONTINUE                                                             GAUSEL65
C                                                                          GAUSEL66
C           LOWER RIGHT HAND CORNER.                                       GAUSEL67
```

```
42      LNR=L(NR,1)                                                     GAUSEL68
        P=C(LNR,NR)                                                     GAUSEL69
        IF(P.EQ.0.) GO TO 9                                             GAUSEL70
        NSF=NSF+1                                                       GAUSEL71
        D=D*P*LSD                                                       GAUSEL72
        IF(NR.EQ.NC) GO TO 8                                            GAUSEL73
C                                                                       GAUSEL74
C            BACK SOLUTION PHASE.                                       GAUSEL75
        DO 61 MC=NRP,NC                                                 GAUSEL76
        C(LNR,MC)=C(LNR,MC)/P                                           GAUSEL77
        IF(NR.EQ.1) GO TO 61                                            GAUSEL78
        DO 6 LL=1,NRM                                                   GAUSEL79
        KR=NR-LL                                                        GAUSEL80
        MR=L(KR,1)                                                      GAUSEL81
        KRP=KR+1                                                        GAUSEL82
        DO 5 MS=KRP,NR                                                  GAUSEL83
        LMS=L(MS,1)                                                     GAUSEL84
        R=C(MR,MS)*C(LMS,MC)                                            GAUSEL85
        C(MR,MC)=C(MR,MC)-R                                             GAUSEL86
5       IF(ABS(C(MR,MC)).LT.ABS(R)*BITS) C(MR,MC)=0.                    GAUSEL87
6       C(MR,MC)=C(MR,MC)/C(MR,KR)                                      GAUSEL88
61      CONTINUE                                                        GAUSEL89
C                                                                       GAUSEL90
C            SHUFFLE SOLUTION ROWS BACK TO NATURAL ORDER.               GAUSEL91
        DO 71 LL=1,NRM                                                  GAUSEL92
        KR=NR-LL                                                        GAUSEL93
        MKR=L(KR,2)                                                     GAUSEL94
        IF(MKR.EQ.0) GO TO 71                                           GAUSEL95
        MKP=L(KR,1)                                                     GAUSEL96
        DO 7 LC=NRP,NC                                                  GAUSEL97
        Q=C(MKR,LC)                                                     GAUSEL98
        C(MKR,LC)=C(MKP,LC)                                             GAUSEL99
7       C(MKP,LC)=Q                                                     GAUSE100
71      CONTINUE                                                        GAUSE101
C                                                                       GAUSE102
C            NORMAL AND SINGULAR RETURNS.  GOOD SOLUTION COULD HAVE D=0. GAUSE103
8       C(1,1)=D                                                        GAUSE104
        GO TO 91                                                        GAUSE105
9       C(1,1)=0.                                                       GAUSE106
   91 RETURN                                                            GAUSE107
         END                                                            GAUSE108
```

```
        SUBROUTINE RAYPLT                                               RAYPLT 2
C       MAIN PLOTTING PROGRAM; INITIALIZES, READS INPUT, PLOTS          RAYPLT 3
C       PROJECTIONS OF RAYS ON A VERTICAL OR HORIZONTAL PLANE.          RAYPLT 4
C          ABS(PLT)=1. PLOTS PROJECTION OF RAYPATH ON VERTICAL PLANE    RAYPLT 5
C                      RECTANGULAR EXPANSION BY FACTOR 'PFACTR'         RAYPLT 6
C                  =2. PLOTS PROJECTION OF RAYPATH ON GROUND            RAYPLT 7
C                  =3. VERICAL PROJECTION USING RADIAL EXPANSION BY FACTO RAYPLT 8
C                      'PFACTR'                                         RAYPLT 9
C       COMMON DECK "FILEC" INSERTED HERE                               CFILEC 2
```

```
      COMMON /FILEC/NPLTDP                                                      CFILEC 4
      COMMON /PLT/ XL,XR,YB,YT,PRESET                                           RAYPLT11
      COMMON/PLT/RMIN,RMAX,ALPHA,APLT                                           RAYPLT12
C                                                                               RAYPLT13
C     COMMON DECK "CONST" INSERTED HERE                                         CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                             CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                                 CCONST 5
C     COMMON DECK "FLAG" INSERTED HERE                                          CFLAG  2
      LOGICAL NEWWR,NEWWP,NEWTRC,PENET                                          CFLAG  4
      COMMON /FLG/ NTYP,NEWWR,NEWWP,NEWTRC,PENET,LINES,IHOP,HPUNCH              CFLAG  5
      COMMON/FLGP/NSET                                                          CFLAG  6
C     COMMON DECK "RKAM" INSERTED HERE                                          RKAMCOM2
      REAL KR,KTH,KPH                                                           RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)               RKAMCOM5
C     COMMON DECK "WW" INSERTED HERE                                            CWW    2
      PARAMETER (NWARSZ=1000)                                                   CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                           CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                        CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),            CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),              CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                  CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),                 CWW2   6
     8 (RCVRH,W(20)),                                                           CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))        CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                              CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                              CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                             CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),               CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))                CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),                CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                      CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                           CWW2  16
      REAL MMODEL,MFORM,MID                                                     CWW3   2
C                                                                               CWW3   3
C     WIND          100-124                                                     CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)                   CWW3   5
C                                                                               CWW3   6
C     DELTA WIND          125-149                                               CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)                CWW3   8
C                                                                               CWW3   9
C     SOUND SPEED 150-174                                                       CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                   CWW3  11
      EQUIVALENCE (W(153),REFC)                                                 CWW3  12
C                                                                               CWW3  13
C     DELTA SOUND SPEED 175-199                                                 CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)                CWW3  15
C                                                                               CWW3  16
C     TEMPERATURE     200-224                                                   CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                   CWW3  18
C                                                                               CWW3  19
C     DELTA TEMPERATURE     225-249                                             CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)                CWW3  21
C                                                                               CWW3  22
C     MOLECULAR   250-274                                                       CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                   CWW3  24
```

```
C                                                                       CWW3   25
C                                                                       CWW3   26
C     RECEIVER HEIGHT   275-299                                        CWW3   27
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)           CWW3   28
C                                                                       CWW3   29
C     TOPOGRAPHY   300-324                                              CWW3   30
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)           CWW3   31
C                                                                       CWW3   32
C     DELTA TOPOGRAPHY   325-349                                        CWW3   33
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)        CWW3   34
C                                                                       CWW3   35
C     UPPER SURFACE TOPOGRAPHY   350-374                                CWW3   36
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)           CWW3   37
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                              CWW3   38
C                                                                       CWW3   39
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                       CWW3   40
C     ABSORPTION         500-524                                        CWW3   41
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)           CWW3   42
C                                                                       CWW3   43
C     DELTA ABSORPTION         525-549                                  CWW3   44
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)        CWW3   45
C                                                                       CWW3   46
C     PRESSURE         550-574                                          CWW3   47
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)           CWW3   48
C                                                                       CWW3   49
C     DELTA PRESSURE         575-599                                    CWW3   50
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)        CWW3   51
C
      REAL LTIC                                                         RAYPLT18
      INTEGER IWDMP(411)                                                RAYPLT19
      EQUIVALENCE(IWDMP,ID)                                             RAYPLT20
C                                                                       RAYPLT21
      EXTERNAL PLOT,PLTLB,PLTLBN,PLTHLB                                 RAYPLT22
C                                                                       RAYPLT23
      DATA NWDSRK/4/                                                    RAYPLT24
C                                                                       RAYPLT25
      IF (.NOT.NEWWR) GO TO 8                                           RAYPLT26
      APLT=ABS(PLT)                                                     RAYPLT27
C                                                                       RAYPLT28
C           NEW W ARRAY -- REINITIALIZE                                 RAYPLT29
        NEWWR=.FALSE.                                                   RAYPLT30
        PRESET=1.                                                       RAYPLT31
C       IF NO ACTIVE PLOTTING,WE ARE STILL DUMPING DATA                 RAYPLT32
        IF(PLT.EQ.0) GO TO 5                                            RAYPLT33
C       INITIALIZE ANNOTATION MODEL                                     RAYPLT34
C  CONVERT COORDINATES OF VERTICAL PLANE FROM GEOGRAPHIC TO GEOMAGNETIC  RAYPLT35
        SW=SIN (PLAT)                                                   RAYPLT36
        CW=SIN (PID2-PLAT)                                              RAYPLT37
        SLM=SIN (LLAT)                                                  RAYPLT38
        CLM=SIN (PID2-LLAT)                                             RAYPLT39
        SRM=SIN (RLAT)                                                  RAYPLT40
        CRM=SIN (PID2-RLAT)                                             RAYPLT41
        CDPHI=SIN (PID2-(LLON-PLON))                                    RAYPLT42
        PHL=ATAN2(SIN (LLON-PLON)*CLM,CDPHI*SW*CLM-CW*SLM)              RAYPLT43
        CTHL=CDPHI*CW*CLM+SW*SLM                                        RAYPLT44
        STHL=SIN (ACOS (CTHL))                                          RAYPLT45
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      CDPHI=SIN (PID2-(RLON-PLON))                                      RAYPLT46
      PHR=ATAN2(SIN (RLON-PLON)*CRM,CDPHI*SW*CRM-CW*SRM)                RAYPLT47
      CTHR=CDPHI*CW*CRM+SW*SRM                                          RAYPLT48
      STHR=SIN (ACOS (CTHR))                                            RAYPLT49
      CLR=CTHL*CTHR+STHL*STHR*SIN (PID2-(PHL-PHR))                      RAYPLT50
      ALPHA=.5*ACOS (CLR)                                               RAYPLT51
      SLR=SQRT (1.-CLR**2)                                              RAYPLT52
C                                                                       RAYPLT53
      IF (APLT.EQ.2.) GO TO 3                                           RAYPLT54
C                                                                       RAYPLT55
C     VERTICAL PROJECTIONS ONLY                                         RAYPLT56
      T=HB                                                              RAYPLT57
      HB=AMIN1(T,HT)                                                    RAYPLT58
      HT=AMAX1(T,HT)                                                    RAYPLT59
      RMIN=EARTHR+HB                                                    RAYPLT60
      YT1=YT                                                            RAYPLT61
      RMAX=EARTHR+HT                                                    RAYPLT62
C                                                                       RAYPLT63
      IF(APLT.NE.4.) GO TO 100                                          RAYPLT64
C                                                                       RAYPLT65
C     SCALE FOR CARTESIAN PROJECTION(=4)                                RAYPLT66
      XR=ALPHA                                                          RAYPLT67
      XR1=XR                                                            RAYPLT68
      XL=-XR                                                            RAYPLT69
      XL1=XL                                                            RAYPLT70
      YB=RMIN                                                           RAYPLT71
      YT=RMAX                                                           RAYPLT72
      GO TO 5                                                           RAYPLT73
C                                                                       RAYPLT74
C     PROJECTIONS 1 AND 3                                               RAYPLT75
100   XR1=RMIN*SIN (ALPHA)                                              RAYPLT76
      XL1=-XR1                                                          RAYPLT77
      YB=RMIN*SIN (PID2-ALPHA)                                          RAYPLT78
      IF(APLT.EQ.3.) RMAX=RMIN+(RMAX-RMIN)*PFACTR                       RAYPLT79
      XR=AMAX1(RMAX*SIN(ALPHA),(RMAX-YB)/2.)                            RAYPLT80
      XL=-XR                                                            RAYPLT81
      YT1=RMAX*(YB/RMIN)                                                RAYPLT82
      YT=2.0*XR                                                         RAYPLT83
      IF(APLT.EQ.1) YT=YT/PFACTR                                        RAYPLT84
      YT=YT+YB                                                          RAYPLT85
      GO TO 5                                                           RAYPLT86
C                                                                       RAYPLT87
C     HORIZONTAL PROJECTION(=2)                                         RAYPLT88
3     ALPH1=ATAN2(STHR*SIN (PHR-PHL),(CTHR-CTHL*CLR)/STHL)              RAYPLT89
      XL=0.0                                                            RAYPLT90
      XL1=0.0                                                           RAYPLT91
      XR=EARTHR*2.0*ALPHA                                               RAYPLT92
      XR1=XR                                                            RAYPLT93
C USE 90% OF X-RANGE FOR Y-RANGE                                        RAYPLT94
      RMAX=0.5*(0.90*XR)/PFACTR                                         RAYPLT95
      YT=RMAX                                                           RAYPLT96
      RMIN=-RMAX                                                        RAYPLT97
      YB=RMIN                                                           RAYPLT98
C                                                                       RAYPLT99
5     IF(NPLTDP.LE.0) GO TO 8                                           RAYPL100
```

```
      WRITE(NPLTDP) 1,NWDSRK,1,411                                          RAYPL101
      WRITE(NPLTDP) (IWDMP(I),I=1,411)                                      RAYPL102
C                                                                           RAYPL103
8     NEW=0                                                                 RAYPL104
      IF (NEWTRC) NEW=1                                                     RAYPL105
      NEWTRC=.FALSE.                                                        RAYPL106
C                                                                           RAYPL107
      IF(NPLTDP.LE.0) GO TO 88                                              RAYPL108
      IF(NEW.NE.1) GO TO 84                                                 RAYPL109
      WRITE(NPLTDP) 1,NWDSRK,17,25                                          RAYPL110
      WRITE(NPLTDP) (IWDMP(I),I=17,25)                                      RAYPL111
C                                                                           RAYPL112
84    WRITE(NPLTDP) 3-NEW,R,TH,PH                                           RAYPL113
C                                                                           RAYPL114
C                                                                           RAYPL115
88    IF(PLT.EQ.0) RETURN                                                   RAYPL116
C                                                                           RAYPL117
      STH=SIN (TH)                                                          RAYPL118
      CTH=SIN (PID2-TH)                                                     RAYPL119
      CR=CTHR*CTH+STHR*STH*SIN (PID2-(PHR-PH))                              RAYPL120
      CL=CTHL*CTH+STHL*STH*SIN (PID2-(PHL-PH))                              RAYPL121
      CEA=ATAN2(CR-CL*CLR,CL*SLR)                                           RAYPL122
C                                                                           RAYPL123
      IF(APLT.NE.4.) GO TO 150                                              RAYPL124
      CALL PLOT(CEA-ALPHA,R,NEW)                                            RAYPL125
      RETURN                                                                RAYPL126
C                                                                           RAYPL127
150   IF(APLT.EQ.2.) GO TO 10                                               RAYPL128
      RX=R                                                                  RAYPL129
      IF(APLT.EQ.3.) RX=RMIN+(R-RMIN)*PFACTR                                RAYPL130
      CALL PLOT(CEA-ALPHA,RX,NEW)                                           RAYPL131
      RETURN                                                                RAYPL132
C                                                                           RAYPL133
10    SL=SQRT(AMAX1(0.,1.-CL**2))                                           RAYPL134
      TMP1=STH*SIN (PH-PHL)                                                 RAYPL135
      TMP2=(CTH-CTHL*CL)/STHL                                               RAYPL136
      ALPH2=0.                                                              RAYPL137
      IF (TMP1.NE.0..OR.TMP2.NE.0.) ALPH2=ATAN2(TMP1,TMP2)                  RAYPL138
      CALL PLOT (EARTHR*CEA,EARTHR*ASIN(SL*SIN (ALPH1-ALPH2)),NEW)          RAYPL139
      RETURN                                                                RAYPL140
C                                                                           RAYPL141
C          DRAW AXES AND CALL FOR LABELING AND TERMINATION OF THIS PLOT     RAYPL142
      ENTRY ENDPLT                                                          RAYPL143
C                                                                           RAYPL144
C     IF NEWWR IS STILL TRUE, NO PLOTS WHERE PRODUCED                       RAYPL145
      IF(NEWWR) RETURN                                                      RAYPL146
      NEWWR=.TRUE.                                                          RAYPL147
C                                                                           RAYPL148
C     SIGNAL END OF PLOT                                                    RAYPL149
      IF(NPLTDP.GT.0) WRITE(NPLTDP) 4,(NWDSRK,I=2,NWDSRK)                   RAYPL150
C                                                                           RAYPL151
      IF(PLT.EQ.0) RETURN                                                   RAYPL152
C                                                                           RAYPL153
      TICKX=0.01*(YT-YB)                                                    RAYPL154
      DTIC=TIC*EARTHR                                                       RAYPL155
      CALL SETXY(APLT,-ALPHA,RMIN,ALPHA,RMAX)
```

```
C
      IF(APLT.EQ.4.) GO TO 200                                          RAYPL156
      IF(APLT.EQ.2.) GO TO 25                                           RAYPL157
C                                                                       RAYPL158
C     CURVLINEAR PROJECTIONS(=1,3)                                      RAYPL159
      CALL ARCTIC(-ALPHA,ALPHA,RMIN,TICKX,PLTHLB)                       RAYPL160
      CALL ARCTIC(-ALPHA,ALPHA,RMAX,-TICKX,PLTHLB)                      RAYPL161
      GO TO 300                                                         RAYPL162
C                                                                       RAYPL163
C     CARTESIAN PROJECTION PUT IN BOTTOM BOUNDARY                       RAYPL164
200   CALL TIKLINE(-ALPHA,RMIN,ALPHA,RMIN,TIC,-TICKX,PLTHLB)           RAYPL165
C     PUT IN TOP BOUNDARY                                               RAYPL166
      CALL TIKLINE(-ALPHA,RMAX,ALPHA,RMAX,TIC,TICKX,PLTHLB)             RAYPL167
C                                                                       RAYPL168
300   TIKL=.02*ALPHA                                                    RAYPL169
      LTIC=TICV                                                         RAYPL170
      IF(APLT.EQ.3.) LTIC=TICV*PFACTR                                   RAYPL171
C     PUT IN LEFT BOUNDARY                                              RAYPL172
      CALL TIKLINE(-ALPHA,RMIN,-ALPHA,RMAX,LTIC,TIKL,PLTLB)             RAYPL173
C     PUT IN RIGHT BOUNDARY                                             RAYPL174
      CALL TIKLINE(ALPHA,RMIN,ALPHA,RMAX,LTIC,-TIKL,PLTLBN)             RAYPL175
C                                                                       RAYPL176
      GO TO 50                                                          RAYPL177
C   DRAW TICKS, BOX FOR HORIZONTAL PLOT                                 RAYPL178
25    CALL DRAWTKS(DTIC,TICV,XL,XR,YB,YT,PLOT)                          RAYPL179
C                                                                       RAYPL180
50    IF(APLT.EQ.2.0) THEN                                              RAYPL181
        CALL PLTANOT(ID,OW/PIT2,XFQMDL,YFQMDL,XL,YB,XR,YT,DEGS,         RAYPL182
     2      LLAT,LLON,RLAT,RLON,HB,HT,APLT,DTIC,DTIC/PFACTR,PLOT)       RAYPL183
      ELSE                                                              RAYPL184
        CALL PLTANOT(ID,OW/PIT2,XFQMDL,YFQMDL,-ALPHA,RMIN,ALPHA,RMAX,   RAYPL185
     2      DEGS,LLAT,LLON,RLAT,RLON,HB,HT,APLT,DTIC,TICV,PLOT)         RAYPL186
      ENDIF                                                             RAYPL187
C                                                                       RAYPL188
      CALL LABPLT                                                       RAYPL189
      CALL PLTEND                                                       RAYPL190
      RETURN                                                            RAYPL191
      END                                                               RAYPL192
                                                                        RAYPL193
```

```
      SUBROUTINE PLOT (X,Y,NEW)                                          PLOT   2
C     PLOTS ONE VECTOR FROM CURRENT PLOT POSITION TO POINT(X,Y)          PLOT   3
C     TAKING BORDER CROSSINGS INTO ACCOUNT.                              PLOT   4
      COMMON /PLT/ XMIN0,XMAX0,YMIN0,YMAX0,RESET                         PLOT   5
      COMMON/PLT/RMIN,RMAX,ALPHA,APLT                                    PLOT   6
      COMMON /DD/ INT,IOR,IT,IS,IC,ICC,IX,IY                             PLOT   7
C DEFINE NOMINAL PLOTTING AREA(ZERO SUFFIXES) AND AN                     PLOT   8
C OUTER CLIPPING BOUNDARY BEYOND WHICH NO VECTORS EXTEND.                PLOT   9
      DATA XOLD,YOLD/0.0,0.0/                                            PLOT  10
C 90% FOR Y RANGE                                                        PLOT  11
C                                                                        PLOT  12
C           COMPUTE SCALE FACTORS                                        PLOT  13
```

```
    1 IF (RESET.EQ.0.) GO TO 5                                          PLOT  14
      RESET=0.                                                          PLOT  15
      IF(APLT.EQ.2.) THEN                                               PLOT  16
         MRNGE=723                                                      PLOT  17
         MINX0=165                                                      PLOT  18
         MINY0=140                                                      PLOT  19
      ELSE                                                              PLOT  20
         MRNGE=813                                                      PLOT  21
         MINX0=165                                                      PLOT  22
         MINY0=140                                                      PLOT  23
      ENDIF                                                             PLOT  24
      IF(APLT.EQ.4.) MINY0=0                                            PLOT  25
C                                                                       PLOT  26
      MAXX0=MINX0+MRNGE                                                 PLOT  27
      MAXY0=MINY0+MRNGE                                                 PLOT  28
C                                                                       PLOT  29
      XSCALE=(MAXX0-MINX0)/(XMAX0-XMIN0)                                PLOT  30
      YSCALE=(MAXY0-MINY0)/(YMAX0-YMIN0)                                PLOT  31
      XMIN=XMIN0                                                        PLOT  32
      YMIN=YMIN0                                                        PLOT  33
      XMAX=XMAX0                                                        PLOT  34
      YMAX=YMAX0                                                        PLOT  35
      IF(APLT.EQ.2.) GO TO 5                                            PLOT  36
C                                                                       PLOT  37
      XMIN=-ALPHA                                                       PLOT  38
      XMAX=ALPHA                                                        PLOT  39
      YMIN=RMIN                                                         PLOT  40
      YMAX=RMAX                                                         PLOT  41
      IF(APLT.NE.4) GO TO 5                                             PLOT  42
      YSCALE=.85*YSCALE                                                 PLOT  43
      MINY0=MINY0+60                                                    PLOT  44
C                                                                       PLOT  45
C          START A NEW LINE                                             PLOT  46
C          HORIZONTAL DISPLACEMENT                                      PLOT  47
5     XS=X-XOLD                                                         PLOT  48
      YS=Y-YOLD                                                         PLOT  49
      S=1.0                                                             PLOT  50
      IF(NEW.EQ.0) GO TO 10                                             PLOT  51
      IF(X.GE.XMIN.AND.X.LE.XMAX.AND.Y.GE.YMIN.AND.Y.LE.YMAX) GO TO 48  PLOT  52
      GO TO 50                                                          PLOT  53
C                                                                       PLOT  54
10    IF (XS) 11,12,16                                                  PLOT  55
C          NEGATIVE                                                     PLOT  56
   11 X1=XMAX                                                           PLOT  57
      X2=XMIN                                                           PLOT  58
      GO TO 20                                                          PLOT  59
C          ZERO                                                         PLOT  60
   12 IF (YS) 13,50,14                                                  PLOT  61
   13 S1=(YMAX-YOLD)/YS                                                 PLOT  62
      S2=(YMIN-YOLD)/YS                                                 PLOT  63
      GO TO 40                                                          PLOT  64
   14 S1=(YMIN-YOLD)/YS                                                 PLOT  65
      S2=(YMAX-YOLD)/YS                                                 PLOT  66
      GO TO 40                                                          PLOT  67
C          POSITIVE                                                     PLOT  68
```

```
   16 X1=XMIN                                                          PLOT  69
      X2=XMAX                                                          PLOT  70
C                                                                      PLOT  71
C           VERTICAL DISPLACEMENT                                      PLOT  72
   20 IF (YS) 21,22,26                                                 PLOT  73
C           NEGATIVE                                                   PLOT  74
   21 Y1=YMAX                                                          PLOT  75
      Y2=YMIN                                                          PLOT  76
      GO TO 30                                                         PLOT  77
C           ZERO                                                       PLOT  78
   22 S1=(X1-XOLD)/XS                                                  PLOT  79
      S2=(X2-XOLD)/XS                                                  PLOT  80
      GO TO 40                                                         PLOT  81
C           POSITIVE                                                   PLOT  82
   26 Y1=YMIN                                                          PLOT  83
      Y2=YMAX                                                          PLOT  84
C                                                                      PLOT  85
   30 S1=AMAX1((X1-XOLD)/XS,(Y1-YOLD)/YS)                              PLOT  86
      S2=AMIN1((X2-XOLD)/XS,(Y2-YOLD)/YS)                              PLOT  87
C                                                                      PLOT  88
C           PLOT LINE -- CHECKING FOR BORDER CROSSINGS                 PLOT  89
40    IF (S2.LT.0..OR.S1.GT.1.) GO TO 50                               PLOT  90
      IF (S1.LT.0.) GO TO 42                                           PLOT  91
C           PREVIOUS POINT OFF GRAPH                                   PLOT  92
      XP=XOLD+XS*S1                                                    PLOT  93
      YP=YOLD+YS*S1                                                    PLOT  94
      IF(APLT.EQ.2.0.OR.APLT.EQ.4.0) GO TO 41                          PLOT  95
      T=XP                                                             PLOT  96
      XP=YP*SIN(T)                                                     PLOT  97
      YP=YP*COS(T)                                                     PLOT  98
C                                                                      PLOT  99
41    IX=MINX0+(XP-XMIN0)*XSCALE+0.5                                   PLOT 100
      IY=MINY0+(YP-YMIN0)*YSCALE+0.5                                   PLOT 101
      CALL DDBP                                                        PLOT 102
      GO TO 48                                                         PLOT 103
C                                                                      PLOT 104
42    IF (S2.GT.1.) GO TO 48                                           PLOT 105
C           CURRENT POINT OFF GRAPH                                    PLOT 106
      S=S2                                                             PLOT 107
C           CURRENT POINT ON GRAPH                                     PLOT 108
48    XP=XOLD+XS*S                                                     PLOT 109
      YP=YOLD+YS*S                                                     PLOT 110
      IF(APLT.EQ.2.0.OR.APLT.EQ.4.0) GO TO 49                          PLOT 111
      T=XP                                                             PLOT 112
      XP=YP*SIN(T)                                                     PLOT 113
      YP=YP*COS(T)                                                     PLOT 114
49    IX=MINX0+(XP-XMIN0)*XSCALE+0.5                                   PLOT 115
      IY=MINY0+(YP-YMIN0)*YSCALE+0.5                                   PLOT 116
      IF(NEW.EQ.0) CALL DDVC                                           PLOT 117
      IF(NEW.NE.0) CALL DDBP                                           PLOT 118
C                                                                      PLOT 119
C           EXIT ROUTINE                                               PLOT 120
   50 XOLD=X                                                           PLOT 121
      YOLD=Y                                                           PLOT 122
      RETURN                                                           PLOT 123
```

```
C
C           TERMINATE THE CURRENT PLOT                                          PLOT 124
                                                                                PLOT 125
      ENTRY PLTEND(X,Y,NEW)                                                     PLOT 126
      CALL DDFR                                                                 PLOT 127
C                                                                               PLOT 128
      RETURN                                                                    PLOT 129
         END                                                                    PLOT 130
```

```
      SUBROUTINE LABPLT                                                         LABPLT 2
C           LABEL THE CURRENT PLOT                                              LABPLT 3
      CHARACTER*80 LABEL,CHID                                                   LABPLT 4
      CHARACTER*4 ANGRANG,ANOTE                                                 LABPLT 5
C     COMMON DECK "SS" INSERTED HERE                                            CSS    2
      REAL MODSURF                                                              CSS    4
      COMMON/SS/ MODSURF(4)                                                     CSS    5
      COMMON/SS/U,PUR,PURR,PURTH,PURPH                                          CSS    6
      COMMON/SS/PUTH,PUPH,PUTHTH,PUPHPH,PUTHPH,USELECT,UTIME                    CSS    7
C     COMMON DECK "GG" INSERTED HERE                                            CGG    2
      REAL MODG                                                                 CGG    4
      COMMON/GG/MODG(4)                                                         CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                          CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME                    CGG    7
C     COMMON DECK "RR" INSERTED HERE                                            CRR    2
      REAL MODREC                                                               CRR    4
      COMMON/RR/ MODREC(4)                                                      CRR    5
      COMMON/RR/F,PFR,PFRR,PFRTH,PFRPH                                          CRR    6
      COMMON/RR/PFTH,PFPH,PFTHTH,PFPHPH,PFTHPH,FSELECT,FTIME                    CRR    7
C     COMMON DECK "UU" INSERTED HERE                                            CUU    2
      REAL MODU                                                                 CUU    4
      COMMON/UU/MODU(4)                                                         CUU    5
     1   ,V   ,PVT   ,PVR   ,PVTH   ,PVPH                                      CUU    6
     2   ,VR  ,PVRT  ,PVRR  ,PVRTH  ,PVRPH                                     CUU    7
     3   ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                        CUU    8
     4   ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                        CUU    9
C     COMMON DECK "CC" INSERTED HERE                                            CCC    2
      REAL MODC                                                                 CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                                CCC    5
C     COMMON DECK "TT" INSERTED HERE                                            CTT    2
      REAL MODT                                                                 CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                                    CTT    5
C     COMMON DECK "MM" INSERTED HERE                                            CMM    2
      REAL M,MODM                                                               CMM    4
      COMMON/MM/MODM(4),M,PMT,PMR,PMTH,PMPH                                     CMM    5
C     COMMON DECK "HDR" INSERTED HERE                                           CHDR   2
      CHARACTER*10 INITID*80,DAT,TOD                                            CHDR   4
      COMMON/HDR/SEC                                                            CHDR   5
      COMMON/HDRC/INITID,DAT,TOD                                                CHDR   6
C     COMMON DECK "RINPLEX" INSERTED HERE                                       CRINPLE2
      REAL KAY2,KAY2I                                                           CRINPLE4
      COMPLEX PNP,POLAR,LPOLAR                                                  CRINPLE5
      LOGICAL SPACE                                                             CRINPLE6
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      CHARACTER DISPM*6                                                      CRINPLE7
      COMMON/RINPL/DISPM                                                     CRINPLE8
      COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                      CRINPLE9
      COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I                                  CRINPL10
      COMMON/RIN/PNP(10),POLAR,LPOLAR,SGN                                    CRINPL11
      COMMON /DD/ INT,IOR,IT,IS,IC,ICC,IX,IY                                 LABPLT15
C     COMMON DECK "CONST" INSERTED HERE                                      CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                          CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                              CCONST 5
C     COMMON DECK "FLAG" INSERTED HERE                                       CFLAG  2
      LOGICAL NEWWR,NEWWP,NEWTRC,PENET                                       CFLAG  4
      COMMON /FLG/ NTYP,NEWWR,NEWWP,NEWTRC,PENET,LINES,IHOP,HPUNCH           CFLAG  5
      COMMON/FLGP/NSET                                                       CFLAG  6
C     COMMON DECK "WW" INSERTED HERE                                         CWW    2
      PARAMETER (NWARSZ=1000)                                                CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                        CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                     CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),         CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),           CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),               CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),              CWW2   6
     8 (RCVRH,W(20)),                                                        CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))     CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                           CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                           CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                          CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),            CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))             CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),             CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                   CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                        CWW2  16
      REAL MMODEL,MFORM,MID                                                  CWW3   2
C                                                                            CWW3   3
C     WIND         100-124                                                   CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)                CWW3   5
C                                                                            CWW3   6
C     DELTA WIND         125-149                                           CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)             CWW3   8
C                                                                            CWW3   9
C     SOUND SPEED 150-174                                                    CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                CWW3  11
      EQUIVALENCE (W(153),REFC)                                              CWW3  12
C                                                                            CWW3  13
C     DELTA SOUND SPEED 175-199                                              CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)             CWW3  15
C                                                                            CWW3  16
C     TEMPERATURE    200-224                                                 CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                CWW3  18
C                                                                            CWW3  19
C     DELTA TEMPERATURE    225-249                                           CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)             CWW3  21
C                                                                            CWW3  22
C     MOLECULAR   250-274                                                    CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                CWW3  24
C                                                                            CWW3  25
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C       RECEIVER HEIGHT   275-299                                          CWW3  26
        EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)           CWW3  27
C                                                                         CWW3  28
C       TOPOGRAPHY    300-324                                             CWW3  29
        EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)           CWW3  30
C                                                                         CWW3  31
C       DELTA TOPOGRAPHY    325-349                                       CWW3  32
        EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)        CWW3  33
C                                                                         CWW3  34
C       UPPER SURFACE TOPOGRAPHY    350-374                               CWW3  35
        EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)           CWW3  36
C       PLOT ENHANCEMENTS CONTROL PARAMETERS                              CWW3  37
C                                                                         CWW3  38
        EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                       CWW3  39
C       ABSORPTION          500-524                                       CWW3  40
        EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)           CWW3  41
C                                                                         CWW3  42
C       DELTA ABSORPTION          525-549                                 CWW3  43
        EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)        CWW3  44
C                                                                         CWW3  45
C       PRESSURE          550-574                                         CWW3  46
        EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)           CWW3  47
C                                                                         CWW3  48
C       DELTA PRESSURE          575-599                                   CWW3  49
        EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)        CWW3  50
C                                                                         CWW3  51
C                                                                         LABPLT19
C       COMMON DECK "AA" INSERTED HERE                                    CAA    2
        REAL MODA                                                         CAA    4
        REAL MU,MUPT,MUPR,MUPTH,MUPPH                                     CAA    5
        REAL KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                                CAA    6
        COMMON/AA/MODA(4),MU,MUPT,MUPR,MUPTH,MUPPH                        CAA    7
        COMMON/AA/KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                           CAA    8
C       COMMON DECK "PP" INSERTED HERE                                    CPP    2
        REAL MODP                                                         CPP    4
        COMMON/PP/MODP(4),P,PPT,PPR,PPTH,PPPH                             CPP    5
C                                                                         LABPLT22
        WRITE(LABEL,900) ID                                               LABPLT23
900     FORMAT(10A8)                                                      LABPLT24
        CHID=LABEL                                                        LABPLT25
        LABEL=CHID(5:)                                                    LABPLT26
        IOR=0                                                             LABPLT27
        IT=0                                                              LABPLT28
        IS=2                                                              LABPLT29
        IX=0                                                              LABPLT30
        IY=1023                                                           LABPLT31
        CALL DDTEXT (8,LABEL)                                             LABPLT32
        IX=1090                                                           LABPLT33
        IY=0                                                              LABPLT34
        CALL DDTEXT (2,DAT)                                               LABPLT35
        IY=1023                                                           LABPLT36
        F=OW/PIT2                                                         LABPLT37
        NANGLE=10                                                         LABPLT38
        ANGRANG='EL ='                                                    LABPLT39
        ANOTE='AZ ='                                                      LABPLT40
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      ANEL=0.                                                          LABPLT41
      IF(ELSTEP.NE.0.0) ANEL=(ELEND-ELBEG)/ELSTEP+1.5                  LABPLT42
      IF(ANEL.GT.1.0.OR.PLT.LT.0.0) GO TO 100                          LABPLT43
         ANGRANG='AZ ='                                                LABPLT44
         ANOTE='EL ='                                                  LABPLT45
         NANGLE=14                                                     LABPLT46
100   WRITE(LABEL,1300)  CHID(1:3),F,ANOTE,W(NANGLE)*DEGS              LABPLT47
1300  FORMAT ('MODEL = ',A,'  ,FREQ =',F9.3,' HZ, ',A,F7.3,' DEG')     LABPLT48
      IX=0                                                             LABPLT49
      IY=IY-32                                                         LABPLT50
      CALL DDTEXT (7,LABEL)                                            LABPLT51
C                                                                      LABPLT52
C INDEX OF OPPOSITE ANGLE                                              LABPLT53
      NANGLE=(10+14-NANGLE)+1                                          LABPLT54
      NANGLE2=NANGLE+2                                                 LABPLT55
      WRITE(LABEL,1400) ANGRANG,(W(I)*DEGS,I=NANGLE,NANGLE2)           LABPLT56
1400  FORMAT(A,F7.2,' DEG TO',F7.2,' DEG, STEP =',F7.2,' DEG')         LABPLT57
      IY=IY-32                                                         LABPLT58
      CALL DDTEXT (7,LABEL)                                            LABPLT59
C                                                                      LABPLT60
      WRITE(LABEL,1500) XMTRH,TLAT*DEGS,TLON*DEGS                      LABPLT61
1500  FORMAT('XMTR HT =',F6.2,' KM ,LAT =',F6.2,' DEG, LONG ='         LABPLT62
     1   ,F6.2,' DEG')                                                 LABPLT63
      IY=IY-32                                                         LABPLT64
      CALL DDTEXT (7,LABEL)                                            LABPLT65
C                                                                      LABPLT66
      IY=IY-32                                                         LABPLT67
      WRITE(LABEL,'(10A8)') MODRIN                                     LABPLT68
      CALL DDTEXT(8,LABEL)                                             LABPLT69
C                                                                      LABPLT70
      IX=1050                                                          LABPLT71
      CALL DDTEXT(1,'MODELS')                                          LABPLT72
      IY=IY-15                                                         LABPLT73
C     LOOP FOR 8 MODELS AND PERTURBATIONS                              LABPLT74
      DO 1700 K=1,16                                                   LABPLT75
      I=(K-1)/2+1                                                      LABPLT76
C     GENERATE ALTERNATING 1,2;3,4 SERIES FOR MODEL AND PERTURBATION   LABPLT77
      J1=2*(K+1-I*2)+1                                                 LABPLT78
      J2=J1+1                                                          LABPLT79
      IF(I.EQ.1) WRITE(LABEL,1600) (MODU(J),J=J1,J2)                   LABPLT80
      IF(I.EQ.2) WRITE(LABEL,1600) (MODC(J),J=J1,J2)                   LABPLT81
      IF(I.EQ.3) WRITE(LABEL,1600) (MODT(J),J=J1,J2)                   LABPLT82
      IF(I.EQ.4 .AND. J1.EQ.1)                                         LABPLT83
     1 WRITE(LABEL,1600) (MODM(J),J=J1,J2)                             LABPLT84
C                                                                      LABPLT85
      IF(I.EQ.5) WRITE(LABEL,1600) (MODG(J),J=J1,J2)                   LABPLT86
      IF(I.EQ.6) WRITE(LABEL,1600) (MODA(J),J=J1,J2)                   LABPLT87
      IF(I.EQ.7) WRITE(LABEL,1600) (MODP(J),J=J1,J2)                   LABPLT88
C NO FURTHER OUTPUT FOR MODELS WITHOUT PERTURBATIONS                   LABPLT89
      IF(J1.GT.1) GO TO 1610                                           LABPLT90
      IF(I.EQ.8) WRITE(LABEL,1600) (MODREC(J),J=J1,J2)                 LABPLT91
1600  FORMAT(2(2(A8,2X,F5.1,1X),2X))                                   LABPLT92
C                                                                      LABPLT93
1610  IF(LABEL(1:1).EQ.' ') GO TO 1700                                 LABPLT94
      IY=IY-32                                                         LABPLT95
```

```
      CALL DDTEXT(2,LABEL)                                                  LABPLT96
1700  LABEL(1:1)=' '                                                        LABPLT97
C                                                                           LABPLT98
          END                                                               LABPLT99



      SUBROUTINE PLTHLB(X,Y,NC)                                             PLTHLB 2
C     HORIZONTAL TICK ANNOTATION ROUTINE FOR RAYPLOT.                       PLTHLB 3
C                                                                           PLTHLB 4
C                                                                           PLTHLB 5
      EXTERNAL PLOT                                                         PLTHLB 6
C                                                                           PLTHLB 7
      CALL PLTANH(X,Y,NC,PLOT)                                              PLTHLB 8
      END                                                                   PLTHLB 9



      SUBROUTINE PLTANH(X,Y,NC,PLOT)                                        PLTANH 2
C                                                                           PLTANH 3
C     TIC LABELING ROUTINE FOR HORIZONTAL PLOT PROJECTIONS                  PLTANH 4
C                                                                           PLTANH 5
      CHARACTER ANNOT*10                                                    PLTANH 6
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                                   PLTANH 7
C     COMMON DECK "WWR" INSERTED HERE                                       CWWR   2
      PARAMETER (NWARSZ=1000)                                               CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                       CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                    CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),        CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),          CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),              CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),             CWW2   6
     8 (RCVRH,W(20)),                                                       CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))    CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                          CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                          CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                         CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),           CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))            CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),            CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                  CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                       CWW2  16
C     COMMON DECK "CONST" INSERTED HERE                                     CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                         CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                             CCONST 5
      COMMON/LABCLT/PROJCT,THMIN,THMAX,RMIN,RMAX                            PLTANH10
C                                                                           PLTANH11
      COMMON/RAYCON/MCONP                                                   PLTANH12
C                                                                           PLTANH13
      DATA LNC/-100/                                                        PLTANH14
C                                                                           PLTANH15
```

```
      IF(NC.LE.0 .OR. NC.GT.2) GO TO 100                                PLTANH16
C                                                                       PLTANH17
C     NORMALIZE LETTER SIZE FACTOR TO .15 INCHES                        PLTANH18
      HLETF=HITLET/.15                                                  PLTANH19
C                                                                       PLTANH20
      IF(LNC.NE.NC) LICM=-100                                           PLTANH21
      LNC=NC                                                            PLTANH22
C                                                                       PLTANH23
      CALL PLOT(X,Y,1)                                                  PLTANH24
      IX=IX-80*HLETF                                                    PLTANH25
      ICM=IX                                                            PLTANH26
      IF(NC.GT.1) THEN                                                  PLTANH27
         ICM=IY                                                         PLTANH28
         IX=IX-40                                                       PLTANH29
      ENDIF                                                             PLTANH30
C                                                                       PLTANH31
C     INSURE THAT OVERLAPS OF ANNOTATIONS DO NOT OCCUR                  PLTANH32
      IF(IABS(ICM-LICM).LT.INT(80*HLETF)) GO TO 100                     PLTANH33
C                                                                       PLTANH34
      IF(PROJCT.EQ.2.0) GO TO 25                                        PLTANH35
      IF(HB.GE.0.0.AND.Y.GT.(RMIN+RMAX)/2) GO TO 100                    PLTANH36
      IF(HB.LT.0.0.AND.Y.LT.(RMIN+RMAX)/2) GO TO 100                    PLTANH37
C                                                                       PLTANH38
25    F=DEGS                                                            PLTANH39
      TMP=(THMAX-THMIN)*DEGS                                            PLTANH40
      IF(TMP.LT.10.) F =EARTHR                                          PLTANH41
      FT=F                                                              PLTANH42
      IF(PROJCT.EQ.2.0 .AND. MCONP.EQ.0) F=F/EARTHR                     PLTANH43
      V=X-THMIN                                                         PLTANH44
      IF(NC.GT.1) V=Y-(RMIN+RMAX)/2.                                    PLTANH45
      IF(ABS(AMOD(TIC*FT+.0001,1.)).GT..001) GO TO 60                   PLTANH46
C                                                                       PLTANH47
      WRITE(ANNOT,50) INT(V*F+SIGN(.5,V))                               PLTANH48
50    FORMAT(I5)                                                        PLTANH49
      GO TO 90                                                          PLTANH50
C                                                                       PLTANH51
60    WRITE(ANNOT,80) V*F                                               PLTANH52
80    FORMAT(F8.2)                                                      PLTANH53
C                                                                       PLTANH54
90    LICM=ICM                                                          PLTANH55
C     ALLOW 8 RASTERS FOR THE LETTER HEIGHT                             PLTANH56
      H=HB                                                              PLTANH57
      IF(PROJCT.EQ.2.0) H=0.                                            PLTANH58
      IF(NC.EQ.1) IY=IY-8*HLETF-SIGN(52.,H)                             PLTANH59
      IOR=0                                                             PLTANH60
95    FORMAT(3G13.6,2I5,1X,A10)                                         PLTANH61
99    FORMAT(2G13.6,5I5,1X,A10)                                         PLTANH62
      CALL DDTEXT(1,ANNOT)                                              PLTANH63
C                                                                       PLTANH64
100   CALL PLOT(X,Y,MIN0(1,NC))                                         PLTANH65
      END                                                               PLTANH66
```

```
      SUBROUTINE SETXY(PROJ,XMIN,YMIN,XMAX,YMAX)                        SETXY  2
C     PLOT INITIALIZATION; SETS PROJECTION PARAMETERS                   SETXY  3
C                                                                       SETXY  4
      COMMON/LABCLT/PROJCT,THMIN,THMAX,RMIN,RMAX                        SETXY  5
C                                                                       SETXY  6
C                                                                       SETXY  7
C   INITIAL ANNOTATION MODEL                                            SETXY  8
      CALL SETANN                                                       SETXY  9
C                                                                       SETXY 10
      PROJCT=PROJ                                                       SETXY 11
      THMIN=XMIN                                                        SETXY 12
      RMIN=YMIN                                                         SETXY 13
      THMAX=XMAX                                                        SETXY 14
      RMAX=YMAX                                                         SETXY 15
      END                                                               SETXY 16


      SUBROUTINE TIKLINE(XL1,YB,XL,YT1,TICV,TIKSZ,PLOT)                 TIKLINE2
C     DRAWS STRAIGHT LINE WITH TICKS AT INTERVALS                       TIKLINE3
C                                                                       TIKLINE4
C                                                                       TIKLINE5
      XDF=XL-XL1                                                        TIKLINE6
      YDF=YT1-YB                                                        TIKLINE7
      DST=SQRT(XDF*XDF+YDF*YDF)                                         TIKLINE8
      TICE=DST                                                          TIKLINE9
      T=0.0                                                             TIKLIN10
      IF(TICV.EQ.0.0) GO TO 50                                          TIKLIN11
      TICE=TICV                                                         TIKLIN12
      T=TIKSZ/TICV                                                      TIKLIN13
C                                                                       TIKLIN14
50    TICVX=TICE*XDF/DST                                                TIKLIN15
      TICVY=TICE*YDF/DST                                                TIKLIN16
      TX=TICVY*T                                                        TIKLIN17
      TY=-TICVX*T                                                       TIKLIN18
      NTIC=1+DST/TICE                                                   TIKLIN19
      CALL PLOT(XL1,YB,-1)                                              TIKLIN20
      DO 100 I=0,NTIC-1                                                 TIKLIN21
        X=XL1+I*TICVX                                                   TIKLIN22
        Y=YB+I*TICVY                                                    TIKLIN23
        CALL PLOT(X,Y,0)                                                TIKLIN24
        CALL PLOT(X+TX,Y+TY,0)                                          TIKLIN25
100   CALL PLOT(X,Y,1)                                                  TIKLIN26
      CALL PLOT(XL,YT1,0)                                               TIKLIN27
      CALL PLOT(XL,YT1,1)                                               TIKLIN28
      END                                                               TIKLIN29


      SUBROUTINE PLTANOT(ID,FREQ,XMF,YMF,XL,YB,XR,YT                    PLTANOT2
```

```
     1    ,DEGS,LLAT,LLON,RLAT,RLON,ALTLOW,ALTHI,PLT,DTICH,DTICV,PLOT)   PLTANOT3
C      PUTS STANDARD ANNOTATIONS ON PLOTS                                PLTANOT4
C                                                                        PLTANOT5
       COMMON/LABCLT/PROJCT,THMIN,THMAX,RMIN,RMAX                        PLTANOT6
       REAL LLAT,LLON                                                    PLTANOT7
       CHARACTER LABEL*80                                                PLTANOT8
       COMMON /DD/ INT,IOR,IT,IS,IC,ICC,IX,IY                            PLTANOT9
C      COMMON DECK "ANNOT" INSERTED HERE                                 ANNOT  2
       CHARACTER*10 ANOTES,HNOTES                                        ANNOT  4
       COMMON/ANNCTL/LENA(4),LENHA(3)                                    ANNOT  5
       COMMON/ANNCTC/ANOTES(2,4),HNOTES(4,3)                             ANNOT  6
C                                                                        PLTANO11
       IF(PLT.EQ.2. .OR. XMF.LE.0.0 .OR. YMF.LE.0.0) GO TO 45            PLTANO12
       CALL PLOT(XL+XMF*(XR-XL),YB+YMF*(YT-YB),1)                        PLTANO13
       IF(FREQ.LE.0.0) GO TO 30                                          PLTANO14
C                                                                        PLTANO15
       WRITE(LABEL,25) FREQ                                              PLTANO16
25     FORMAT('FREQ =',F9.3)                                             PLTANO17
       CALL DDTEXT(2,LABEL)                                              PLTANO18
       IY=IY+40                                                          PLTANO19
C                                                                        PLTANO20
30     WRITE(LABEL,35) ID                                                PLTANO21
35     FORMAT('MODEL = ',A3)                                             PLTANO22
       CALL DDTEXT(2,LABEL)                                              PLTANO23
C                                                                        PLTANO24
45     NSPY=97                                                           PLTANO25
       IOR=0                                                             PLTANO26
C                                                                        PLTANO27
C FIRST THE LOW ALTITUDE-LATITUDE ANNOTATION                             PLTANO28
50     CALL PLOT(XL,YB,1)                                                PLTANO29
       IX=IX-155                                                         PLTANO30
       IY=IY-NSPY                                                        PLTANO31
       WRITE(LABEL,1840) DEGS*LLON                                       PLTANO32
       CALL DDTEXT(2,LABEL)                                              PLTANO33
       WRITE(LABEL,1850) DEGS*LLAT                                       PLTANO34
       IY=IY-32                                                          PLTANO35
       CALL DDTEXT(2,LABEL)                                              PLTANO36
C                                                                        PLTANO37
C NEXT THE RIGHT LATITUDE ANNOTATION                                     PLTANO38
       CALL PLOT(XR,YB,1)                                                PLTANO39
       IX=IX-130                                                         PLTANO40
       IY=IY-NSPY                                                        PLTANO41
       WRITE(LABEL,1840) DEGS*RLON                                       PLTANO42
       CALL DDTEXT(2,LABEL)                                              PLTANO43
       WRITE(LABEL,1850) DEGS*RLAT                                       PLTANO44
       IY=IY-32                                                          PLTANO45
       CALL DDTEXT(2,LABEL)                                              PLTANO46
C                                                                        PLTANO47
       XMID=(XL+XR)/2.0                                                  PLTANO48
       IF(PLT.EQ.2.0) GO TO 55                                           PLTANO49
C                                                                        PLTANO50
C PUT THE HORIZONTAL TIC LABEL                                           PLTANO51
       Y=YT                                                              PLTANO52
       IF(ALTLOW.GE.0.0) Y=YB                                            PLTANO53
       CALL PLOT(XMID,Y,1)                                               PLTANO54
```

```
C                                                                       PLTANO55
      IF(ALTLOW.LT.0.0) IY=IY+80                                        PLTANO56
      IF(ALTLOW.GE.0.0) IY=IY-95                                        PLTANO57
      GO TO 60                                                          PLTANO58
C                                                                       PLTANO59
55    CALL PLOT(XMID,YB,1)                                              PLTANO60
      IY=IY-95                                                          PLTANO61
C                                                                       PLTANO62
60    IX=IX-235                                                         PLTANO63
      NOTEA=1                                                           PLTANO64
      TMP=(THMAX-THMIN)*DEGS                                            PLTANO65
      IF(TMP.GT.10.) NOTEA=2                                            PLTANO66
C                                                                       PLTANO67
      CALL DDTEXT (LENHA(NOTEA),HNOTES(1,NOTEA))                        PLTANO68
C                                                                       PLTANO69
C PUT THE VERTICAL TIC LABEL                                            PLTANO70
      CALL PLOT(XL,(YB+YT)/2.0,1)                                       PLTANO71
      IOR=1                                                             PLTANO72
      IF(PLT.NE.2.) GO TO 100                                           PLTANO73
C                                                                       PLTANO74
C   HORIZONTAL PLOT  PUT Y-AXIS ANNOTATION                              PLTANO75
C                                                                       PLTANO76
      IX=IX-125                                                         PLTANO77
      IY=200                                                            PLTANO78
      CALL DDTEXT (LENHA(3),HNOTES(1,3))                                PLTANO79
      GO TO 200                                                         PLTANO80
C                                                                       PLTANO81
100   IX=IX-125                                                         PLTANO82
      IY=IY-75                                                          PLTANO83
      NOTEA=1                                                           PLTANO84
      IF(ALTLOW.GE.0.0) NOTEA=3                                         PLTANO85
      IF(ABS(ALTHI-ALTLOW).GE.1.) NOTEA=NOTEA+1                         PLTANO86
      CALL DDTEXT (LENA(NOTEA),ANOTES(1,NOTEA))                         PLTANO87
C                                                                       PLTANO88
200   IOR=0                                                             PLTANO89
1840  FORMAT(F7.2,' DEG E.')                                            PLTANO90
1850  FORMAT(F7.2,' DEG N.')                                            PLTANO91
C                                                                       PLTANO92
      END                                                               PLTANO93
```

```
      SUBROUTINE DRAWTKS(DTICH,DTICV,XLPR,XR,YBPR,YT,PLOT)              DRAWTKS2
C                                                                       DRAWTKS3
C     HORIZONTAL PLOT PROJECTION SUPPORT ROUTINE.                       DRAWTKS4
C     DRAW BOUNDARY TO PLOT AREA, TICS AND TIC LABELS.                  DRAWTKS5
C                                                                       DRAWTKS6
      EXTERNAL PLOT                                                     DRAWTKS7
C                                                                       DRAWTKS8
      XL=XLPR                                                           DRAWTKS9
      YB=YBPR                                                           DRAWTK10
      YMID=.5*(YB+YT)                                                   DRAWTK11
      TICX=.01*(YT-YB)                                                  DRAWTK12
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      TICY=.01*(XR-XL)                                                    DRAWTK13
      YBP=YB                                                              DRAWTK14
      IF(DTICV.GT.0.) YBP=YMID-AINT((YMID-YB)/DTICV)*DTICV                DRAWTK15
C                                                                         DRAWTK16
      NTICX=(XR-XL)/DTICH                                                 DRAWTK17
      NTICY=1                                                             DRAWTK18
      IF(DTICV.GT.0.) NTICY=(YT-YBP+DTICV)/DTICV                          DRAWTK19
C&     PRINT *,"DRAWTKS ",XLPR,XR,YBPR,YBP,YT,DTICH,DTICV,NTICX,NTICY     DRAWTK20
      IOF=0                                                               DRAWTK21
C                                                                         DRAWTK22
C     TWO PASSES BOTTOM AND LEFT THEN TOP AND RIGHT                       DRAWTK23
      DO 100 J=1,2                                                        DRAWTK24
      CALL PLOT(XL,YBPR,1)                                                DRAWTK25
      DO 30 I=1,NTICY                                                     DRAWTK26
      Y=YBP+(I-1)*DTICV                                                   DRAWTK27
      CALL PLOT(XL,Y,0)                                                   DRAWTK28
      CALL PLOT(XL+TICY,Y,0)                                              DRAWTK29
30    CALL PLTANH(XL,Y,IOF+2,PLOT)                                        DRAWTK30
      CALL PLOT(XL,YT,0)                                                  DRAWTK31
C                                                                         DRAWTK32
      CALL PLOT(XLPR,YB,1)                                                DRAWTK33
C                                                                         DRAWTK34
      DO 40 I=1,NTICX                                                     DRAWTK35
      X=XLPR+I*DTICH                                                      DRAWTK36
      CALL PLOT(X,YB,0)                                                   DRAWTK37
      CALL PLOT(X,YB+TICX,0)                                              DRAWTK38
      CALL PLTANH(X,YB,IOF+1,PLOT)                                        DRAWTK39
40    CALL PLOT(X,YB,1)                                                   DRAWTK40
      CALL PLOT(XR,YB,0)                                                  DRAWTK41
      YB=YT                                                               DRAWTK42
      XL=XR                                                               DRAWTK43
      TICX=-TICX                                                          DRAWTK44
      TICY=-TICY                                                          DRAWTK45
100   IOF=10                                                              DRAWTK46
C                                                                         DRAWTK47
      CALL PLOT(XLPR,YMID,1)                                              DRAWTK48
      CALL PLOT(XR,YMID,0)                                                DRAWTK49
      END                                                                 DRAWTK50
```

```
      SUBROUTINE PLTLB(X,PY,NCP)                                          PLTLB  2
C     PUT VERTICAL TIC ANNOTATIONS ON RAY PLOT                            PLTLB  3
C     THIS IS A SPECIAL PURPOSE SUBSTITUTE FOR THE 'PLOT' ROUTINE         PLTLB  4
C     IT COMPUTES THE NEAREST ROUNDED TIC POSITIONS FOR VERTICAL LINES.   PLTLB  5
C     WHEN THE NC PARAMETER IS > 0 AN ANNOTATION IS GENERATED             PLTLB  6
C     AT THE TIC POSITION. THE ADDITIONAL NC VALUE < 0 ALLOWS FOR         PLTLB  7
C     SIMPLE PEN UP MOTION TO THE X,Y POSITION.                           PLTLB  8
C                                                                         PLTLB  9
      CHARACTER ANNOT*10                                                  PLTLB 10
C                                                                         PLTLB 11
C     COMMON DECK "WWR" INSERTED HERE                                     CWWR   2
      PARAMETER (NWARSZ=1000)                                             CWW1   3
```

```
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                    CWW1    4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                 CWW2    2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),     CWW2    3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),       CWW2    4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),           CWW2    5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),          CWW2    6
     8 (RCVRH,W(20)),                                                    CWW2    7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2    8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                       CWW2    9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                       CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                      CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),        CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))         CWW2   13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),         CWW2   14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))               CWW2   15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                    CWW2   16
      COMMON /DD/ IINT,IOR,IT,IS,IC,ICC,IX,IY                            PLTLB  13
      COMMON/LABCLT/PROJCT,THMIN,THMAX,RMIN,RMAX                         PLTLB  14
C                                                                        PLTLB  15
      DATA LIY/-100/                                                     PLTLB  16
C                                                                        PLTLB  17
      NC=NCP                                                             PLTLB  18
      GO TO 10                                                           PLTLB  19
C                                                                        PLTLB  20
      ENTRY PLTLBN(X,PY,NCP)                                             PLTLB  21
      NC=0                                                               PLTLB  22
C                                                                        PLTLB  23
10    Y=PY                                                               PLTLB  24
C                                                                        PLTLB  25
      IF(NCP.LT.0) GO TO 200                                             PLTLB  26
      F=1.                                                               PLTLB  27
      IF(AMAX1(ABS(RMAX-EARTHR),ABS(RMIN-EARTHR)).LT.1.) F=1000.         PLTLB  28
      Y=INT((Y-EARTHR)*F)/F+EARTHR                                       PLTLB  29
      IF(NC.EQ.0) GO TO 100                                              PLTLB  30
C                                                                        PLTLB  31
      V=Y                                                                PLTLB  32
      IF(PROJCT.EQ.3.) V=RMIN+(Y-RMIN)/PFACTR                            PLTLB  33
      IF(ABS(AINT(TICV*F)-TICV*F).GT..001) GO TO 60                      PLTLB  34
C                                                                        PLTLB  35
      WRITE(ANNOT,50) INT(ABS(V-EARTHR)*F)                               PLTLB  36
50    FORMAT(I3)                                                         PLTLB  37
      GO TO 90                                                           PLTLB  38
C                                                                        PLTLB  39
60    WRITE(ANNOT,80) ABS(V-EARTHR)*F                                    PLTLB  40
80    FORMAT(F6.2)                                                       PLTLB  41
C                                                                        PLTLB  42
90    CALL PLOT(X,PY,1)                                                  PLTLB  43
      CALL PLOT(X,Y,1)                                                   PLTLB  44
C     INSURE THAT OVERLAPS OF ANNOTATIONS DO NOT OCCUR                   PLTLB  45
      IF(IABS(IY-LIY).LT.80) GO TO 100                                   PLTLB  46
      LIY=IY                                                             PLTLB  47
      IX=IX-100                                                          PLTLB  48
      IOR=0                                                              PLTLB  49
      CALL DDTEXT(1,ANNOT)                                               PLTLB  50
C                                                                        PLTLB  51
```

```
100   CALL PLOT(X,Y,NC)                                                    PLTLB 52
      RETURN                                                               PLTLB 53
C                                                                          PLTLB 54
200   CALL PLOT(X,Y,1)                                                     PLTLB 55
      RETURN                                                               PLTLB 56
      END                                                                  PLTLB 57



      SUBROUTINE ARCTIC(THMIN,THMAX,HEIGHT,TICY,PLOT)                      ARCTIC 2
C     DRAW RANGE AXIS IN RAY TRACE PLOT. INCLUDES ANY CURVILINEAR          ARCTIC 3
C     PROJECTIONS PROVIDED IN DDGRAPH.                                     ARCTIC 4
C     COMMON DECK "WWR" INSERTED HERE                                      CWWR   2
      PARAMETER (NWARSZ=1000)                                              CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                      CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                   CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),       CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),         CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),             CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),            CWW2   6
     8 (RCVRH,W(20)),                                                      CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))   CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                         CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                         CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                        CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),          CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))           CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),           CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                 CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                      CWW2  16
      COMMON /DDSCALE/ XMIN,XMAX,YMIN,YMAX,MINX,MAXX,MINY,MAXY,SCX,SCY,    ARCTIC 6
     1 NSCX,NXCY,MSCX,MSCY,ISCX,ISCY                                       ARCTIC 7
C                                                                          ARCTIC 8
      NTIC=2                                                               ARCTIC 9
      IF(TIC.NE.0.) NTIC=1+(THMAX-THMIN)/TIC                               ARCTIC10
      NLINE=MAX0(2,100/NTIC)                                               ARCTIC11
C                                                                          ARCTIC12
      TICN=TIC/(NLINE-2)                                                   ARCTIC13
      DO 10 I=1,NTIC                                                       ARCTIC14
      X=THMIN+(I-1)*TIC                                                    ARCTIC15
      CALL PLOT(X,HEIGHT+TICY,1)                                           ARCTIC16
      DO 10 J=2,NLINE                                                      ARCTIC17
      XJ=X+(J-2)*TICN                                                      ARCTIC18
      IF(XJ.GT.THMAX) GO TO 15                                             ARCTIC19
10    CALL PLOT(XJ,HEIGHT,0)                                               ARCTIC20
C                                                                          ARCTIC21
15    CALL PLOT(THMAX,HEIGHT,0)                                            ARCTIC22
      CALL PLOT(THMAX,HEIGHT+TICY,1)                                       ARCTIC23
      RETURN                                                               ARCTIC24
      END                                                                  ARCTIC25
```

```
      BLOCK DATA PLOTBL                                                 PLOTBL 2
C     BLOCK DATA INITIALIZING PLOT ROUTINE COUNTERS AND                 PLOTBL 3
C     EXTREME VALUES VARIABLES.                                         PLOTBL 4
      COMMON/KNKN/KNBP,KNVC,KNDT                                        PLOTBL 5
      COMMON/DDLIM/MXIX,MXIY,MNIX,MNIY                                  PLOTBL 6
      DATA MXIX,MXIY,MNIX,MNIY/2*-1000,2*1000/                          PLOTBL 7
      DATA KNBP,KNVC,KNDT/3*0/                                          PLOTBL 8
      END                                                               PLOTBL 9
```

```
      SUBROUTINE DDINIT(N,TEXT)                                         DDINIT 2
C     INITIALIZES PLOTTING PROCESS(DDPLOT)                              DDINIT 3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                           DDINIT 4
C     COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
      CHARACTER TEXT*(*)                                                DDINIT 6
C                                                                       DDINIT 7
      DATA IDD/0/                                                       DDINIT 8
10    FORMAT(5A10)                                                      DDINIT 9
      IF(IDD.EQ.0) REWIND NDEVGRP                                       DDINIT10
      IDD=1                                                             DDINIT11
      WRITE(NDEVGRP) 0,0,0                                              DDINIT12
      WRITE(NDEVGRP) M,LEN(TEXT),TEXT                                   DDINIT13
      END                                                               DDINIT14
```

```
      SUBROUTINE DDBP                                                   DDBP   2
C     SETS A VECTOR ORIGIN(DDPLOT)                                      DDBP   3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                           DDBP   4
C     COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                               DDBP   6
      COMMON/KNKN/KNBP,KNVC,KNDT                                        DDBP   7
      COMMON/DDLIM/MXIX,MXIY,MNIX,MNIY                                  DDBP   8
      MNIX=MIN0(MNIX,IX)                                                DDBP   9
      MXIX=MAX0(MXIX,IX)                                                DDBP  10
      MNIY=MIN0(MNIY,IY)                                                DDBP  11
      MXIY=MAX0(MXIY,IY)                                                DDBP  12
      IF(IX.LT.0.OR.IX.GT.1023.OR.IY.LT.0.OR.IY.GT.1023                 DDBP  13
     1  ) PRINT 10,'DDBP ',KNBP,IX,IY                                   DDBP  14
10    FORMAT(A10,3I5)                                                   DDBP  15
      KNBP=KNBP+1                                                       DDBP  16
      WRITE(NDEVGRP) 1,IX,IY                                            DDBP  17
      END                                                               DDBP  18
```

```
      SUBROUTINE DDVC                                                    DDVC   2
C     PLOTS A VECTOR(DDPLOT)                                             DDVC   3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                            DDVC   4
C     COMMON DECK "RAYDEV" INSERTED HERE                                 CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                               CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN                CRAYDEV5
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                                DDVC   6
      COMMON/KNKN/KNBP,KNVC,KNDT                                         DDVC   7
      COMMON/DDLIM/MXIX,MXIY,MNIX,MNIY                                   DDVC   8
      MNIX=MIN0(MNIX,IX)                                                 DDVC   9
      MXIX=MAX0(MXIX,IX)                                                 DDVC  10
      MNIY=MIN0(MNIY,IY)                                                 DDVC  11
      MXIY=MAX0(MXIY,IY)                                                 DDVC  12
      IF(IX.LT.0.OR.IX.GT.1023.OR.IY.LT.0.OR.IY.GT.1023                  DDVC  13
     1  ) PRINT 10,'DDVC ',KNVC,IX,IY                                    DDVC  14
10    FORMAT(A10,3I5)                                                    DDVC  15
      KNVC=KNVC+1                                                        DDVC  16
      WRITE(NDEVGRP) 2,IX,IY                                             DDVC  17
      END                                                                DDVC  18
```

```
      SUBROUTINE DDTEXT(N,TEXT)                                          DDTEXT 2
C     WRITES A CHARACTER ARRAY PACKED A10(DDPLOT)                        DDTEXT 3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                            DDTEXT 4
C     COMMON DECK "RAYDEV" INSERTED HERE                                 CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                               CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN                CRAYDEV5
      CHARACTER TEXT*(*)                                                 DDTEXT 6
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                                DDTEXT 7
      COMMON/KNKN/KNBP,KNVC,KNDT                                         DDTEXT 8
100   FORMAT(A10,2I5,I2,1X,8A10)                                         DDTEXT 9
      KNDT=KNDT+1                                                        DDTEXT10
      WRITE(NDEVGRP) 3,IX,IY                                             DDTEXT11
      WRITE(NDEVGRP) IOR,N,N*10,(TEXT(I:I),I=1,N*10)                     DDTEXT12
      END                                                                DDTEXT13
```

```
      SUBROUTINE DDTAB                                                   DDTAB  2
C     INITIALIZES TABULAR PLOTTING(DDPLOT)                               DDTAB  3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                            DDTAB  4
C     COMMON DECK "RAYDEV" INSERTED HERE                                 CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                               CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN                CRAYDEV5
      END                                                                DDTAB  6
```

```
      SUBROUTINE DDFR                                                   DDFR   2
C     ADVANCE ONE PLOTTING FRAME(DDPLOT)                                DDFR   3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                           DDFR   4
C     COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
      FORMAT(A10)                                                       DDFR   6
10    WRITE(NDEVGRP) -2,0,0                                             DDFR   7
      END                                                               DDFR   8
```

```
      SUBROUTINE DDEND                                                  DDEND  2
C     EMPTIES PLOT BUFFER AND RELEASES PLOTTING COMMAND FILE(DDPLOT)    DDEND  3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                           DDEND  4
C     COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
      COMMON/KNKN/KNBP,KNVC,KNDT                                        DDEND  6
      COMMON/DDLIM/MXIX,MXIY,MNIX,MNIY                                  DDEND  7
10    FORMAT(3A10,5I5)                                                  DDEND  8
      WRITE(NDEVGRP) -1,0,0                                             DDEND  9
      END                                                               DDEND 10
```

```
      SUBROUTINE DASH                                                   DASH   2
C     ACTIVATE DASHED LINE CONNECTIONS(DISSPLA)                         DASH   3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                           DASH   4
C     COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
      WRITE(NDEVGRP) 37,0,0                                             DASH   6
      END                                                               DASH   7
```

```
      SUBROUTINE RESET(S)                                               RESET  2
C     RESETS AN OPTION TO ITS DEFAULT VALUE(DISSPLA)                    RESET  3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                           RESET  4
C     COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
      CHARACTER S*10                                                    RESET  6
      WRITE(NDEVGRP) 38,0,0                                             RESET  7
```

```
      WRITE(NDEVGRP) S                                                  RESET  8
      END                                                               RESET  9



      SUBROUTINE HEIGHT(H)                                              HEIGHT 2
C     SETS REFERENCE CHARACTER HEIGHT IN INCHES(DISSPLA)                HEIGHT 3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                           HEIGHT 4
C     COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
      WRITE(NDEVGRP) 13,H,0                                             HEIGHT 6
      END                                                               HEIGHT 7



      SUBROUTINE MX1ALF(T1,T2)                                          MX1ALF 2
C     SPECIFY USE OF ALTERNATE CHARACTER SET NUMBER 1(DISSPLA)          MX1ALF 3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                           MX1ALF 4
C     COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
      WRITE(NDEVGRP) 11,T1,T2                                           MX1ALF 6
      END                                                               MX1ALF 7



      SUBROUTINE MX2ALF(T1,T2)                                          MX2ALF 2
C     SPECIFY USE OF ALTERNATE CHARACTER SET NUMBER 2(DISSPLA)          MX2ALF 3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                           MX2ALF 4
C     COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
      WRITE(NDEVGRP) 12,T1,T2                                           MX2ALF 6
      END                                                               MX2ALF 7



      SUBROUTINE SCMPLX                                                 SCMPLX 2
C     SPECIFY USE OF SIMPLEX CHARACTER SET(DISSPLA)                     SCMPLX 3
C     WRITE PARAMETERS TO GRAPHICS CALLS FILE                           SCMPLX 4
C     COMMON DECK "RAYDEV" INSERTED HERE                                CRAYDEV2
C     DEVICE ASSIGNED TO RAYTRC INPUT FILE                              CRAYDEV4
      COMMON/RAYDEV/NRYIND,NDEVTMP,NFRMAT,NDEVGRP,NDEVBIN               CRAYDEV5
      WRITE(NDEVGRP) 10,0,0                                             SCMPLX 6
      END                                                               SCMPLX 7
```

DISPERSION-RELATION ROUTINES (Tape File 4)

```
      SUBROUTINE ANWNL                                                      ANWNL  8
C     DISPERSION RELATION FOR ACOUSTIC WAVES NO WIND, NO LOSSES             ANWNL  9
C     COMMON DECK "RKAM" INSERTED HERE                                      RKAMCOM2
      REAL KR,KTH,KPH                                                       RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)           RKAMCOM5
C     COMMON DECK "CC" INSERTED HERE                                        CCC    2
      REAL MODC                                                             CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                            CCC    5
C     COMMON DECK "CONST" INSERTED HERE                                     CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                         CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                             CCONST 5
C     COMMON DECK "RK" INSERTED HERE                                        CRK    2
C     DEFINE SIZE REQUIRED FOR RAY STATE SAVE ARRAY                         CRK    4
      PARAMETER (LRKAMS=87+2*100,NXRKMS=12+LRKAMS,MXEQPT=21)                CRK    5
      PARAMETER (NRKSAV=NXRKMS+MXEQPT-1)                                    CRK    6
      COMMON /RK/ NEQS,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART        CRK    7
C     COMMON DECK "RINREAL" INSERTED HERE                                   CRINREA2
      LOGICAL SPACE                                                         CRINREA4
      REAL LPOLAR,LPOLRI,KPHK,KPHKI,KAY2,KAY2I                              CRINREA5
      CHARACTER DISPM*6                                                     CRINREA6
      COMMON/RINPL/DISPM                                                    CRINREA7
      COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                     CRINREA8
      COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I,                                CRINREA9
     1              H,HI,PHT,PHTI,PHR,PHRI,PHTH,PHTHI,PHPH,PHPHI           CRINRE10
     2, PHOW,PHOWI,PHKR,PHKRI,PHKTH,PHKTI, PHKPH,PHKPI                      CRINRE11
     3 ,KPHK,KPHKI,POLAR,POLARI,LPOLAR,LPOLRI,SGN                           CRINRE12
C     COMMON DECK "UU" INSERTED HERE                                        CUU    2
      REAL MODU                                                             CUU    4
      COMMON/UU/MODU(4)                                                     CUU    5
     1  ,V  ,PVT  ,PVR  ,PVTH  ,PVPH                                        CUU    6
     2  ,VR ,PVRT ,PVRR ,PVRTH ,PVRPH                                       CUU    7
     3  ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                      CUU    8
     4  ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                      CUU    9
C     COMMON DECK "WW" INSERTED HERE                                        CWW    2
      PARAMETER (NWARSZ=1000)                                               CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                       CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                    CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),        CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),          CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),              CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),             CWW2   6
     8 (RCVRH,W(20)),                                                       CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))    CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                          CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                          CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                         CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),           CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))            CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),            CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                  CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                       CWW2  16
      REAL MMODEL,MFORM,MID                                                 CWW3   2
C                                                                           CWW3   3
C     WIND         100-124                                                  CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)               CWW3   5
```

```
C                                                                       CWW3    6
C     DELTA WIND          125-149                                       CWW3    7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)        CWW3    8
C                                                                       CWW3    9
C     SOUND SPEED 150-174                                               CWW3   10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)           CWW3   11
      EQUIVALENCE (W(153),REFC)                                         CWW3   12
C                                                                       CWW3   13
C     DELTA SOUND SPEED 175-199                                         CWW3   14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)        CWW3   15
C                                                                       CWW3   16
C     TEMPERATURE     200-224                                           CWW3   17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)           CWW3   18
C                                                                       CWW3   19
C     DELTA TEMPERATURE     225-249                                     CWW3   20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)        CWW3   21
C                                                                       CWW3   22
C     MOLECULAR   250-274                                               CWW3   23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)           CWW3   24
C                                                                       CWW3   25
C     RECEIVER HEIGHT   275-299                                         CWW3   26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)           CWW3   27
C                                                                       CWW3   28
C     TOPOGRAPHY    300-324                                             CWW3   29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)           CWW3   30
C                                                                       CWW3   31
C     DELTA TOPOGRAPHY    325-349                                       CWW3   32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)        CWW3   33
C                                                                       CWW3   34
C     UPPER SURFACE TOPOGRAPHY    350-374                               CWW3   35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)           CWW3   36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                              CWW3   37
C                                                                       CWW3   38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                       CWW3   39
C     ABSORPTION          500-524                                       CWW3   40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)           CWW3   41
C                                                                       CWW3   42
C     DELTA ABSORPTION          525-549                                 CWW3   43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)        CWW3   44
C                                                                       CWW3   45
C     PRESSURE          550-574                                         CWW3   46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)           CWW3   47
C                                                                       CWW3   48
C     DELTA PRESSURE          575-599                                   CWW3   49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)        CWW3   50
C                                                                       CWW3   51
C                                                                       ANWNL  17
      REAL KS,MKS                                                       ANWNL  18
      REAL KVECT(24)                                                    ANWNL  19
      REAL VSET(20)                                                     ANWNL  20
      EQUIVALENCE(KVECT,KAY2),(VSET,V)                                  ANWNL  21
C                                                                       ANWNL  22
      DATA MODRIN/8HACOUSTIC ,8H WAVE ** ,8H** NO WI ,8HND *** N        ANNBL   2
     1  ,8HO LOSSES ,3*1H /                                             ANNBL   3
      DATA DISPM/'ANWNL'/                                               ANNBL   4
```

```
      DATA TYPE/3*1H0 /                                                 ANNBL  5
C                                                                       ANWNL 25
      ENTRY IDISPER                                                     ANWNL 26
      CALL ISPEED                                                       ANWNL 27
      CALL IRECVR                                                       ANWNL 28
      CALL ITOPOG                                                       ANWNL 29
      CALL ISURFAC                                                      ANWNL 30
      RETURN                                                            ANWNL 31
C                                                                       ANWNL 32
      ENTRY DISPER                                                      ANWNL 33
      ENTRY RINDEX                                                      ANWNL 34
C                                                                       ANWNL 35
      SPACE=.FALSE.                                                     ANWNL 36
C                                                                       ANWNL 37
      KS=KR*KR+KTH*KTH+KPH*KPH                                          ANWNL 38
C     SOUND SPEED                                                       ANWNL 39
      CALL SPEED                                                        ANWNL 40
      OWS=OW*OW                                                         ANWNL 41
      KAY2=OWS/CS                                                       ANWNL 42
C                                                                       ANWNL 43
      H=OW*OW - CS*KS                                                   ANWNL 44
      MKS=-KS                                                           ANWNL 45
      PHT=MKS*PCST                                                      ANWNL 46
      PHR=MKS*PCSR                                                      ANWNL 47
      PHTH=MKS*PCSTH                                                    ANWNL 48
      PHPH=MKS*PCSPH                                                    ANWNL 49
C                                                                       ANWNL 50
      PHOW=2.0*OW                                                       ANWNL 51
      CS2=-2.0*CS                                                       ANWNL 52
      PHKR=CS2*KR                                                       ANWNL 53
      PHKTH=CS2*KTH                                                     ANWNL 54
      PHKPH=CS2*KPH                                                     ANWNL 55
      KPHK=CS2*KS                                                       ANWNL 56
      RETURN                                                            ANWNL 57
      END                                                               ANWNL 58
```

```
      SUBROUTINE AWWNL                                                  AWWNL  8
C     DISPERSION RELATION FOR ACOUSTIC WAVES WITH WIND, NO LOSSES       AWWNL  9
C     COMMON DECK "RKAM" INSERTED HERE                                  RKAMCOM2
      REAL KR,KTH,KPH                                                   RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)       RKAMCOM5
C     COMMON DECK "CC" INSERTED HERE                                    CCC    2
      REAL MODC                                                         CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                        CCC    5
C     COMMON DECK "CONST" INSERTED HERE                                 CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                     CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                         CCONST 5
C     COMMON DECK "RK" INSERTED HERE                                    CRK    2
C     DEFINE SIZE REQUIRED FOR RAY STATE SAVE ARRAY                     CRK    4
      PARAMETER (LRKAMS=87+2*100,NXRKMS=12+LRKAMS,MXEQPT=21)            CRK    5
      PARAMETER (NRKSAV=NXRKMS+MXEQPT-1)                                CRK    6
```

```
      COMMON /RK/ NEQS,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART     CRK    7
C     COMMON DECK "RINREAL" INSERTED HERE                               CRINREA2
      LOGICAL SPACE                                                     CRINREA4
      REAL LPOLAR,LPOLRI,KPHK,KPHKI,KAY2,KAY2I                          CRINREA5
      CHARACTER DISPM*6                                                 CRINREA6
      COMMON/RINPL/DISPM                                                CRINREA7
      COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                 CRINREA8
      COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I,                            CRINREA9
     1               H,HI,PHT,PHTI,PHR,PHRI,PHTH,PHTHI,PHPH,PHPHI       CRINRE10
     2, PHOW,PHOWI,PHKR,PHKRI,PHKTH,PHKTI, PHKPH,PHKPI                  CRINRE11
     3 ,KPHK,KPHKI,POLAR,POLARI,LPOLAR,LPOLRI,SGN                       CRINRE12
C     COMMON DECK "UU" INSERTED HERE                                    CUU    2
      REAL MODU                                                         CUU    4
      COMMON/UU/MODU(4)                                                 CUU    5
     1  ,V  ,PVT  ,PVR  ,PVTH  ,PVPH                                    CUU    6
     2  ,VR ,PVRT ,PVRR ,PVRTH ,PVRPH                                   CUU    7
     3  ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                  CUU    8
     4  ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                  CUU    9
C     COMMON DECK "WW" INSERTED HERE                                    CWW    2
      PARAMETER (NWARSZ=1000)                                           CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         CWW2   6
     8 (RCVRH,W(20)),                                                   CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))        CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),        CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))              CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                   CWW2  16
      REAL MMODEL,MFORM,MID                                             CWW3   2
C                                                                       CWW3   3
C     WIND          100-124                                           CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)           CWW3   5
C                                                                       CWW3   6
C     DELTA WIND          125-149                                       CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)        CWW3   8
C                                                                       CWW3   9
C     SOUND SPEED 150-174                                               CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)           CWW3  11
      EQUIVALENCE (W(153),REFC)                                         CWW3  12
C                                                                       CWW3  13
C     DELTA SOUND SPEED 175-199                                         CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)        CWW3  15
C                                                                       CWW3  16
C     TEMPERATURE     200-224                                           CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)           CWW3  18
C                                                                       CWW3  19
C     DELTA TEMPERATURE     225-249                                     CWW3  20
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      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)          CWW3  21
                                                                          CWW3  22
C                                                                         CWW3  23
C     MOLECULAR   250-274                                                 CWW3  24
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)             CWW3  25
C                                                                         CWW3  26
C     RECEIVER HEIGHT   275-299                                           CWW3  27
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)             CWW3  28
C                                                                         CWW3  29
C     TOPOGRAPHY   300-324                                                CWW3  30
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)             CWW3  31
C                                                                         CWW3  32
C     DELTA TOPOGRAPHY   325-349                                          CWW3  33
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)          CWW3  34
C                                                                         CWW3  35
C     UPPER SURFACE TOPOGRAPHY   350-374                                  CWW3  36
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)             CWW3  37
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                CWW3  38
C                                                                         CWW3  39
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                         CWW3  40
C     ABSORPTION         500-524                                          CWW3  41
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)             CWW3  42
C                                                                         CWW3  43
C     DELTA ABSORPTION        525-549                                     CWW3  44
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)          CWW3  45
C                                                                         CWW3  46
C     PRESSURE         550-574                                            CWW3  47
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)             CWW3  48
C                                                                         CWW3  49
C     DELTA PRESSURE         575-599                                      CWW3  50
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)          CWW3  51
C                                                                         AWWNL 17
C                                                                         AWWNL 18
      REAL KS,KV                                                          AWWNL 19
      REAL KVECT(24)                                                      AWWNL 20
      EQUIVALENCE(KVECT,KAY2)                                             AWWNL 21
C                                                                         AWNBL  2
      DATA MODRIN/8HACOUSTIC ,8H WAVE ** ,8H* WITH W ,8HIND ****          AWNBL  3
     1  ,8H** NO LO ,4HSSES ,2*1H /                                       AWNBL  4
      DATA DISPM/'AWWNL'/                                                 AWNBL  5
      DATA TYPE/3*1H1 /                                                   AWWNL 24
C                                                                         AWWNL 25
      ENTRY IDISPER                                                       AWWNL 26
      CALL ISPEED                                                         AWWNL 27
      CALL IWINDR                                                         AWWNL 28
      CALL IRECVR                                                         AWWNL 29
      CALL ITOPOG                                                         AWWNL 30
      CALL ISURFAC                                                        AWWNL 31
      RETURN                                                              AWWNL 32
C                                                                         AWWNL 33
      ENTRY DISPER                                                        AWWNL 34
C                                                                         AWWNL 35
      SPACE=.FALSE.                                                       AWWNL 36
C                                                                         AWWNL 37
      KS=KR*KR+KTH*KTH+KPH*KPH                                            AWWNL 38
C     WIND VELOCITY
```

```
      CALL WINDR                                                        AWWNL 39
      KV=KR*VR+KTH*VTH+KPH*VPH                                          AWWNL 40
      VLS=KV*KV/KS                                                      AWWNL 41
C     SOUND SPEED                                                       AWWNL 42
      CALL SPEED                                                        AWWNL 43
      OWS=OW*OW                                                         AWWNL 44
      KAY2=OWS/(SQRT(CS)+KV/SQRT(KS))**2                                AWWNL 45
C                                                                       AWWNL 46
      OWI=OW-KV                                                         AWWNL 47
      H=OWI*OWI - CS*KS                                                 AWWNL 48
      POWIT=-KR*PVRT - KTH*PVTHT - KPH*PVPHT                            AWWNL 49
      PHT=2.0*OWI*POWIT - KS*PCST                                       AWWNL 50
      POWIR=-KR*PVRR - KTH*PVTHR - KPH*PVPHR                            AWWNL 51
      PHR=2.0*OWI*POWIR - KS*PCSR                                       AWWNL 52
      POWITH=-KR*PVRTH - KTH*PVTHTH - KPH*PVPHTH                        AWWNL 53
      PHTH=2.0*OWI*POWITH - KS*PCSTH                                    AWWNL 54
      POWIPH=-KR*PVRPH - KTH*PVTHPH - KPH*PVPHPH                        AWWNL 55
      PHPH=2.0*OWI*POWIPH - KS*PCSPH                                    AWWNL 56
C                                                                       AWWNL 57
      PHOW=2.0*OWI                                                      AWWNL 58
      PHKR=-2.0*(OWI*VR + CS*KR)                                        AWWNL 59
      PHKTH=-2.0*(OWI*VTH + CS*KTH)                                     AWWNL 60
      PHKPH=-2.0*(OWI*VPH + CS*KPH)                                     AWWNL 61
      KPHK=-2.0*(OWI*KV + CS*KS)                                        AWWNL 62
      RETURN                                                            AWWNL 63
      END                                                               AWWNL 64
```

```
      SUBROUTINE ANWWL                                                  ANWWL  8
C     DISPERSION RELATION FOR ACOUSTIC WAVES NO WIND, WITH LOSSES       ANWWL  9
C     COMMON DECK "RKAM" INSERTED HERE                                  RKAMCOM2
      REAL KR,KTH,KPH                                                   RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)       RKAMCOM5
C     COMMON DECK "CC" INSERTED HERE                                    CCC    2
      REAL MODC                                                         CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                        CCC    5
C     COMMON DECK "CONST" INSERTED HERE                                 CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                     CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                         CCONST 5
C     COMMON DECK "RK" INSERTED HERE                                    CRK    2
C     DEFINE SIZE REQUIRED FOR RAY STATE SAVE ARRAY                     CRK    4
      PARAMETER (LRKAMS=87+2*100,NXRKMS=12+LRKAMS,MXEQPT=21)            CRK    5
      PARAMETER (NRKSAV=NXRKMS+MXEQPT-1)                                CRK    6
      COMMON /RK/ NEQS,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART    CRK    7
C     COMMON DECK "RINREAL" INSERTED HERE                               CRINREA2
      LOGICAL SPACE                                                     CRINREA4
      REAL LPOLAR,LPOLRI,KPHK,KPHKI,KAY2,KAY2I                          CRINREA5
      CHARACTER DISPM*6                                                 CRINREA6
      COMMON/RINPL/DISPM                                                CRINREA7
      COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                 CRINREA8
      COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I,                            CRINREA9
     1           H,HI,PHT,PHTI,PHR,PHRI,PHTH,PHTHI,PHPH,PHPHI           CRINRE10
```

```
     2,  PHOW,PHOWI,PHKR,PHKRI,PHKTH,PHKTI,  PHKPH,PHKPI                    CRINRE11
     3  ,KPHK,KPHKI,POLAR,POLARI,LPOLAR,LPOLRI,SGN                         CRINRE12
C     COMMON DECK "UU" INSERTED HERE                                       CUU     2
      REAL MODU                                                            CUU     4
      COMMON/UU/MODU(4)                                                    CUU     5
     1   ,V   ,PVT   ,PVR   ,PVTH   ,PVPH                                 CUU     6
     2   ,VR  ,PVRT  ,PVRR  ,PVRTH  ,PVRPH                                CUU     7
     3   ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                   CUU     8
     4   ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                   CUU     9
C     COMMON DECK "WW" INSERTED HERE                                       CWW     2
      PARAMETER (NWARSZ=1000)                                              CWW1    3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                      CWW1    4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                   CWW2    2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),       CWW2    3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),         CWW2    4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),             CWW2    5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),            CWW2    6
     8 (RCVRH,W(20)),                                                      CWW2    7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))   CWW2    8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                         CWW2    9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                         CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                        CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),          CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))           CWW2   13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),           CWW2   14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                 CWW2   15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                      CWW2   16
      REAL MMODEL,MFORM,MID                                                CWW3    2
C                                                                          CWW3    3
C     WIND          100-124                                              CWW3    4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)              CWW3    5
C                                                                          CWW3    6
C     DELTA WIND          125-149                                          CWW3    7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)           CWW3    8
C                                                                          CWW3    9
C     SOUND SPEED 150-174                                                  CWW3   10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)              CWW3   11
      EQUIVALENCE (W(153),REFC)                                            CWW3   12
C                                                                          CWW3   13
C     DELTA SOUND SPEED 175-199                                            CWW3   14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)           CWW3   15
C                                                                          CWW3   16
C     TEMPERATURE     200-224                                              CWW3   17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)              CWW3   18
C                                                                          CWW3   19
C     DELTA TEMPERATURE     225-249                                        CWW3   20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)           CWW3   21
C                                                                          CWW3   22
C     MOLECULAR   250-274                                                  CWW3   23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)              CWW3   24
C                                                                          CWW3   25
C     RECEIVER HEIGHT   275-299                                            CWW3   26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)              CWW3   27
C                                                                          CWW3   28
C     TOPOGRAPHY    300-324                                                CWW3   29
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      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)          CWW3  30
C                                                                      CWW3  31
C     DELTA TOPOGRAPHY   325-349                                       CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)       CWW3  33
C                                                                      CWW3  34
C     UPPER SURFACE TOPOGRAPHY   350-374                               CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)          CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                             CWW3  37
C                                                                      CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                      CWW3  39
C     ABSORPTION         500-524                                       CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)          CWW3  41
C                                                                      CWW3  42
C     DELTA ABSORPTION         525-549                                 CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)       CWW3  44
C                                                                      CWW3  45
C     PRESSURE         550-574                                         CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)          CWW3  47
C                                                                      CWW3  48
C     DELTA PRESSURE         575-599                                   CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)       CWW3  50
C                                                                      CWW3  51
C                                                                      ANWWL 17
C     COMMON DECK "AA" INSERTED HERE                                   CAA    2
      REAL MODA                                                        CAA    4
      REAL MU,MUPT,MUPR,MUPTH,MUPPH                                    CAA    5
      REAL KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                               CAA    6
      COMMON/AA/MODA(4),MU,MUPT,MUPR,MUPTH,MUPPH                       CAA    7
      COMMON/AA/KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                          CAA    8
C                                                                      ANWWL 19
C     COMMON DECK "PP" INSERTED HERE                                   CPP    2
      REAL MODP                                                        CPP    4
      COMMON/PP/MODP(4),P,PPT,PPR,PPTH,PPPH                            CPP    5
C                                                                      ANWWL 21
C     COMMON DECK "MM" INSERTED HERE                                   CMM    2
      REAL M,MODM                                                      CMM    4
      COMMON/MM/MODM(4),M,PMT,PMR,PMTH,PMPH                            CMM    5
C                                                                      ANWWL 23
      REAL KS,MKS                                                      ANWWL 24
      REAL KVECT(24)                                                   ANWWL 25
      REAL VSET(20)                                                    ANWWL 26
      EQUIVALENCE(KVECT,KAY2),(VSET,V)                                 ANWWL 27
C                                                                      ANWWL 28
      DATA MODRIN/8HACOUSTIC ,8H WAVE ** ,8H** NO WI ,8HND *** W       ANWBL  2
     1  ,8HWITH LOS ,3HSES ,2*1H /                                     ANWBL  3
      DATA DISPM/'ANWWL'/                                              ANWBL  4
      DATA TYPE/3*1H2 /                                                ANWBL  5
C                                                                      ANWWL 31
      ENTRY IDISPER                                                    ANWWL 32
      CALL ISPEED                                                      ANWWL 33
      CALL IRECVR                                                      ANWWL 34
      CALL ITOPOG                                                      ANWWL 35
      CALL ISURFAC                                                     ANWWL 36
C                                                                      ANWWL 37
      CALL IPRES                                                       ANWWL 38
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      CALL IABSRP                                                       ANWWL 39
      RETURN                                                            ANWWL 40
C                                                                       ANWWL 41
      ENTRY DISPER                                                      ANWWL 42
      ENTRY RINDEX                                                      ANWWL 43
C                                                                       ANWWL 44
      SPACE=.FALSE.                                                     ANWWL 45
C                                                                       ANWWL 46
      KS=KR*KR+KTH*KTH+KPH*KPH                                          ANWWL 47
C     SOUND SPEED                                                       ANWWL 48
      CALL SPEED                                                        ANWWL 49
      OWS=OW*OW                                                         ANWWL 50
      KAY2=OWS/CS                                                       ANWWL 51
C                                                                       ANWWL 52
      H=OW*OW - CS*KS                                                   ANWWL 53
      MKS=-KS                                                           ANWWL 54
      PHT=MKS*PCST                                                      ANWWL 55
      PHR=MKS*PCSR                                                      ANWWL 56
      PHTH=MKS*PCSTH                                                    ANWWL 57
      PHPH=MKS*PCSPH                                                    ANWWL 58
C                                                                       ANWWL 59
      PHOW=2.0*OW                                                       ANWWL 60
      CS2=-2.0*CS                                                       ANWWL 61
      PHKR=CS2*KR                                                       ANWWL 62
      PHKTH=CS2*KTH                                                     ANWWL 63
      PHKPH=CS2*KPH                                                     ANWWL 64
      KPHK=CS2*KS                                                       ANWWL 65
C                                                                       ANWWL 66
      CALL PRES                                                         ANWWL 67
      CALL ABSRP                                                        ANWWL 68
      GMS=GAMMA-1.0                                                     ANWWL 69
      KAY2I=-(OWI/(GAMMA*P))*(4./3.*MU+GMS*GMS*M/(GAMMA*RGAS)*KAP)*KAY2 ANWWL 70
      RETURN                                                            ANWWL 71
      END                                                               ANWWL 72
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      SUBROUTINE AWWWL                                                  AWWWL  8
C     DISPERSION RELATION FOR ACOUSTIC WAVES WITH WIND, WITH LOSSES     AWWWL  9
C     COMMON DECK "RKAM" INSERTED HERE                                  RKAMCOM2
      REAL KR,KTH,KPH                                                   RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)       RKAMCOM5
C     COMMON DECK "CC" INSERTED HERE                                    CCC    2
      REAL MODC                                                         CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                        CCC    5
C     COMMON DECK "CONST" INSERTED HERE                                 CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                     CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                         CCONST 5
C     COMMON DECK "RK" INSERTED HERE                                    CRK    2
C     DEFINE SIZE REQUIRED FOR RAY STATE SAVE ARRAY                     CRK    4
      PARAMETER (LRKAMS=87+2*100,NXRKMS=12+LRKAMS,MXEQPT=21)            CRK    5
      PARAMETER (NRKSAV=NXRKMS+MXEQPT-1)                                CRK    6
      COMMON /RK/ NEQS,STEP,MODE,E1MAX,E1MIN,E2MAX,E2MIN,FACT,RSTART    CRK    7
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C       COMMON DECK "RINREAL" INSERTED HERE                                    CRINREA2
        LOGICAL SPACE                                                          CRINREA4
        REAL LPOLAR,LPOLRI,KPHK,KPHKI,KAY2,KAY2I                               CRINREA5
        CHARACTER DISPM*6                                                      CRINREA6
        COMMON/RINPL/DISPM                                                     CRINREA7
        COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                      CRINREA8
        COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I,                                 CRINREA9
      1               H,HI,PHT,PHTI,PHR,PHRI,PHTH,PHTHI,PHPH,PHPHI             CRINRE10
      2, PHOW,PHOWI,PHKR,PHKRI,PHKTH,PHKTI, PHKPH,PHKPI                        CRINRE11
      3 ,KPHK,KPHKI,POLAR,POLARI,LPOLAR,LPOLRI,SGN                             CRINRE12
C       COMMON DECK "UU" INSERTED HERE                                         CUU     2
        REAL MODU                                                              CUU     4
        COMMON/UU/MODU(4)                                                      CUU     5
      1  ,V  ,PVT  ,PVR  ,PVTH  ,PVPH                                         CUU     6
      2  ,VR ,PVRT ,PVRR ,PVRTH ,PVRPH                                        CUU     7
      3  ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                       CUU     8
      4  ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                       CUU     9
C       COMMON DECK "WW" INSERTED HERE                                         CWW     2
        PARAMETER (NWARSZ=1000)                                                CWW1    3
        COMMON/WW/ID(10),MAXW,W(NWARSZ)                                        CWW1    4
        REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                     CWW2    2
        EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),         CWW2    3
      1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),            CWW2    4
      2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                CWW2    5
      3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),               CWW2    6
      8 (RCVRH,W(20)),                                                         CWW2    7
      4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))      CWW2    8
      5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                            CWW2    9
      6 (HMIN,W(27)),(RGMAX,W(28)),                                            CWW2   10
      8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                           CWW2   11
      6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),             CWW2   12
      7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))              CWW2   13
      9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),              CWW2   14
      1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                    CWW2   15
      2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                         CWW2   16
        REAL MMODEL,MFORM,MID                                                  CWW3    2
C                                                                              CWW3    3
C       WIND          100-124                                                  CWW3    4
        EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)                CWW3    5
C                                                                              CWW3    6
C       DELTA WIND          125-149                                            CWW3    7
        EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)             CWW3    8
C                                                                              CWW3    9
C       SOUND SPEED 150-174                                                    CWW3   10
        EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                CWW3   11
        EQUIVALENCE (W(153),REFC)                                              CWW3   12
C                                                                              CWW3   13
C       DELTA SOUND SPEED 175-199                                              CWW3   14
        EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)             CWW3   15
C                                                                              CWW3   16
C       TEMPERATURE     200-224                                                CWW3   17
        EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                CWW3   18
C                                                                              CWW3   19
C       DELTA TEMPERATURE     225-249                                          CWW3   20
        EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)             CWW3   21
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C                                                                       CWW3  22
C                                                                       CWW3  23
C     MOLECULAR   250-274                                               CWW3  24
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)           CWW3  25
C                                                                       CWW3  26
C     RECEIVER HEIGHT   275-299                                         CWW3  27
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)           CWW3  28
C                                                                       CWW3  29
C     TOPOGRAPHY   300-324                                              CWW3  30
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)           CWW3  31
C                                                                       CWW3  32
C     DELTA TOPOGRAPHY   325-349                                        CWW3  33
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)        CWW3  34
C                                                                       CWW3  35
C     UPPER SURFACE TOPOGRAPHY   350-374                                CWW3  36
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)           CWW3  37
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                              CWW3  38
C                                                                       CWW3  39
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                       CWW3  40
C     ABSORPTION         500-524                                        CWW3  41
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)           CWW3  42
C                                                                       CWW3  43
C     DELTA ABSORPTION         525-549                                  CWW3  44
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)        CWW3  45
C                                                                       CWW3  46
C     PRESSURE         550-574                                          CWW3  47
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)           CWW3  48
C                                                                       CWW3  49
C     DELTA PRESSURE         575-599                                    CWW3  50
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)        CWW3  51
C                                                                       AWWWL 17
C                                                                       CAA    2
C     COMMON DECK "AA" INSERTED HERE                                    CAA    4
      REAL MODA                                                         CAA    5
      REAL MU,MUPT,MUPR,MUPTH,MUPPH                                     CAA    6
      REAL KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                                CAA    7
      COMMON/AA/MODA(4),MU,MUPT,MUPR,MUPTH,MUPPH                        CAA    8
      COMMON/AA/KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                           AWWWL 19
C                                                                       CPP    2
C     COMMON DECK "PP" INSERTED HERE                                    CPP    4
      REAL MODP                                                         CPP    5
      COMMON/PP/MODP(4),P,PPT,PPR,PPTH,PPPH                             AWWWL 21
C                                                                       CMM    2
C     COMMON DECK "MM" INSERTED HERE                                    CMM    4
      REAL M,MODM                                                       CMM    5
      COMMON/MM/MODM(4),M,PMT,PMR,PMTH,PMPH                             AWWWL 23
C                                                                       AWWWL 24
      REAL KS,KV                                                        AWWWL 25
      REAL KVECT(24)                                                    AWWWL 26
      EQUIVALENCE(KVECT,KAY2)                                           AWWWL 27
C                                                                       AWWBL  2
      DATA MODRIN/8HACOUSTIC ,8H WAVE ** ,8H* WITH W ,8HIND ****        AWWBL  3
     1  ,8H** WITH  ,6HLOSSES ,2*1H /                                  AWWBL  4
      DATA DISPM/'AWWWL'/                                               AWWBL  5.
      DATA TYPE/3*1H3 /                                                 AWWWL 30
C
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      ENTRY IDISPER                                                     AWWWL 31
      CALL ISPEED                                                       AWWWL 32
      CALL IWINDR                                                       AWWWL 33
      CALL IRECVR                                                       AWWWL 34
      CALL ITOPOG                                                       AWWWL 35
      CALL ISURFAC                                                      AWWWL 36
C                                                                       AWWWL 37
      CALL IPRES                                                        AWWWL 38
      CALL IABSRP                                                       AWWWL 39
      RETURN                                                            AWWWL 40
C                                                                       AWWWL 41
      ENTRY DISPER                                                      AWWWL 42
C                                                                       AWWWL 43
      SPACE=.FALSE.                                                     AWWWL 44
C                                                                       AWWWL 45
      KS=KR*KR+KTH*KTH+KPH*KPH                                          AWWWL 46
C     WIND VELOCITY                                                     AWWWL 47
      CALL WINDR                                                        AWWWL 48
      KV=KR*VR+KTH*VTH+KPH*VPH                                          AWWWL 49
      VLS=KV*KV/KS                                                      AWWWL 50
C     SOUND SPEED                                                       AWWWL 51
      CALL SPEED                                                        AWWWL 52
      OWS=OW*OW                                                         AWWWL 53
      KAY2=OWS/(SQRT(CS)+KV/SQRT(KS))**2                                AWWWL 54
C                                                                       AWWWL 55
      OWI=OW-KV                                                         AWWWL 56
      H=OWI*OWI - CS*KS                                                 AWWWL 57
      POWIT=-KR*PVRT - KTH*PVTHT - KPH*PVPHT                            AWWWL 58
      PHT=2.0*OWI*POWIT - KS*PCST                                       AWWWL 59
      POWIR=-KR*PVRR - KTH*PVTHR - KPH*PVPHR                            AWWWL 60
      PHR=2.0*OWI*POWIR - KS*PCSR                                       AWWWL 61
      POWITH=-KR*PVRTH - KTH*PVTHTH - KPH*PVPHTH                        AWWWL 62
      PHTH=2.0*OWI*POWITH - KS*PCSTH                                    AWWWL 63
      POWIPH=-KR*PVRPH - KTH*PVTHPH - KPH*PVPHPH                        AWWWL 64
      PHPH=2.0*OWI*POWIPH - KS*PCSPH                                    AWWWL 65
C                                                                       AWWWL 66
      PHOW=2.0*OWI                                                      AWWWL 67
      PHKR=-2.0*(OWI*VR + CS*KR)                                        AWWWL 68
      PHKTH=-2.0*(OWI*VTH + CS*KTH)                                     AWWWL 69
      PHKPH=-2.0*(OWI*VPH + CS*KPH)                                     AWWWL 70
      KPHK=-2.0*(OWI*KV + CS*KS)                                        AWWWL 71
C                                                                       AWWWL 72
      CALL PRES                                                         AWWWL 73
      CALL ABSRP                                                        AWWWL 74
      GMS=GAMMA-1.0                                                     AWWWL 75
      KAY2I=-(OW/(GAMMA*P))*(4./3.*MU+GMS*GMS*M/(GAMMA*RGAS)*KAP)*KAY2  AWWWL 76
      RETURN                                                            AWWWL 77
      END                                                               AWWWL 78
```

ATMOSPHERIC MODEL ROUTINES (Tape File 5)

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      SUBROUTINE WLINEAR                                                    WLINEAR8
C     LINEAR WIND VELOCITY PROFILE                                          WLINEAR9
C     PROVIDES CONSTANT RADIAL, ZONAL AND MERIDONAL WINDS                   WLINEA10
C     EXCEPT THAT A POSSIBLE LINEAR HEIGHT GRADIENT OF THE ZONAL            WLINEA11
C     COMPONENT IS ALLOWED.                                                 WLINEA12
C     COMMON DECK "RKAM" INSERTED HERE                                      RKAMCOM2
      REAL KR,KTH,KPH                                                       RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)           RKAMCOM5
C     COMMON DECK "UU" INSERTED HERE                                        CUU     2
      REAL MODU                                                             CUU     4
      COMMON/UU/MODU(4)                                                     CUU     5
     1  ,V   ,PVT   ,PVR   ,PVTH   ,PVPH                                    CUU     6
     2  ,VR  ,PVRT  ,PVRR  ,PVRTH  ,PVRPH                                   CUU     7
     3  ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                      CUU     8
     4  ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                      CUU     9
C     COMMON DECK "WW" INSERTED HERE                                        CWW     2
      PARAMETER (NWARSZ=1000)                                               CWW1    3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                       CWW1    4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                    CWW2    2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),        CWW2    3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),          CWW2    4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),              CWW2    5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),             CWW2    6
     8 (RCVRH,W(20)),                                                       CWW2    7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))    CWW2    8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                          CWW2    9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                          CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                         CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),           CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))            CWW2   13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),            CWW2   14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                  CWW2   15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                       CWW2   16
      REAL MMODEL,MFORM,MID                                                 CWW3    2
C                                                                           CWW3    3
C     WIND          100-124                                                 CWW3    4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)               CWW3    5
C                                                                           CWW3    6
C     DELTA WIND          125-149                                           CWW3    7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)            CWW3    8
C                                                                           CWW3    9
C     SOUND SPEED 150-174                                                   CWW3   10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)               CWW3   11
      EQUIVALENCE (W(153),REFC)                                             CWW3   12
C                                                                           CWW3   13
C     DELTA SOUND SPEED 175-199                                             CWW3   14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)            CWW3   15
C                                                                           CWW3   16
C     TEMPERATURE     200-224                                               CWW3   17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)               CWW3   18
C                                                                           CWW3   19
C     DELTA TEMPERATURE     225-249                                         CWW3   20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)            CWW3   21
C                                                                           CWW3   22
C     MOLECULAR   250-274                                                   CWW3   23
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```
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)
C
C     RECEIVER HEIGHT   275-299
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)
C
C     TOPOGRAPHY   300-324
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)
C
C     DELTA TOPOGRAPHY   325-349
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)
C
C     UPPER SURFACE TOPOGRAPHY   350-374
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)
C     PLOT ENHANCEMENTS CONTROL PARAMETERS
C
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)
C     ABSORPTION         500-524
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)
C
C     DELTA ABSORPTION         525-549
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)
C
C     PRESSURE         550-574
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)
C
C     DELTA PRESSURE         575-599
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)
C
C     COMMON DECK "B1" INSERTED HERE
      INTEGER UMX,UNTBL,UITBL,UFRMTBL,IDSU(10)
      COMMON/B1/UMX,UNTBL(10),UITBL(10),UFRMTBL(10),UGP(10)
      EQUIVALENCE (UGP,IDSU)
      EQUIVALENCE (W(103),UR0)
      EQUIVALENCE (W(104),UTH0),(W(105),UPH0),(W(106),PUPHZ0)
C
      DATA RECOGU/1.0/
      DATA UMX/1/
      DATA UNTBL/1,11,8*0/
      DATA UITBL/1,9*0/
      DATA UFRMTBL/1,9*0/
C
      ENTRY IWINDR
C
      IF(RECOGU .NE. UMODEL)
     1    CALL RERROR('SPEED   ','WRNG MODEL',RECOGU)
C
      MODU(1)=7HWLINEAR
      MODU(2)=UID
      CALL IPWINDR
C
      RETURN
C
       ENTRY WINDR
       H = R - EARTHR
C
```

```
CWW3   24
CWW3   25
CWW3   26
CWW3   27
CWW3   28
CWW3   29
CWW3   30
CWW3   31
CWW3   32
CWW3   33
CWW3   34
CWW3   35
CWW3   36
CWW3   37
CWW3   38
CWW3   39
CWW3   40
CWW3   41
CWW3   42
CWW3   43
CWW3   44
CWW3   45
CWW3   46
CWW3   47
CWW3   48
CWW3   49
CWW3   50
CWW3   51
CB1     2
CB1     4
CB1     5
CB1     6
WLINEA17
WLINEA18
WLINEA19
WLINEA20
WNEARBL2
WNEARBL3
WNEARBL4
WNEARBL5
WLINEA23
WLINEA24
WLINEA25
WLINEA26
WLINEA27
WLINEA28
WLINEA29
WLINEA30
WLINEA31
WLINEA32
WLINEA33
WLINEA34
WLINEA35
WLINEA36
WLINEA37
```

```
      CALL CLEAR(V,20)                                                  WLINEA38
C                                                                       WLINEA39
       VR = UR0                                                         WLINEA40
       VTH = UTH0                                                       WLINEA41
       VPH = (UPH0 + PUPHZ0 * H)                                        WLINEA42
      V=SQRT(VR*VR+VTH*VTH+VPH*VPH)                                     WLINEA43
      PVR=PUPHZ0                                                        WLINEA44
      IF(V.NE.0.0) PVR=VPH/V*PUPHZ0                                     WLINEA45
      PVPHR = PUPHZ0                                                    WLINEA46
      CALL PWINDR                                                       WLINEA47
       RETURN                                                           WLINEA48
       END                                                              WLINEA49
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```
       SUBROUTINE WTIDE                                                 WTIDE  8
C      WIND VELOCITY MODEL                                              WTIDE  9
C      PROVIDES WIND FIELD OF THE ATMOSPHERIC TIDES BY ZONAL AND        WTIDE 10
C      MERIDONAL HEIGHT PROFILES THAT ARE SINUSOIDAL AND IN PHASE       WTIDE 11
C      QUADRATURE.                                                      WTIDE 12
C                                                                       WTIDE 13
       REAL LAMZ                                                        WTIDE 14
C      COMMON DECK "RKAM" INSERTED HERE                                 RKAMCOM2
       REAL KR,KTH,KPH                                                  RKAMCOM4
       COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)      RKAMCOM5
C      COMMON DECK "UU" INSERTED HERE                                   CUU    2
       REAL MODU                                                        CUU    4
       COMMON/UU/MODU(4)                                                CUU    5
      1   ,V   ,PVT   ,PVR   ,PVTH   ,PVPH                             CUU    6
      2   ,VR  ,PVRT  ,PVRR  ,PVRTH  ,PVRPH                            CUU    7
      3   ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                               CUU    8
      4   ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                               CUU    9
C      COMMON DECK "WW" INSERTED HERE                                   CWW    2
       PARAMETER (NWARSZ=1000)                                          CWW1   3
       COMMON/WW/ID(10),MAXW,W(NWARSZ)                                  CWW1   4
       REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                               CWW2   2
       EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),   CWW2   3
      1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),     CWW2   4
      2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),         CWW2   5
      3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),        CWW2   6
      8 (RCVRH,W(20)),                                                  CWW2   7
      4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
      5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                     CWW2   9
      6 (HMIN,W(27)),(RGMAX,W(28)),                                     CWW2  10
      8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                    CWW2  11
      6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),      CWW2  12
      7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))       CWW2  13
      9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),       CWW2  14
      1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))             CWW2  15
      2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                  CWW2  16
       REAL MMODEL,MFORM,MID                                            CWW3   2
C                                                                       CWW3   3
C      WIND        100-124                                              CWW3   4
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      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)
C
C     DELTA WIND         125-149
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)
C
C     SOUND SPEED 150-174
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)
      EQUIVALENCE (W(153),REFC)
C
C     DELTA SOUND SPEED 175-199
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)
C
C     TEMPERATURE    200-224
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)
C
C     DELTA TEMPERATURE    225-249
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)
C
C     MOLECULAR   250-274
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)
C
C     RECEIVER HEIGHT   275-299
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)
C
C     TOPOGRAPHY   300-324
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)
C
C     DELTA TOPOGRAPHY   325-349
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)
C
C     UPPER SURFACE TOPOGRAPHY   350-374
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)
C     PLOT ENHANCEMENTS CONTROL PARAMETERS
C
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)
C     ABSORPTION         500-524
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)
C
C     DELTA ABSORPTION         525-549
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)
C
C     PRESSURE         550-574
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)
C
C     DELTA PRESSURE         575-599
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)
C
C     COMMON DECK "B1" INSERTED HERE
      INTEGER UMX,UNTBL,UITBL,UFRMTBL,IDSU(10)
      COMMON/B1/UMX,UNTBL(10),UITBL(10),UFRMTBL(10),UGP(10)
      EQUIVALENCE (UGP,IDSU)
C     COMMON DECK "CONST" INSERTED HERE
      COMMON/PCONST/CREF,RGAS,GAMMA
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10
      EQUIVALENCE (W(103),UPH0)
```

```
CWW3    5
CWW3    6
CWW3    7
CWW3    8
CWW3    9
CWW3   10
CWW3   11
CWW3   12
CWW3   13
CWW3   14
CWW3   15
CWW3   16
CWW3   17
CWW3   18
CWW3   19
CWW3   20
CWW3   21
CWW3   22
CWW3   23
CWW3   24
CWW3   25
CWW3   26
CWW3   27
CWW3   28
CWW3   29
CWW3   30
CWW3   31
CWW3   32
CWW3   33
CWW3   34
CWW3   35
CWW3   36
CWW3   37
CWW3   38
CWW3   39
CWW3   40
CWW3   41
CWW3   42
CWW3   43
CWW3   44
CWW3   45
CWW3   46
CWW3   47
CWW3   48
CWW3   49
CWW3   50
CWW3   51
CB1     2
CB1     4
CB1     5
CB1     6
CCONST  2
CCONST  4
CCONST  5
WTIDE  20
```

```
      EQUIVALENCE (W(104),UTH0),(W(105),LAMZ),(W(106),TTAU),(W(107),TAU)WTIDE 21
                                                                        WTIDE 22
C                                                                       WTIDE 23
      DATA RECOGU/5.0/                                                  WDEBL  2
      DATA UMX/1/                                                       WDEBL  3
      DATA UNTBL/1,11,8*0/                                              WDEBL  4
      DATA UITBL/1,9*0/                                                 WDEBL  5
      DATA UFRMTBL/1,9*0/                                               WTIDE 26
C                                                                       WTIDE 27
C                                                                       WTIDE 28
      ENTRY IWINDR                                                      WTIDE 29
C                                                                       WTIDE 30
      IF(RECOGU .NE. UMODEL)                                            WTIDE 31
     1    CALL RERROR('SPEED  ','WRNG MODEL',RECOGU)                    WTIDE 32
C                                                                       WTIDE 33
      MODU(1)=5HWTIDE                                                   WTIDE 34
      MODU(2)=UID                                                       WTIDE 35
      CALL IPWINDR                                                      WTIDE 36
C                                                                       WTIDE 37
      Q=PID2/LAMZ                                                       WTIDE 38
      S=PID2/TAU                                                        WTIDE 39
      RETURN                                                            WTIDE 40
C                                                                       WTIDE 41
      ENTRY WINDR                                                       WTIDE 42
C                                                                       WTIDE 43
      CALL CLEAR(V,20)                                                  WTIDE 44
C                                                                       WTIDE 45
      ARG=PID2*((R-EARTHR)/LAMZ+TTAU)                                   WTIDE 46
C                                                                       WTIDE 47
      CSA=COS(ARG)                                                      WTIDE 48
      SSA=SIN(ARG)                                                      WTIDE 49
      VTH=UTH0*SSA                                                      WTIDE 50
      VPH=UPH0*CSA                                                      WTIDE 51
C                                                                       WTIDE 52
      PVTHR=CSA*Q*UTH0                                                  WTIDE 53
      PVPHR=SSA*Q*UPH0                                                  WTIDE 54
C      V=SQRT(VTH*VTH+VPH*VPH)                                          WTIDE 55
      PVTHT=CSA*S*UTH0                                                  WTIDE 56
      PVPHT=SSA*S*UPH0                                                  WTIDE 57
      CALL PWINDR                                                       WTIDE 58
      RETURN                                                            WTIDE 59
      END


      SUBROUTINE ULOGZ2                                                 ULOGZ2 8
C     LOGARITHMIC WIND VELOCITY PROFILE                                 ULOGZ2 9
C     SINGULARITY IS AVOIDED BY A LINEAR TANGENT UNIQUELY               ULOGZ210
C     DETERMINED BY CONTINUITY OF VALUE AND SLOPE GOING THROUGH         ULOGZ211
C     THE ORIGIN.                                                       ULOGZ212
      REAL K                                                            ULOGZ213
      EQUIVALENCE (USTAR,W(103)),(K,W(104)),(Z0,W(105))                 ULOGZ214
C                                                                       ULOGZ215
C     COMMON DECK "RKAM" INSERTED HERE                                  RKAMCOM2
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```
      REAL KR,KTH,KPH                                                    RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)        RKAMCOM5
C     COMMON DECK "UU" INSERTED HERE                                     CUU    2
      REAL MODU                                                          CUU    4
      COMMON/UU/MODU(4)                                                  CUU    5
     1  ,V   ,PVT   ,PVR   ,PVTH   ,PVPH                                 CUU    6
     2  ,VR  ,PVRT  ,PVRR  ,PVRTH  ,PVRPH                                CUU    7
     3  ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                   CUU    8
     4  ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                   CUU    9
C     COMMON DECK "WW" INSERTED HERE                                     CWW    2
      PARAMETER (NWARSZ=1000)                                            CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                    CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                 CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),     CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),       CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),           CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),          CWW2   6
     8 (RCVRH,W(20)),                                                    CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                       CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                       CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                      CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),        CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))         CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),         CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))               CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                    CWW2  16
      REAL MMODEL,MFORM,MID                                              CWW3   2
C                                                                        CWW3   3
C     WIND          100-124                                            CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)            CWW3   5
C                                                                        CWW3   6
C     DELTA WIND          125-149                                        CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)         CWW3   8
C                                                                        CWW3   9
C     SOUND SPEED 150-174                                                CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)            CWW3  11
      EQUIVALENCE (W(153),REFC)                                          CWW3  12
C                                                                        CWW3  13
C     DELTA SOUND SPEED 175-199                                          CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)         CWW3  15
C                                                                        CWW3  16
C     TEMPERATURE     200-224                                            CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)            CWW3  18
C                                                                        CWW3  19
C     DELTA TEMPERATURE     225-249                                      CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)         CWW3  21
C                                                                        CWW3  22
C     MOLECULAR   250-274                                                CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)            CWW3  24
C                                                                        CWW3  25
C     RECEIVER HEIGHT   275-299                                          CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)            CWW3  27
C                                                                        CWW3  28
C     TOPOGRAPHY    300-324                                              CWW3  29
```

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      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)          CWW3  30
C                                                                      CWW3  31
C     DELTA TOPOGRAPHY   325-349                                       CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)       CWW3  33
C                                                                      CWW3  34
C     UPPER SURFACE TOPOGRAPHY   350-374                               CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)          CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                             CWW3  37
C                                                                      CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                      CWW3  39
C     ABSORPTION         500-524                                       CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)          CWW3  41
C                                                                      CWW3  42
C     DELTA ABSORPTION         525-549                                 CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)       CWW3  44
C                                                                      CWW3  45
C     PRESSURE         550-574                                         CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)          CWW3  47
C                                                                      CWW3  48
C     DELTA PRESSURE         575-599                                   CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)       CWW3  50
C                                                                      CWW3  51
C     COMMON DECK "B1" INSERTED HERE                                   CB1    2
      INTEGER UMX,UNTBL,UITBL,UFRMTBL,IDSU(10)                         CB1    4
      COMMON/B1/UMX,UNTBL(10),UITBL(10),UFRMTBL(10),UGP(10)            CB1    5
      EQUIVALENCE (UGP,IDSU)                                           CB1    6
C     COMMON DECK "GG" INSERTED HERE                                   CGG    2
      REAL MODG                                                        CGG    4
      COMMON/GG/MODG(4)                                                CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                 CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME           CGG    7
      DATA RECOGU/6.0/                                                 ULOGZ221
      DATA UMX/1/                                                      UGZ2BL 2
      DATA UNTBL/1,11,8*0/                                             UGZ2BL 3
      DATA UITBL/1,9*0/                                                UGZ2BL 4
      DATA UFRMTBL/1,9*0/                                              UGZ2BL 5
C                                                                      ULOGZ224
      ENTRY IWINDR                                                     ULOGZ225
C                                                                      ULOGZ226
       IF(RECOGU .NE. UMODEL)                                          ULOGZ227
     1    CALL RERROR('ULOGZ2 ','WRNG MODEL',RECOGU)                  ULOGZ228
C                                                                      ULOGZ229
       MODU(1)=6HULOGZ2                                                ULOGZ230
       MODU(2)=UID                                                     ULOGZ231
C                                                                      ULOGZ232
       Z0E=Z0*EXP(1.0)                                                 ULOGZ233
       C=USTAR/K                                                       ULOGZ234
       CZ0E=C/Z0E                                                      ULOGZ235
       CALL IPWINDR                                                    ULOGZ236
C                                                                      ULOGZ237
       RETURN                                                          ULOGZ238
C                                                                      ULOGZ239
        ENTRY WINDR                                                    ULOGZ240
       CALL CLEAR(V,20)                                                ULOGZ241
       CALL TOPOG                                                      ULOGZ242
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      Z = G/PGR                                                          ULOGZ243
      IF(Z.GT.Z0E) GO TO 100                                             ULOGZ244
C                                                                        ULOGZ245
      VPH=CZ0E*Z                                                         ULOGZ246
      PVPHR=CZ0E*PGR                                                     ULOGZ247
      PVPHTH=CZ0E*PGTH                                                   ULOGZ248
      PVPHPH=CZ0E*PGPH                                                   ULOGZ249
      GO TO 120                                                          ULOGZ250
C                                                                        ULOGZ251
100   VPH=C*ALOG(Z/Z0)                                                   ULOGZ252
      CZ=C/Z                                                             ULOGZ253
      PVPHR=CZ*PGR                                                       ULOGZ254
      PVPHTH=CZ*PGTH                                                     ULOGZ255
      PVPHPH=CZ*PGPH                                                     ULOGZ256
C                                                                        ULOGZ257
120   V=ABS(VPH)                                                         ULOGZ258
      PVR=SIGN(PVPHR,VPH)                                                ULOGZ259
C                                                                        ULOGZ260
      CALL PWINDR                                                        ULOGZ261
       RETURN                                                            ULOGZ262
       END                                                               ULOGZ263
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       SUBROUTINE VVORTX3                                                VVORTX39
C     WIND VELOCITY MODEL                                                VVORTX10
C     VERTICAL VORTEX WIND PERTURBATION WITH VISCOUS CORE AND             VVORTX11
C     MULTIPLIES VELOCITY FIELD BY A GUASSIAN HEIGHT PROFILE.            VVORTX12
C                                                                        VVORTX13
C     COMMON DECK "CONST" INSERTED HERE                                  CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                      CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                          CCONST 5
C     COMMON DECK "RKAM" INSERTED HERE                                   RKAMCOM2
      REAL KR,KTH,KPH                                                    RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)        RKAMCOM5
C     COMMON DECK "UU" INSERTED HERE                                     CUU    2
      REAL MODU                                                          CUU    4
      COMMON/UU/MODU(4)                                                  CUU    5
     1  ,V  ,PVT  ,PVR  ,PVTH  ,PVPH                                     CUU    6
     2  ,VR ,PVRT ,PVRR ,PVRTH ,PVRPH                                    CUU    7
     3  ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                   CUU    8
     4  ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                   CUU    9
C     COMMON DECK "WW" INSERTED HERE                                     CWW    2
      PARAMETER (NWARSZ=1000)                                            CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                    CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                 CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),     CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),       CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),           CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),          CWW2   6
     8 (RCVRH,W(20)),                                                    CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                       CWW2   9
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     6 (HMIN,W(27)),(RGMAX,W(28)),                                          CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                         CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),           CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))            CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),            CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                  CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                       CWW2  16
      REAL MMODEL,MFORM,MID                                                 CWW3   2
C                                                                           CWW3   3
C     WIND          100-124                                                 CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)               CWW3   5
C                                                                           CWW3   6
C     DELTA WIND          125-149                                           CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)            CWW3   8
C                                                                           CWW3   9
C     SOUND SPEED 150-174                                                   CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)               CWW3  11
      EQUIVALENCE (W(153),REFC)                                             CWW3  12
C                                                                           CWW3  13
C     DELTA SOUND SPEED 175-199                                             CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)            CWW3  15
C                                                                           CWW3  16
C     TEMPERATURE     200-224                                               CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)               CWW3  18
C                                                                           CWW3  19
C     DELTA TEMPERATURE     225-249                                         CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)            CWW3  21
C                                                                           CWW3  22
C     MOLECULAR   250-274                                                   CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)               CWW3  24
C                                                                           CWW3  25
C     RECEIVER HEIGHT   275-299                                             CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)               CWW3  27
C                                                                           CWW3  28
C     TOPOGRAPHY    300-324                                                 CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)               CWW3  30
C                                                                           CWW3  31
C     DELTA TOPOGRAPHY    325-349                                           CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)            CWW3  33
C                                                                           CWW3  34
C     UPPER SURFACE TOPOGRAPHY    350-374                                   CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)               CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                  CWW3  37
C                                                                           CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                           CWW3  39
C     ABSORPTION          500-524                                           CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)               CWW3  41
C                                                                           CWW3  42
C     DELTA ABSORPTION          525-549                                     CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)            CWW3  44
C                                                                           CWW3  45
C     PRESSURE          550-574                                             CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)               CWW3  47
C                                                                           CWW3  48
C     DELTA PRESSURE          575-599                                       CWW3  49
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      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)          CWW3  50
C                                                                         CWW3  51
       EQUIVALENCE (U0,W(103)),(R0,W(104)),(TH0,W(105)),(PH0,W(106))      VVORTX18
       EQUIVALENCE (HWIDTH,W(107)),(HVMAX,W(108))                         VVORTX19
C     COMMON DECK "B1" INSERTED HERE                                      CB1    2
      INTEGER UMX,UNTBL,UITBL,UFRMTBL,IDSU(10)                            CB1    4
      COMMON/B1/UMX,UNTBL(10),UITBL(10),UFRMTBL(10),UGP(10)               CB1    5
      EQUIVALENCE (UGP,IDSU)                                              CB1    6
      DATA RECOGU/9.0/                                                    VVORTX21
      DATA UMX/1/                                                         VRTX3BL2
      DATA UNTBL/1,11,8*0/                                                VRTX3BL3
      DATA UITBL/1,9*0/                                                   VRTX3BL4
      DATA UFRMTBL/1,9*0/                                                 VRTX3BL5
C                                                                         VVORTX24
       ENTRY IWINDR                                                       VVORTX25
C                                                                         VVORTX26
       IF(RECOGU .NE. UMODEL)                                             VVORTX27
     1    CALL RERROR('SPEED   ','WRNG MODEL',RECOGU)                    VVORTX28
C                                                                         VVORTX29
       MODU(1)=7HVVORTX3                                                  VVORTX30
       MODU(2)=UID                                                        VVORTX31
        DENOM=0.0                                                         VVORTX32
        IF(HWIDTH.NE.0.0) DENOM=1.0/HWIDTH**2                             VVORTX33
       CALL IPWINDR                                                       VVORTX34
C                                                                         VVORTX35
       RETURN                                                             VVORTX36
C                                                                         VVORTX37
        ENTRY WINDR                                                       VVORTX38
       CALL CLEAR(V,20)                                                   VVORTX39
       DR=R-EARTHR-HVMAX                                                  VVORTX40
        DTH = TH - (PID2-TH0)                                             VVORTX41
        DPH = PH - PH0                                                    VVORTX42
        RAD2 = EARTHR * SQRT(DTH * DTH + DPH * DPH)                       VVORTX43
        A = 1.397                                                         VVORTX44
        B = - 1.26                                                        VVORTX45
       EXPO=RAD2/R0                                                       VVORTX46
       EXPO=B*EXPO*EXPO                                                   VVORTX47
       EXB=0.0                                                            VVORTX48
        IF(EXPO .GT. -675.0) EXB = EXP(EXPO)                              VVORTX49
       FX=1.-EXB                                                          VVORTX50
        DUM = A * EARTHR * U0 * R0 / RAD2 * * 2                           VVORTX51
       FZ=EXP(-DR*DR*DENOM)                                               VVORTX52
       DFDZ=-2.*DR*DENOM                                                  VVORTX53
       DUM=FZ*DUM                                                         VVORTX54
C                                                                         VVORTX55
        DUX = FX / RAD2 + RAD2 * B * EXB / R0 * * 2                       VVORTX56
        VTH = - DUM * FX * DPH                                            VVORTX57
        VPH = DUM * FX * DTH                                              VVORTX58
      V=SQRT(VTH*VTH + VPH*VPH)                                           VVORTX59
        DUM2=2.*DUM*EARTHR*EARTHR                                         VVORTX60
        PVTHTH = DUM2 * DTH * DPH / RAD2 * DUX                            VVORTX61
        PVPHPH = - PVTHTH                                                 VVORTX62
        PVTHPH = DPH**2 * DUM2 / RAD2 * DUX -DUM*FX                       VVORTX63
        PVPHTH = - DTH**2* DUM2 / RAD2* DUX + DUM*FX                      VVORTX64
C                                                                         VVORTX65
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      PVTH=(VTH*PVTHTH + VPH*PVPHTH)/V                                  VVORTX66
      PVPH=(VTH*PVTHPH + VPH*PVPHPH)/V                                  VVORTX67
C                                                                       VVORTX68
      PVTHR=VTH*DFDZ                                                    VVORTX69
      PVPHR=VPH*DFDZ                                                    VVORTX70
      PVR=(VTH*PVTHR+VPH*PVPHR)/V                                       VVORTX71
C                                                                       VVORTX72
      CALL PWINDR                                                       VVORTX73
       RETURN                                                           VVORTX74
       END                                                              VVORTX75
```

```
       SUBROUTINE WGAUSS2                                               WGAUSS28
C      WIND VELOCITY MODEL                                              WGAUSS29
C      EXPONENTIALLY DECAYING EFFECT IN ALL THREE DIRECTIONS.           WGAUSS10
C      COMMON DECK "CONST" INSERTED HERE                                CCONST 2
       COMMON/PCONST/CREF,RGAS,GAMMA                                    CCONST 4
       COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                        CCONST 5
C      COMMON DECK "RKAM" INSERTED HERE                                 RKAMCOM2
       REAL KR,KTH,KPH                                                  RKAMCOM4
       COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)      RKAMCOM5
C      COMMON DECK "UU" INSERTED HERE                                   CUU    2
       REAL MODU                                                        CUU    4
       COMMON/UU/MODU(4)                                                CUU    5
      1  ,V  ,PVT  ,PVR  ,PVTH  ,PVPH                                   CUU    6
      2  ,VR ,PVRT ,PVRR ,PVRTH ,PVRPH                                  CUU    7
      3  ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                 CUU    8
      4  ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                 CUU    9
C      COMMON DECK "WW" INSERTED HERE                                   CWW    2
       PARAMETER (NWARSZ=1000)                                          CWW1   3
       COMMON/WW/ID(10),MAXW,W(NWARSZ)                                  CWW1   4
       REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                               CWW2   2
       EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),   CWW2   3
      1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),     CWW2   4
      2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),         CWW2   5
      3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),        CWW2   6
      8 (RCVRH,W(20)),                                                  CWW2   7
      4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2  8
      5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                     CWW2   9
      6 (HMIN,W(27)),(RGMAX,W(28)),                                     CWW2  10
      8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                    CWW2  11
      6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),      CWW2  12
      7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))       CWW2  13
      9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),       CWW2  14
      1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))             CWW2  15
      2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                  CWW2  16
       REAL MMODEL,MFORM,MID                                            CWW3   2
C                                                                       CWW3   3
C      WIND         100-124                                             CWW3   4
       EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)          CWW3   5
C                                                                       CWW3   6
C      DELTA WIND         125-149                                       CWW3   7
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      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)          CWW3   8
C                                                                         CWW3   9
C     SOUND SPEED 150-174                                                 CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)             CWW3  11
      EQUIVALENCE (W(153),REFC)                                           CWW3  12
C                                                                         CWW3  13
C     DELTA SOUND SPEED 175-199                                           CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)          CWW3  15
C                                                                         CWW3  16
C     TEMPERATURE    200-224                                              CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)             CWW3  18
C                                                                         CWW3  19
C     DELTA TEMPERATURE    225-249                                        CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)          CWW3  21
C                                                                         CWW3  22
C     MOLECULAR   250-274                                                 CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)             CWW3  24
C                                                                         CWW3  25
C     RECEIVER HEIGHT   275-299                                           CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)             CWW3  27
C                                                                         CWW3  28
C     TOPOGRAPHY   300-324                                                CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)             CWW3  30
C                                                                         CWW3  31
C     DELTA TOPOGRAPHY   325-349                                          CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)          CWW3  33
C                                                                         CWW3  34
C     UPPER SURFACE TOPOGRAPHY   350-374                                  CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)             CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                CWW3  37
C                                                                         CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                         CWW3  39
C     ABSORPTION         500-524                                          CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)             CWW3  41
C                                                                         CWW3  42
C     DELTA ABSORPTION         525-549                                    CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)          CWW3  44
C                                                                         CWW3  45
C     PRESSURE         550-574                                            CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)             CWW3  47
C                                                                         CWW3  48
C     DELTA PRESSURE         575-599                                      CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)          CWW3  50
C                                                                         CWW3  51
C     COMMON DECK "B1" INSERTED HERE                                      CB1    2
      INTEGER UMX,UNTBL,UITBL,UFRMTBL,IDSU(10)                            CB1    4
      COMMON/B1/UMX,UNTBL(10),UITBL(10),UFRMTBL(10),UGP(10)               CB1    5
      EQUIVALENCE (UGP,IDSU)                                              CB1    6
      EQUIVALENCE (UPH0,W(103)),(WH,W(104)),(WTH,W(105))                  WGAUSS16
      EQUIVALENCE  (WPH,W(106)),(H0,W(107)),(WGTH0,W(108)),(PH0,W(109))   WGAUSS17
      DATA RECOGU/7.0/                                                    WGAUSS18
      DATA UMX/1/                                                         WUSS2L 2
      DATA UNTBL/1,11,8*0/                                                WUSS2L 3
      DATA UITBL/1,9*0/                                                   WUSS2L 4
      DATA UFRMTBL/1,9*0/                                                 WUSS2L 5
```

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C                                                                       WGAUSS21
      ENTRY IWINDR                                                      WGAUSS22
C                                                                       WGAUSS23
      IF(RECOGU .NE. UMODEL)                                            WGAUSS24
     1    CALL RERROR('SPEED  ','WRNG MODEL',RECOGU)                   WGAUSS25
C                                                                       WGAUSS26
      MODU(1)=7HWGAUSS2                                                 WGAUSS27
      MODU(2)=UID                                                       WGAUSS28
      CALL IPWINDR                                                      WGAUSS29
C                                                                       WGAUSS30
      WIDH=0.0                                                          WGAUSS31
      WIDTH=0.0                                                         WGAUSS32
      WIDPH=0.0                                                         WGAUSS33
      TH0= PID2-WGTH0                                                   WGAUSS34
      IF(WH.NE.0.0) WIDH=1.0/WH                                         WGAUSS35
      IF(WTH.NE.0.0) WIDTH=1.0/WTH                                      WGAUSS36
      IF(WPH.NE.0.0) WIDPH=1.0/WPH                                      WGAUSS37
      RETURN                                                            WGAUSS38
C                                                                       WGAUSS39
       ENTRY WINDR                                                      WGAUSS40
      CALL CLEAR(V,20)                                                  WGAUSS41
       H = R - EARTHR                                                   WGAUSS42
      DFH=(H-H0)*WIDH                                                   WGAUSS43
      DFTH=(TH-TH0)*WIDTH                                               WGAUSS44
      DFPH=(PH-PH0)*WIDPH                                               WGAUSS45
      EXPO=-(DFH*DFH+DFTH*DFTH+DFPH*DFPH)                               WGAUSS46
      EXPN=0.0                                                          WGAUSS47
      IF(EXPO.GT.-200.0) EXPN=EXP(EXPO)                                 WGAUSS48
       VPH = UPH0*EXPN                                                  WGAUSS49
       PVPHR = - 2. * VPH * DFH*WIDH                                    WGAUSS50
       PVPHTH = - 2. * VPH * DFTH*WIDTH                                 WGAUSS51
       PVPHPH = - 2. * VPH * DFPH*WIDPH                                 WGAUSS52
       END                                                              WGAUSS53
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```
       SUBROUTINE NPWIND                                                NPWIND 8
C      DO-NOTHING WIND-VELOCITY PERTURBATION MODEL                      NPWIND 9
C      COMMON DECK "UU" INSERTED HERE                                   CUU    2
       REAL MODU                                                        CUU    4
       COMMON/UU/MODU(4)                                                CUU    5
      1  ,V  ,PVT  ,PVR  ,PVTH  ,PVPH                                   CUU    6
      2  ,VR ,PVRT ,PVRR ,PVRTH ,PVRPH                                  CUU    7
      3  ,VTH,PVTHT,PVTHR,PVTHTH,PVTHPH                                 CUU    8
      4  ,VPH,PVPHT,PVPHR,PVPHTH,PVPHPH                                 CUU    9
C      COMMON DECK "WW" INSERTED HERE                                   CWW    2
       PARAMETER (NWARSZ=1000)                                          CWW1   3
       COMMON/WW/ID(10),MAXW,W(NWARSZ)                                  CWW1   4
       REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                               CWW2   2
       EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),   CWW2   3
      1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),     CWW2   4
      2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),         CWW2   5
      3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),        CWW2   6
```

```
     8 (RCVRH,W(20)),                                                                  CWW2    7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))               CWW2    8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                                     CWW2    9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                                     CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                                    CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),                      CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))                       CWW2   13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),                       CWW2   14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                             CWW2   15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                                  CWW2   16
      REAL MMODEL,MFORM,MID                                                            CWW3    2
C                                                                                      CWW3    3
C      WIND         100-124                                                           CWW3    4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)                          CWW3    5
C                                                                                      CWW3    6
C     DELTA WIND         125-149                                                       CWW3    7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)                       CWW3    8
C                                                                                      CWW3    9
C     SOUND SPEED 150-174                                                            CWW3   10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                          CWW3   11
      EQUIVALENCE (W(153),REFC)                                                        CWW3   12
C                                                                                      CWW3   13
C     DELTA SOUND SPEED 175-199                                                      CWW3   14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)                       CWW3   15
C                                                                                      CWW3   16
C     TEMPERATURE    200-224                                                         CWW3   17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                          CWW3   18
C                                                                                      CWW3   19
C     DELTA TEMPERATURE    225-249                                                   CWW3   20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)                       CWW3   21
C                                                                                      CWW3   22
C     MOLECULAR   250-274                                                            CWW3   23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                          CWW3   24
C                                                                                      CWW3   25
C     RECEIVER HEIGHT   275-299                                                      CWW3   26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                          CWW3   27
C                                                                                      CWW3   28
C     TOPOGRAPHY   300-324                                                           CWW3   29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)                          CWW3   30
C                                                                                      CWW3   31
C     DELTA TOPOGRAPHY   325-349                                                     CWW3   32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)                       CWW3   33
C                                                                                      CWW3   34
C     UPPER SURFACE TOPOGRAPHY   350-374                                             CWW3   35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)                          CWW3   36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                           CWW3   37
C                                                                                      CWW3   38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                                      CWW3   39
C     ABSORPTION         500-524                                                     CWW3   40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)                          CWW3   41
C                                                                                      CWW3   42
C     DELTA ABSORPTION         525-549                                               CWW3   43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)                       CWW3   44
C                                                                                      CWW3   45
C     PRESSURE         550-574                                                       CWW3   46
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      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)          CWW3  47
                                                                       CWW3  48
C                                                                      CWW3  49
C     DELTA PRESSURE          575-599                                  CWW3  50
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)       CWW3  51
C                                                                      CB2    2
C     COMMON DECK "B2" INSERTED HERE                                   CB2    4
      INTEGER DUMX,DUNTBL,DUITBL,DUFRMTB,IDSDU(10)                     CB2    5
      COMMON/B2/DUMX,DUNTBL(10),DUITBL(10),DUFRMTB(10),DUGP(10)        CB2    6
      EQUIVALENCE (DUGP,IDSDU)                                         NPWIND13
      DATA RECOGDU/0.0/                                                NINDBL 2
      DATA DUMX/1/                                                     NINDBL 3
      DATA DUNTBL/1,11,8*0/                                            NINDBL 4
      DATA DUITBL/1,9*0/                                               NINDBL 5
      DATA DUFRMTB/1,9*0/                                              NPWIND16
C                                                                      NPWIND17
      ENTRY IPWINDR                                                    NPWIND18
      IF(RECOGDU .NE. DUMODEL)                                         NPWIND19
     1    CALL RERROR('DWINDR ','WRNG MODEL',RECOGDU)                  NPWIND20
      MODU(3)=6HNPWIND                                                 NPWIND21
      MODU(4)=DUID                                                     NPWIND22
      RETURN                                                           NPWIND23
C                                                                      NPWIND24
      ENTRY PWINDR                                                     NPWIND25
      RETURN                                                           NPWIND26
      END
```

```
      SUBROUTINE GAMRTDM                                               GAMRTDM8
C     SOUND SPEED MODEL, C**2=GAMMA*R*T/M                              GAMRTDM9
C     COMMON DECK "CC" INSERTED HERE                                   CCC    2
      REAL MODC                                                        CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                       CCC    5
C     COMMON DECK "TT" INSERTED HERE                                   CTT    2
      REAL MODT                                                        CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                           CTT    5
C     COMMON DECK "MM" INSERTED HERE                                   CMM    2
      REAL M,MODM                                                      CMM    4
      COMMON/MM/MODM(4),M,PMT,PMR,PMTH,PMPH                            CMM    5
C     COMMON DECK "CONST" INSERTED HERE                                CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                    CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                        CCONST 5
C     COMMON DECK "WW" INSERTED HERE                                   CWW    2
      PARAMETER (NWARSZ=1000)                                          CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                  CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                               CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),   CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),     CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),         CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),        CWW2   6
     8 (RCVRH,W(20)),                                                  CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                     CWW2   9
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```
     6 (HMIN,W(27)),(RGMAX,W(28)),                                          CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                         CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),           CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))            CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),            CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                  CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                       CWW2  16
      REAL MMODEL,MFORM,MID                                                 CWW3   2
C                                                                           CWW3   3
C     WIND          100-124                                                 CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)               CWW3   5
C                                                                           CWW3   6
C     DELTA WIND          125-149                                           CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)            CWW3   8
C                                                                           CWW3   9
C     SOUND SPEED 150-174                                                   CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)               CWW3  11
      EQUIVALENCE (W(153),REFC)                                             CWW3  12
C                                                                           CWW3  13
C     DELTA SOUND SPEED 175-199                                             CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)            CWW3  15
C                                                                           CWW3  16
C     TEMPERATURE     200-224                                               CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)               CWW3  18
C                                                                           CWW3  19
C     DELTA TEMPERATURE     225-249                                         CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)            CWW3  21
C                                                                           CWW3  22
C     MOLECULAR   250-274                                                   CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)               CWW3  24
C                                                                           CWW3  25
C     RECEIVER HEIGHT   275-299                                             CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)               CWW3  27
C                                                                           CWW3  28
C     TOPOGRAPHY    300-324                                                 CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)               CWW3  30
C                                                                           CWW3  31
C     DELTA TOPOGRAPHY    325-349                                           CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)            CWW3  33
C                                                                           CWW3  34
C     UPPER SURFACE TOPOGRAPHY    350-374                                   CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)               CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                  CWW3  37
C                                                                           CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                           CWW3  39
C     ABSORPTION          500-524                                           CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)               CWW3  41
C                                                                           CWW3  42
C     DELTA ABSORPTION          525-549                                     CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)            CWW3  44
C                                                                           CWW3  45
C     PRESSURE          550-574                                             CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)               CWW3  47
C                                                                           CWW3  48
C     DELTA PRESSURE          575-599                                       CWW3  49
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```
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)          CWW3  50
C                                                                         CWW3  51
C                                                                         GAMRTD15
C     COMMON DECK "B3" INSERTED HERE                                      CB3    2
      INTEGER CMX,CNTBL,CITBL,CFRMTBL,IDSC(10)                            CB3    4
      COMMON/B3/CMX,CNTBL(10),CITBL(10),CFRMTBL(10),CGP(512)              CB3    5
      EQUIVALENCE (CGP,IDSC),(ANC,CGP(11))                                CB3    6
      DATA CMX/1/                                                         GRTDMBL2
      DATA CNTBL/1,11,8*0/                                                GRTDMBL3
      DATA CITBL/1,9*0/                                                   GRTDMBL4
      DATA CFRMTBL/1,9*0/                                                 GRTDMBL5
      DATA RECOGC/1.0/                                                    GAMRTD19
C                                                                         GAMRTD20
      ENTRY ISPEED                                                        GAMRTD21
C                                                                         GAMRTD22
       IF(REFC.GT.0.0) CREF=REFC                                          GAMRTD23
       IF(RECOGC .NE. CMODEL)                                             GAMRTD24
     1    CALL RERROR('SPEED  ','WRNG MODEL',RECOGC)                     GAMRTD25
       MODC(1)=7HGAMRTDM                                                  GAMRTD26
       MODC(2)=CID                                                        GAMRTD27
       CALL ITEMP                                                         GAMRTD28
       CALL IMOLWT                                                        GAMRTD29
       CALL IPSPEED                                                       GAMRTD30
C                                                                         GAMRTD31
       RETURN                                                             GAMRTD32
C                                                                         GAMRTD33
       ENTRY SPEED                                                        GAMRTD34
       CALL TEMP                                                          GAMRTD35
       CALL MOLWT                                                         GAMRTD36
       CS=GAMMA*RGAS*T/M                                                  GAMRTD37
       PCST=CS*(PTT/T - PMT/M)                                            GAMRTD38
       PCSR=CS*(PTR/T - PMR/M)                                            GAMRTD39
       PCSTH=CS*(PTTH/T - PMTH/M)                                         GAMRTD40
       PCSPH=CS*(PTPH/T - PMPH/M)                                         GAMRTD41
C                                                                         GAMRTD42
C                                                                         GAMRTD43
       CALL PSPEED                                                        GAMRTD44
       RETURN                                                             GAMRTD45
       END                                                                GAMRTD46
```

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      SUBROUTINE CSTANH                                                   CSTANH10
C     SPEED PROFILE REPRESENTED BY A SEQUENCE OF LINEAR SEGMENTS          CSTANH11
C     SMOOTHLY JOINED BY HYPERBOLIC FUNCTIONS. PARAMETERS ARE INPUT       CSTANH12
C     AS TABULAR DATA WITH SLOPES COMPUTED FROM SPEED DATA.               CSTANH13
C                                                                         CSTANH14
      REAL ALC(20),Z(19),B(19),DL(19)                                     CSTANH15
C     COMMON DECK "RKAM" INSERTED HERE                                    RKAMCOM2
      REAL KR,KTH,KPH                                                     RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)         RKAMCOM5
C     COMMON DECK "B3" INSERTED HERE                                      CB3    2
      INTEGER CMX,CNTBL,CITBL,CFRMTBL,IDSC(10)                            CB3    4
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      COMMON/B3/CMX,CNTBL(10),CITBL(10),CFRMTBL(10),CGP(512)                CB3    5
      EQUIVALENCE (CGP,IDSC),(ANC,CGP(11))                                 CB3    6
C     COMMON DECK "CC" INSERTED HERE                                       CCC    2
      REAL MODC                                                            CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                           CCC    5
C     COMMON DECK "CONST" INSERTED HERE                                    CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                        CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                            CCONST 5
C     COMMON DECK "WW" INSERTED HERE                                       CWW    2
      PARAMETER (NWARSZ=1000)                                              CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                      CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                   CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),       CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),         CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),             CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),            CWW2   6
     8 (RCVRH,W(20)),                                                      CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))   CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                         CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                         CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                        CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),          CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))           CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),           CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                 CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                      CWW2  16
      REAL MMODEL,MFORM,MID                                                CWW3   2
C                                                                          CWW3   3
C     WIND         100-124                                                 CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)              CWW3   5
C                                                                          CWW3   6
C     DELTA WIND         125-149                                           CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)           CWW3   8
C                                                                          CWW3   9
C     SOUND SPEED 150-174                                                  CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)              CWW3  11
      EQUIVALENCE (W(153),REFC)                                            CWW3  12
C                                                                          CWW3  13
C     DELTA SOUND SPEED 175-199                                            CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)           CWW3  15
C                                                                          CWW3  16
C     TEMPERATURE    200-224                                               CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)              CWW3  18
C                                                                          CWW3  19
C     DELTA TEMPERATURE    225-249                                         CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)           CWW3  21
C                                                                          CWW3  22
C     MOLECULAR   250-274                                                  CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)              CWW3  24
C                                                                          CWW3  25
C     RECEIVER HEIGHT   275-299                                            CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)              CWW3  27
C                                                                          CWW3  28
C     TOPOGRAPHY   300-324                                                 CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)              CWW3  30
```

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C                                                                       CWW3  31
C                                                                       CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)        CWW3  33
C                                                                       CWW3  34
C     UPPER SURFACE TOPOGRAPHY   350-374                                 CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)           CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                              CWW3  37
C                                                                       CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                       CWW3  39
C     ABSORPTION         500-524                                        CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)           CWW3  41
C                                                                       CWW3  42
C     DELTA ABSORPTION         525-549                                  CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)        CWW3  44
C                                                                       CWW3  45
C     PRESSURE         550-574                                          CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)           CWW3  47
C                                                                       CWW3  48
C     DELTA PRESSURE         575-599                                    CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)        CWW3  50
C                                                                       CWW3  51
C                                                                       CSTANH21
      EQUIVALENCE (Z0,CGP(12)),(CS0,CGP(32)),(DL0,CGP(52))             CSTANH22
      EQUIVALENCE (Z,CGP(13)),(B,CGP(33)),(DL,CGP(53))                  CSTANH23
C                                                                       CSTANH24
      DATA RECOGC,N/2.0,0/                                              CSTANH25
      DATA PCST,PCSTH,PCSPH/3*0.0/                                      CANHBL 2
      DATA ANC/0.0/                                                     CANHBL 3
      DATA CMX/2/                                                       CANHBL 4
      DATA CNTBL/1,11,72,7*0/                                           CANHBL 5
      DATA CITBL/1,20,8*0/                                              CANHBL 6
      DATA CFRMTBL/1,2,8*0/                                             CANHBL 7
C                                                                       CSTANH28
      ENTRY ISPEED                                                      CSTANH29
C                                                                       CSTANH30
      IF(REFC.GT.0.0) CREF=REFC                                         CSTANH31
C                                                                       CSTANH32
      CALL IPSPEED                                                      CSTANH33
C                                                                       CSTANH34
C     IF HAD PREVIOUS CALL BUT NOTHING THIS TIME, EXIT NOW              CSTANH35
C     RETAINING PREVIOUS TABULAR DATA COUNT                             CSTANH36
      IF(N.GT.0 .AND. ANC.EQ.0.0) RETURN                                CSTANH37
C                                                                       CSTANH38
      IF(RECOGC .NE. CMODEL)                                            CSTANH39
     1    CALL RERROR('SPEED  ','WRNG MODEL',RECOGC)                    CSTANH40
      MODC(1)=6HCSTANH                                                  CSTANH41
      MODC(2)=CID                                                       CSTANH42
      N=ANC/3                                                           CSTANH43
      IF(ANC.NE.3*N.OR.N.LE.0)                                          CSTANH44
     1    CALL RERROR('CSTANH','BAD NUMBER',ANC+2.0)                    CSTANH45
      N=N-2                                                             CSTANH46
      ANC=0.0                                                           CSTANH47
C                                                                       CSTANH48
C                                                                       CSTANH49
C     CONVERT 'C' ARRAY INPUT(OVERLAYS 'B' ARRAY) TO 'B' ARRAY          CSTANH50
```

```
C
      ZM1=Z0                                                              CSTANH51
      CS0=CS0*CS0                                                         CSTANH52
      CSM1=CS0                                                            CSTANH53
      NP1=N+1                                                             CSTANH54
      DO 10 I=1,NP1                                                       CSTANH55
         ZR=Z(I)                                                          CSTANH56
         ALC(I)=ALCOSH((ZR-Z0) / DL(I))                                   CSTANH57
         CS=B(I)**2                                                       CSTANH58
         B(I)=(CS-CSM1)/(ZR-ZM1)                                          CSTANH59
         ZM1=ZR                                                           CSTANH60
10       CSM1=CS                                                          CSTANH61
C                                                                         CSTANH62
      RETURN                                                              CSTANH63
C                                                                         CSTANH64
      ENTRY SPEED                                                         CSTANH65
C                                                                         CSTANH66
      IF(N.LE.0)                                                          CSTANH67
     1    CALL RERROR('CSTANH','BAD N VALUE',FLOAT(N))                    CSTANH68
C                                                                         CSTANH69
      ZR=R-EARTHR                                                         CSTANH70
      SUM = 0.                                                            CSTANH71
      PCSR=B(1)                                                           CSTANH72
      DO 1 I = 1, N                                                       CSTANH73
      SAV=0.5*(B(I+1)-B(I))                                               CSTANH74
      PCSR= PCSR+ SAV * (1.+TANH ((ZR-Z(I)) /DL(I)))                      CSTANH75
    1 SUM = SUM+DL(I) * SAV *(ALCOSH((ZR-Z(I))/DL(I))-ALC(I))             CSTANH76
      CS = CS0+SUM + 0.5*(B(1) + B(N + 1)) * (ZR-Z0)                      CSTANH77
C                                                                         CSTANH78
      CALL PSPEED                                                         CSTANH79
      RETURN                                                              CSTANH80
      END                                                                 CSTANH81
                                                                          CSTANH82
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      SUBROUTINE NPSPEED                                                  NPSPEED8
C     DO-NOTHING SOUND SPEED PERTURBATION MODEL                           NPSPEED9
C     COMMON DECK "CC" INSERTED HERE                                      CCC    2
      REAL MODC                                                           CCC    4
      COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                          CCC    5
C     COMMON DECK "WW" INSERTED HERE                                      CWW    2
      PARAMETER (NWARSZ=1000)                                             CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                     CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                  CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),      CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),        CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),            CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),           CWW2   6
     8 (RCVRH,W(20)),                                                     CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))  CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                        CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                        CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                       CWW2  11
```

```
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),      CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))       CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),       CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))             CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                  CWW2  16
      REAL MMODEL,MFORM,MID                                            CWW3   2
C                                                                      CWW3   3
C     WIND          100-124                                          CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)          CWW3   5
C                                                                      CWW3   6
C     DELTA WIND          125-149                                    CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)       CWW3   8
C                                                                      CWW3   9
C     SOUND SPEED 150-174                                              CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)          CWW3  11
      EQUIVALENCE (W(153),REFC)                                        CWW3  12
C                                                                      CWW3  13
C     DELTA SOUND SPEED 175-199                                        CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)       CWW3  15
C                                                                      CWW3  16
C     TEMPERATURE    200-224                                           CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)          CWW3  18
C                                                                      CWW3  19
C     DELTA TEMPERATURE    225-249                                     CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)       CWW3  21
C                                                                      CWW3  22
C     MOLECULAR   250-274                                              CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)          CWW3  24
C                                                                      CWW3  25
C     RECEIVER HEIGHT   275-299                                        CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)          CWW3  27
C                                                                      CWW3  28
C     TOPOGRAPHY   300-324                                             CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)          CWW3  30
C                                                                      CWW3  31
C     DELTA TOPOGRAPHY   325-349                                       CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)       CWW3  33
C                                                                      CWW3  34
C     UPPER SURFACE TOPOGRAPHY   350-374                               CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)          CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                             CWW3  37
C                                                                      CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                      CWW3  39
C     ABSORPTION          500-524                                      CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)          CWW3  41
C                                                                      CWW3  42
C     DELTA ABSORPTION          525-549                                CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)       CWW3  44
C                                                                      CWW3  45
C     PRESSURE          550-574                                        CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)          CWW3  47
C                                                                      CWW3  48
C     DELTA PRESSURE          575-599                                  CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)       CWW3  50
C                                                                      CWW3  51
```

```
C                                                                       NPSPEE12
C       COMMON DECK "B2" INSERTED HERE                                  CB2    2
        INTEGER DUMX,DUNTBL,DUITBL,DUFRMTB,IDSDU(10)                    CB2    4
        COMMON/B2/DUMX,DUNTBL(10),DUITBL(10),DUFRMTB(10),DUGP(10)       CB2    5
        EQUIVALENCE (DUGP,IDSDU)                                        CB2    6
C                                                                       NPSPEE14
        DATA DUMX/1/                                                    NPEEDBL2
        DATA DUNTBL/1,11,8*0/                                           NPEEDBL3
        DATA DUITBL/1,9*0/                                              NPEEDBL4
        DATA DUFRMTB/1,9*0/                                             NPEEDBL5
C                                                                       NPSPEE17
        DATA RECOGDC/0.0/                                               NPSPEE18
C                                                                       NPSPEE19
        ENTRY IPSPEED                                                   NPSPEE20
        IF(RECOGDC .NE. DCMODEL)                                        NPSPEE21
       1    CALL RERROR('DSPEED ','WRNG MODEL',RECOGDC)                 NPSPEE22
        MODC(3)=7HNPSPEED                                               NPSPEE23
        MODC(4)=DCID                                                    NPSPEE24
        RETURN                                                          NPSPEE25
C                                                                       NPSPEE26
        ENTRY PSPEED                                                    NPSPEE27
        RETURN                                                          NPSPEE28
        END                                                             NPSPEE29
```

```
        SUBROUTINE CBLOB2                                               CBLOB2 8
C       SOUND SPEED PERTURBATION MODEL                                  CBLOB2 9
C       MULTIPLICATIVE PERTURBATION WITH EXPONENTIALLY DECAYING         CBLOB210
C       EFFECT IN ALL THREE DIRECTIONS. GIVE LATITUDE                   CBLOB211
C       INSTEAD OF CO-LATITUDE.                                         CBLOB212
C       COMMON DECK "CONST" INSERTED HERE                               CCONST 2
        COMMON/PCONST/CREF,RGAS,GAMMA                                   CCONST 4
        COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                       CCONST 5
C       COMMON DECK "RKAM" INSERTED HERE                                RKAMCOM2
        REAL KR,KTH,KPH                                                 RKAMCOM4
        COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)     RKAMCOM5
C       COMMON DECK "B4" INSERTED HERE                                  CB4    2
        INTEGER DCMX,DCNTBL,DCITBL,DCFRMTB,IDSDC(10)                    CB4    4
        COMMON/B4/DCMX,DCNTBL(10),DCITBL(10),DCFRMTB(10),DCGP(10)       CB4    5
        EQUIVALENCE (DCGP,IDSDC)                                        CB4    6
C                                                                       CBLOB216
C       COMMON DECK "CC" INSERTED HERE                                  CCC    2
        REAL MODC                                                       CCC    4
        COMMON/CC/MODC(4),CS,PCST,PCSR,PCSTH,PCSPH                      CCC    5
C       COMMON DECK "WW" INSERTED HERE                                  CWW    2
        PARAMETER (NWARSZ=1000)                                         CWW1   3
        COMMON/WW/ID(10),MAXW,W(NWARSZ)                                 CWW1   4
        REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                              CWW2   2
        EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),  CWW2   3
       1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),    CWW2   4
       2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),        CWW2   5
       3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),       CWW2   6
```

```
     8 (RCVRH,W(20)),                                                                  CWW2    7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))               CWW2    8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                                     CWW2    9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                                     CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                                    CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),                      CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))                       CWW2   13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),                       CWW2   14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                             CWW2   15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                                  CWW2   16
      REAL MMODEL,MFORM,MID                                                            CWW3    2
C                                                                                      CWW3    3
C      WIND          100-124                                                           CWW3    4
       EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)                         CWW3    5
C                                                                                      CWW3    6
C      DELTA WIND          125-149                                                     CWW3    7
       EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)                      CWW3    8
C                                                                                      CWW3    9
C      SOUND SPEED 150-174                                                             CWW3   10
       EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                         CWW3   11
       EQUIVALENCE (W(153),REFC)                                                       CWW3   12
C                                                                                      CWW3   13
C      DELTA SOUND SPEED 175-199                                                       CWW3   14
       EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)                      CWW3   15
C                                                                                      CWW3   16
C      TEMPERATURE     200-224                                                         CWW3   17
       EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                         CWW3   18
C                                                                                      CWW3   19
C      DELTA TEMPERATURE     225-249                                                   CWW3   20
       EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)                      CWW3   21
C                                                                                      CWW3   22
C      MOLECULAR    250-274                                                           CWW3   23
       EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                         CWW3   24
C                                                                                      CWW3   25
C      RECEIVER HEIGHT    275-299                                                      CWW3   26
       EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                         CWW3   27
C                                                                                      CWW3   28
C      TOPOGRAPHY    300-324                                                          CWW3   29
       EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)                         CWW3   30
C                                                                                      CWW3   31
C      DELTA TOPOGRAPHY    325-349                                                     CWW3   32
       EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)                      CWW3   33
C                                                                                      CWW3   34
C      UPPER SURFACE TOPOGRAPHY    350-374                                             CWW3   35
       EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)                         CWW3   36
C      PLOT ENHANCEMENTS CONTROL PARAMETERS                                            CWW3   37
C                                                                                      CWW3   38
       EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                                     CWW3   39
C      ABSORPTION          500-524                                                     CWW3   40
       EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)                         CWW3   41
C                                                                                      CWW3   42
C      DELTA ABSORPTION          525-549                                               CWW3   43
       EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)                      CWW3   44
C                                                                                      CWW3   45
C      PRESSURE         550-574                                                        CWW3   46
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      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)                CWW3  47
C                                                                            CWW3  48
C     DELTA PRESSURE          575-599                                        CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)             CWW3  50
C                                                                            CWW3  51
C                                                                            CBLOB219
      EQUIVALENCE (C0,W(178)), (Z0,W(179)),(CBTH0,W(180))                    CBLOB220
      EQUIVALENCE (PH0,W(181)),(WZ,W(182)),(WTH,W(183)),(WPH,W(184))         CBLOB221
      DATA RECOGDC/2.0/                                                      CBLOB222
      DATA DCMX/1/                                                           COB2BL 2
      DATA DCNTBL/1,11,8*0/                                                  COB2BL 3
      DATA DCITBL/1,9*0/                                                     COB2BL 4
      DATA DCFRMTB/1,9*0/                                                    COB2BL 5
C                                                                            CBLOB225
      ENTRY IPSPEED                                                          CBLOB226
      IF(RECOGDC .NE. DCMODEL)                                               CBLOB227
     1    CALL RERROR('DSPEED ','WRNG MODEL',RECOGDC)                        CBLOB228
C                                                                            CBLOB229
      MODC(3)=6HCBLOB2                                                       CBLOB230
      MODC(4)=DCID                                                           CBLOB231
C                                                                            CBLOB232
      FWZ=0.0                                                                CBLOB233
      FWTH=0.0                                                               CBLOB234
      FWPH=0.0                                                               CBLOB235
      TH0= PID2-CBTH0                                                        CBLOB236
      IF(WZ.NE.0.0) FWZ=2.0/WZ/WZ                                            CBLOB237
      IF(WTH.NE.0.0) FWTH=2.0/WTH/WTH                                        CBLOB238
      IF(WPH.NE.0.0) FWPH=2.0/WPH/WPH                                        CBLOB239
      RETURN                                                                 CBLOB240
C                                                                            CBLOB241
      ENTRY PSPEED                                                           CBLOB242
C                                                                            CBLOB243
      IF(C0.EQ.0.0) RETURN                                                   CBLOB244
C                                                                            CBLOB245
      DZ=R-EARTHR-Z0                                                         CBLOB246
      DTH=TH-TH0                                                             CBLOB247
      DPH=PH-PH0                                                             CBLOB248
      DEXPO=0.0                                                              CBLOB249
      EXPO=-0.5*(DZ*DZ*FWZ+DTH*DTH*FWTH+DPH*DPH*FWPH)                        CBLOB250
      IF(EXPO .GT. -200.0) DEXPO=C0*EXP(EXPO)                                CBLOB251
      DEL=1.0+DEXPO                                                          CBLOB252
C                                                                            CBLOB253
      PCSR=PCSR*DEL-CS*DEXPO*FWZ*DZ                                          CBLOB254
      PCSTH=PCSTH*DEL-CS*DEXPO*FWTH*DTH                                      CBLOB255
      PCSPH=PCSPH*DEL-CS*DEXPO*FWPH*DPH                                      CBLOB256
      CS=CS*DEL                                                              CBLOB257
      RETURN                                                                 CBLOB258
      END                                                                    CBLOB259


      SUBROUTINE TLINEAR                                                     TLINEAR8
C     LINEAR TEMPERATURE PROFILE                                             TLINEAR9
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C       COMMON DECK "RKAM" INSERTED HERE                                        RKAMCOM2
        REAL KR,KTH,KPH                                                         RKAMCOM4
        COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)             RKAMCOM5
C       COMMON DECK "MM" INSERTED HERE                                          CMM     2
        REAL M,MODM                                                             CMM     4
        COMMON/MM/MODM(4),M,PMT,PMR,PMTH,PMPH                                   CMM     5
C       COMMON DECK "TT" INSERTED HERE                                          CTT     2
        REAL MODT                                                               CTT     4
        COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                                  CTT     5
C       COMMON DECK "WW" INSERTED HERE                                          CWW     2
        PARAMETER (NWARSZ=1000)                                                 CWW1    3
        COMMON/WW/ID(10),MAXW,W(NWARSZ)                                         CWW1    4
        REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                      CWW2    2
        EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),          CWW2    3
       1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),            CWW2    4
       2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                CWW2    5
       3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),               CWW2    6
       8 (RCVRH,W(20)),                                                         CWW2    7
       4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))      CWW2    8
       5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                            CWW2    9
       6 (HMIN,W(27)),(RGMAX,W(28)),                                            CWW2   10
       8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                           CWW2   11
       6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),             CWW2   12
       7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))              CWW2   13
       9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),              CWW2   14
       1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                    CWW2   15
       2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                         CWW2   16
        REAL MMODEL,MFORM,MID                                                   CWW3    2
C                                                                               CWW3    3
C       WIND          100-124                                                   CWW3    4
        EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)                 CWW3    5
C                                                                               CWW3    6
C       DELTA WIND          125-149                                             CWW3    7
        EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)              CWW3    8
C                                                                               CWW3    9
C       SOUND SPEED 150-174                                                     CWW3   10
        EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                 CWW3   11
        EQUIVALENCE (W(153),REFC)                                               CWW3   12
C                                                                               CWW3   13
C       DELTA SOUND SPEED 175-199                                               CWW3   14
        EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)              CWW3   15
C                                                                               CWW3   16
C       TEMPERATURE     200-224                                                 CWW3   17
        EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                 CWW3   18
C                                                                               CWW3   19
C       DELTA TEMPERATURE     225-249                                           CWW3   20
        EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)              CWW3   21
C                                                                               CWW3   22
C       MOLECULAR   250-274                                                     CWW3   23
        EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                 CWW3   24
C                                                                               CWW3   25
C       RECEIVER HEIGHT   275-299                                               CWW3   26
        EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                 CWW3   27
C                                                                               CWW3   28
C       TOPOGRAPHY    300-324                                                   CWW3   29
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      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)                CWW3  30
C                                                                            CWW3  31
C     DELTA TOPOGRAPHY   325-349                                             CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)             CWW3  33
C                                                                            CWW3  34
C     UPPER SURFACE TOPOGRAPHY   350-374                                     CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)                CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                   CWW3  37
C                                                                            CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                            CWW3  39
C     ABSORPTION         500-524                                             CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)                CWW3  41
C                                                                            CWW3  42
C     DELTA ABSORPTION         525-549                                       CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)             CWW3  44
C                                                                            CWW3  45
C     PRESSURE         550-574                                               CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)                CWW3  47
C                                                                            CWW3  48
C     DELTA PRESSURE         575-599                                         CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)             CWW3  50
C                                                                            CWW3  51
       EQUIVALENCE (TGND, W(203)), (A, W(204))                               TLINEA14
C     COMMON DECK "B5" INSERTED HERE                                         CB5    2
      INTEGER TMX,TNTBL,TITBL,TFRMTBL,IDST(10)                               CB5    4
      COMMON/B5/TMX,TNTBL(10),TITBL(10),TFRMTBL(10),TGP(262)                 CB5    5
      EQUIVALENCE (TGP,IDST),(ANT,TGP(11))                                   CB5    6
      DATA RECOGT/1.0/                                                       TLINEA16
      DATA ANT/0.0/                                                          TNEARBL2
      DATA TMX/1/                                                            TNEARBL3
      DATA TNTBL/1,11,8*0/                                                   TNEARBL4
      DATA TITBL/1,9*0/                                                      TNEARBL5
      DATA TFRMTBL/1,9*0/                                                    TNEARBL6
      ENTRY ITEMP                                                            TLINEA19
C                                                                            TLINEA20
      IF(RECOGT .NE. TMODEL)                                                 TLINEA21
     1    CALL RERROR('TEMP    ','WRNG MODEL',RECOGT)                        TLINEA22
C                                                                            TLINEA23
      MODT(1)=7HTLINEAR                                                      TLINEA24
      MODT(2)=TID                                                            TLINEA25
      CALL IPTEMP                                                            TLINEA26
C                                                                            TLINEA27
      RETURN                                                                 TLINEA28
C                                                                            TLINEA29
       ENTRY TEMP                                                            TLINEA30
       H = R - EARTHR                                                        TLINEA31
       T = TGND + A * H                                                      TLINEA32
      CALL CLEAR(PTT,4)                                                      TLINEA33
      PTR=A                                                                  TLINEA34
C                                                                            TLINEA35
      CALL PTEMP                                                             TLINEA36
       RETURN                                                                TLINEA37
       END                                                                   TLINEA38
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      SUBROUTINE TTANH5                                                 TTANH5 9
C     TEMPERATURE PROFILE REPRESENTED BY A SEQUENCE OF LINEAR SEGMENTS  TTANH510
C     SMOOTHLY JOINED BY HYPERBOLIC FUNCTIONS. PARAMETERS ARE INPUT     TTANH511
C     AS TABULAR DATA WITH SLOPES COMPUTED FROM TEMPERATURE DATA.       TTANH512
C     REFERENCE TEMPERATURE T0 IS READ FROM TABULAR DATA.               TTANH513
      DIMENSION C(20), TM(19), Z(19), DL(19)                            TTANH514
C     COMMON DECK "RKAM" INSERTED HERE                                  RKAMCOM2
      REAL KR,KTH,KPH                                                   RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)       RKAMCOM5
C     COMMON DECK "TT" INSERTED HERE                                    CTT    2
      REAL MODT                                                         CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                            CTT    5
C     COMMON DECK "WW" INSERTED HERE                                    CWW    2
      PARAMETER (NWARSZ=1000)                                           CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         CWW2   6
     8 (RCVRH,W(20)),                                                   CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))        CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),        CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))              CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                   CWW2  16
      REAL MMODEL,MFORM,MID                                             CWW3   2
C                                                                       CWW3   3
C     WIND          100-124                                           CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)           CWW3   5
C                                                                       CWW3   6
C     DELTA WIND          125-149                                       CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)        CWW3   8
C                                                                       CWW3   9
C     SOUND SPEED 150-174                                               CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)           CWW3  11
      EQUIVALENCE (W(153),REFC)                                         CWW3  12
C                                                                       CWW3  13
C     DELTA SOUND SPEED 175-199                                         CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)        CWW3  15
C                                                                       CWW3  16
C     TEMPERATURE    200-224                                            CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)           CWW3  18
C                                                                       CWW3  19
C     DELTA TEMPERATURE    225-249                                      CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)        CWW3  21
C                                                                       CWW3  22
C     MOLECULAR   250-274                                               CWW3  23
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      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                CWW3  24
C                                                                            CWW3  25
C     RECEIVER HEIGHT   275-299                                              CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                CWW3  27
C                                                                            CWW3  28
C     TOPOGRAPHY   300-324                                                   CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)                CWW3  30
C                                                                            CWW3  31
C     DELTA TOPOGRAPHY   325-349                                             CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)             CWW3  33
C                                                                            CWW3  34
C     UPPER SURFACE TOPOGRAPHY   350-374                                     CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)                CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                   CWW3  37
C                                                                            CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                            CWW3  39
C     ABSORPTION         500-524                                             CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)                CWW3  41
C                                                                            CWW3  42
C     DELTA ABSORPTION         525-549                                       CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)             CWW3  44
C                                                                            CWW3  45
C     PRESSURE         550-574                                               CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)                CWW3  47
C                                                                            CWW3  48
C     DELTA PRESSURE         575-599                                         CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)             CWW3  50
C                                                                            CWW3  51
C     COMMON DECK "B5" INSERTED HERE                                         CB5    2
      INTEGER TMX,TNTBL,TITBL,TFRMTBL,IDST(10)                               CB5    4
      COMMON/B5/TMX,TNTBL(10),TITBL(10),TFRMTBL(10),TGP(262)                 CB5    5
      EQUIVALENCE (TGP,IDST),(ANT,TGP(11))                                   CB5    6
      EQUIVALENCE                (Z0,TGP(12)),(TM,TGP(33))                   TTANH519
      EQUIVALENCE (Z,TGP(13)),(C,TGP(32)),(DL,TGP(53))                       TTANH520
C                                                                            TTANH521
      DATA RECOGT,N/7.0,0/                                                   TTANH522
      DATA ANT/0.0/                                                          TNH5BL 2
      DATA TMX/2/                                                            TNH5BL 3
      DATA TNTBL/1,11,72,7*0/                                                TNH5BL 4
      DATA TITBL/1,20,8*0/                                                   TNH5BL 5
      DATA TFRMTBL/1,2,8*0/                                                  TNH5BL 6
C                                                                            TTANH525
      COSH (X) = (EXP (X) + 1. / (EXP (X))) / 2.                             TTANH526
C                                                                            TTANH527
      ENTRY ITEMP                                                            TTANH528
C                                                                            TTANH529
      CALL IPTEMP                                                            TTANH530
C                                                                            TTANH531
C     IF HAD PREVIOUS CALL BUT NOTHING THIS TIME, EXIT NOW                   TTANH532
C     RETAINING PREVIOUS TABULAR DATA COUNT                                  TTANH533
      IF(N.GT.0 .AND. ANT.EQ.0.0) RETURN                                     TTANH534
C                                                                            TTANH535
      IF(RECOGT .NE. TMODEL)                                                 TTANH536
     1    CALL RERROR('TEMP    ','WRNG MODEL',RECOGT)                        TTANH537
C                                                                            TTANH538
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      MODT(1)=7HTTANH5                                                  TTANH539
      MODT(2)=TID                                                       TTANH540
C                                                                       TTANH541
      N=(ANT+1)/3 - 2                                                   TTANH542
C                                                                       TTANH543
      IF(N.LE.0)                                                        TTANH544
     1    CALL RERROR('TTANH5','BAD N VALUE',FLOAT(N))                 TTANH545
C                                                                       TTANH546
      ANT=0.0                                                           TTANH547
C                                                                       TTANH548
C                                                                       TTANH549
C     CONVERT 'T' ARRAY INPUT(OVERLAYS 'C' ARRAY) TO 'C' ARRAY          TTANH550
C                                                                       TTANH551
      T0=C(1)                                                           TTANH552
      TIM1=T0                                                           TTANH553
      ZIM1=0.0                                                          TTANH554
      NP1=N+1                                                           TTANH555
      DO 10 I=1,NP1                                                     TTANH556
         TI=TM(I)                                                       TTANH557
         ZI=Z(I)                                                        TTANH558
         C(I)=(TI-TIM1)/(ZI-ZIM1)                                       TTANH559
         TIM1=TI                                                        TTANH560
10       ZIM1=ZI                                                        TTANH561
C                                                                       TTANH562
C                                                                       TTANH563
      RETURN                                                            TTANH564
C                                                                       TTANH565
      ENTRY TEMP                                                        TTANH566
      H = R - EARTHR                                                    TTANH567
      SUM = 0.                                                          TTANH568
C                                                                       TTANH569
C     LOOP TO SUM OVER ALL COEFFICIENTS                                 TTANH570
C     USE SPECIAL FUNCTION 'ALCOSH' WHICH ALLOWS FOR LARGE ARGUMENTS.   TTANH571
      DO 1 I = 1, N                                                     TTANH572
    1 SUM = SUM + DL(I) * (C(I + 1) - C(I)) / 2. *(ALCOSH((H - Z        TTANH573
     1(I)) / DL(I)) - ALCOSH((Z(I)-Z0) / DL(I)))                        TTANH574
      T = T0 + SUM + (C(1) + C(N + 1)) * (H - Z0) * 0.5                 TTANH575
      SUM = 0.                                                          TTANH576
      DO 2 I = 1, N                                                     TTANH577
    2 SUM = SUM + (C(I + 1) - C(I)) / 2. * (1. + TANH ((H - Z(I)) /DL   TTANH578
     1 (I)))                                                            TTANH579
      PTT=0.0                                                           TTANH580
      PTR = C(1) + SUM                                                  TTANH581
      PTTH=0.0                                                          TTANH582
      PTPH=0.0                                                          TTANH583
C                                                                       TTANH584
C                                                                       TTANH583
      CALL PTEMP                                                        TTANH584
      RETURN                                                            TTANH585
      END                                                               TTANH586
```

```
      SUBROUTINE TTABLE                                                 TTABLE 8
C     TABULAR TEMPERATURE PROFILE THAT MAKES A CUBIC INTERPOLATION      TTABLE 9
```

```
C      BETWEEN POINTS TO INSURE A CONTINUOUS TERMPERATURE GRADIENT      TTABLE10
       DIMENSION HPC(250),FN2C(250),ALPHA(250),TTBETA(250),GAMM(250),   TTABLE11
      1 DELTA(250),SLOPE(250),MAT(4,5)                                  TTABLE12
       REAL MAT                                                         TTABLE13
C      COMMON DECK "CONST" INSERTED HERE                                CCONST 2
       COMMON/PCONST/CREF,RGAS,GAMMA                                    CCONST 4
       COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                        CCONST 5
C      COMMON DECK "RKAM" INSERTED HERE                                 RKAMCOM2
       REAL KR,KTH,KPH                                                  RKAMCOM4
       COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)      RKAMCOM5
C      COMMON DECK "TT" INSERTED HERE                                   CTT    2
       REAL MODT                                                        CTT    4
       COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                           CTT    5
C      COMMON DECK "WW" INSERTED HERE                                   CWW    2
       PARAMETER (NWARSZ=1000)                                          CWW1   3
       COMMON/WW/ID(10),MAXW,W(NWARSZ)                                  CWW1   4
       REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                               CWW2   2
       EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),   CWW2   3
      1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),     CWW2   4
      2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),         CWW2   5
      3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),        CWW2   6
      8 (RCVRH,W(20)),                                                  CWW2   7
      4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
      5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                     CWW2   9
      6 (HMIN,W(27)),(RGMAX,W(28)),                                     CWW2  10
      8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                    CWW2  11
      6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),      CWW2  12
      7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))       CWW2  13
      9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),       CWW2  14
      1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))             CWW2  15
      2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                  CWW2  16
       REAL MMODEL,MFORM,MID                                            CWW3   2
C                                                                       CWW3   3
C      WIND          100-124                                           CWW3   4
       EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)          CWW3   5
C                                                                       CWW3   6
C      DELTA WIND          125-149                                      CWW3   7
       EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)       CWW3   8
C                                                                       CWW3   9
C      SOUND SPEED 150-174                                              CWW3  10
       EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)          CWW3  11
       EQUIVALENCE (W(153),REFC)                                        CWW3  12
C                                                                       CWW3  13
C      DELTA SOUND SPEED 175-199                                        CWW3  14
       EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)       CWW3  15
C                                                                       CWW3  16
C      TEMPERATURE     200-224                                          CWW3  17
       EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)          CWW3  18
C                                                                       CWW3  19
C      DELTA TEMPERATURE     225-249                                    CWW3  20
       EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)       CWW3  21
C                                                                       CWW3  22
C      MOLECULAR    250-274                                             CWW3  23
       EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)          CWW3  24
C                                                                       CWW3  25
```

```
C       RECEIVER HEIGHT   275-299                                                CWW3   26
        EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                 CWW3   27
                                                                                CWW3   28
C                                                                               CWW3   29
C       TOPOGRAPHY   300-324                                                    CWW3   30
        EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)                 CWW3   31
C                                                                               CWW3   32
C       DELTA TOPOGRAPHY   325-349                                              CWW3   33
        EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)              CWW3   34
C                                                                               CWW3   35
C       UPPER SURFACE TOPOGRAPHY   350-374                                      CWW3   36
        EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)                 CWW3   37
C       PLOT ENHANCEMENTS CONTROL PARAMETERS                                    CWW3   38
C                                                                               CWW3   39
        EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                             CWW3   40
C       ABSORPTION         500-524                                              CWW3   41
        EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)                 CWW3   42
C                                                                               CWW3   43
C       DELTA ABSORPTION         525-549                                        CWW3   44
        EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)              CWW3   45
C                                                                               CWW3   46
C       PRESSURE         550-574                                                CWW3   47
        EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)                 CWW3   48
C                                                                               CWW3   49
C       DELTA PRESSURE         575-599                                          CWW3   50
        EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)              CWW3   51
C                                                                               CB5     2
C       COMMON DECK "B5" INSERTED HERE                                          CB5     4
        INTEGER TMX,TNTBL,TITBL,TFRMTBL,IDST(10)                                CB5     5
        COMMON/B5/TMX,TNTBL(10),TITBL(10),TFRMTBL(10),TGP(262)                  CB5     6
        EQUIVALENCE (TGP,IDST),(ANT,TGP(11))                                    TTABLE19
        EQUIVALENCE (AN,TGP(11)),(HPC,TGP(12)),(FN2C,TGP(262))                  TTABLE20
C                                                                               TTABLE21
        DATA RECOGT,NOC/6.0,0/                                                  TTLEBL  2
        DATA ANT/0.0/                                                           TTLEBL  3
        DATA TMX/2/                                                             TTLEBL  4
        DATA TNTBL/1,11,512,7*0/                                                TTLEBL  5
        DATA TITBL/1,250,8*0/                                                   TTLEBL  6
        DATA TFRMTBL/1,2,8*0/                                                   TTABLE24
C                                                                               TTABLE25
        ENTRY ITEMP                                                             TTABLE26
C                                                                               TTABLE27
C                                                                               TTABLE28
        CALL IPTEMP                                                             TTABLE29
C                                                                               TTABLE30
C       IF HAD PREVIOUS CALL BUT NOTHING THIS TIME, EXIT NOW                    TTABLE31
C       RETAINING PREVIOUS TABULAR DATA COUNT                                   TTABLE32
        IF(NOC.GT.0 .AND. ANT.LE.0.0) RETURN                                    TTABLE33
C                                                                               TTABLE34
        IF(RECOGT.NE.TMODEL)                                                    TTABLE35
     1    CALL RERROR('TEMP    ','WRNG MODEL',RECOGT)                           TTABLE36
C                                                                               TTABLE37
        NOC=ANT/2                                                               TTABLE38
        IF(ANT.NE.2*NOC .OR. NOC.LE.1)                                          TTABLE39
     1     CALL RERROR('TTABLE','BAD NUMBER',ANT)                               TTABLE40
        ANT=0.0
```

```
C
      MODT(1)=6HTTABLE                                                  TTABLE41
      MODT(2)=TID                                                       TTABLE42
C                                                                       TTABLE43
C                                                                       TTABLE44
                                                                        TTABLE45
      SLOPE(1)=(FN2C(2)-FN2C(1))/(HPC(2)-HPC(1))                        TTABLE46
      SLOPE(NOC)=0.                                                     TTABLE47
      NMAX=1                                                            TTABLE48
      DO 6 I=2,NOC                                                      TTABLE49
      IF (FN2C(I).GT.FN2C(NMAX)) NMAX=I                                 TTABLE50
      IF (I.EQ.NOC) GO TO 4                                             TTABLE51
      DO 3 J=1,3                                                        TTABLE52
      M=I+J-2                                                           TTABLE53
      MAT(J,1)=1.                                                       TTABLE54
      MAT(J,2)=HPC(M)                                                   TTABLE55
      MAT(J,3)=HPC(M)**2                                                TTABLE56
    3 MAT(J,4)=FN2C(M)                                                  TTABLE57
      CALL GAUSEL (MAT,4,3,4,NRANK)                                     TTABLE58
      IF (NRANK.LT.3) GO TO 60                                          TTABLE59
      SLOPE(I)=MAT(2,4)+2.*MAT(3,4)*HPC(I)                              TTABLE60
    4 DO 5 J=1,2                                                        TTABLE61
      M=I+J-2                                                           TTABLE62
      MAT(J,1)=1.                                                       TTABLE63
      MAT(J,2)=HPC(M)                                                   TTABLE64
      MAT(J,3)=HPC(M)**2                                                TTABLE65
      MAT(J,4)=HPC(M)**3                                                TTABLE66
      MAT(J,5)=FN2C(M)                                                  TTABLE67
      L=J+2                                                             TTABLE68
      MAT(L,1)=0.                                                       TTABLE69
      MAT(L,2)=1.                                                       TTABLE70
      MAT(L,3)=2.*HPC(M)                                                TTABLE71
      MAT(L,4)=3.*HPC(M)**2                                             TTABLE72
    5 MAT(L,5)=SLOPE(M)                                                 TTABLE73
      CALL GAUSEL (MAT,4,4,5,NRANK)                                     TTABLE74
      IF (NRANK.LT.4) GO TO 60                                          TTABLE75
      ALPHA(I)=MAT(1,5)                                                 TTABLE76
      TTBETA(I)=MAT(2,5)                                                TTABLE77
      GAMM(I)=MAT(3,5)                                                  TTABLE78
    6 DELTA(I)=MAT(4,5)                                                 TTABLE79
      HMAX=HPC(NMAX)                                                    TTABLE80
      NH=2                                                              TTABLE81
C                                                                       TTABLE82
C                                                                       TTABLE83
      RETURN                                                            TTABLE84
C                                                                       TTABLE85
   60 PRINT 6000, I,HPC(I)                                              TTABLE86
 6000 FORMAT(' THE',I4,'TH POINT IN THE TEMPERATURE PROFILE HAS'        TTABLE87
     1,' THE HEIGHT',F8.2,' KM, WHICH IS THE SAME AS ANOTHER POINT.')   TTABLE88
      CALL EXIT                                                         TTABLE89
C                                                                       TTABLE90
      ENTRY TEMP                                                        TTABLE91
C                                                                       TTABLE92
C                                                                       TTABLE93
      IF(NOC.LE.0)                                                      TTABLE94
     1    CALL RERROR('TTABLE','BAD N VALUE',FLOAT(NOC))                TTABLE95
C
```

```
      H=R-EARTHR                                                        TTABLE96
      PTT=0.0                                                           TTABLE97
      PTR=0.0                                                           TTABLE98
      PTTH=0.0                                                          TTABLE99
      PTPH=0.0                                                          TTABL100
      IF (H.GE.HPC(1)) GO TO 12                                         TTABL101
   11 NH=2                                                              TTABL102
      T=FN2C(1)+SLOPE(1)*(H-HPC(1))                                     TTABL103
      PTR=SLOPE(1)                                                      TTABL104
      RETURN                                                            TTABL105
   12 IF (H.GE.HPC(NOC)) GO TO 18                                       TTABL106
      NSTEP=1                                                           TTABL107
      IF (H.LT.HPC(NH-1)) NSTEP=-1                                      TTABL108
   15 IF (HPC(NH-1).LE.H.AND.H.LT.HPC(NH)) GO TO 16                     TTABL109
      NH=NH+NSTEP                                                       TTABL110
      GO TO 15                                                          TTABL111
   16 T=(ALPHA(NH)+H*(TTBETA(NH)+H*(GAMM(NH)+H*DELTA(NH))))             TTABL112
      PTR=(TTBETA(NH)+H*(2.*GAMM(NH)+H*3.*DELTA(NH)))                   TTABL113
      RETURN                                                            TTABL114
   18 T=FN2C(NOC)                                                       TTABL115
C                                                                       TTABL116
      CALL PTEMP                                                        TTABL117
      RETURN                                                            TTABL118
         END                                                            TTABL119
```

```
      SUBROUTINE NTEMP                                                  NTEMP  9
C     DO-NOTHING TEMPERATURE MODEL                                      NTEMP 10
C     COMMON DECK "TT" INSERTED HERE                                    CTT    2
      REAL MODT                                                         CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                            CTT    5
C     COMMON DECK "WW" INSERTED HERE                                    CWW    2
      PARAMETER (NWARSZ=1000)                                           CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         CWW2   6
     8 (RCVRH,W(20)),                                                   CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))        CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),        CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))              CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                   CWW2  16
      REAL MMODEL,MFORM,MID                                             CWW3   2
C                                                                       CWW3   3
C     WIND        100-124                                             CWW3   4
```

```
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)
C
C     DELTA WIND          125-149
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)
C
C     SOUND SPEED 150-174
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)
      EQUIVALENCE (W(153),REFC)
C
C     DELTA SOUND SPEED 175-199
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)
C
C     TEMPERATURE     200-224
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)
C
C     DELTA TEMPERATURE     225-249
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)
C
C     MOLECULAR   250-274
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)
C
C     RECEIVER HEIGHT   275-299
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)
C
C     TOPOGRAPHY    300-324
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)
C
C     DELTA TOPOGRAPHY    325-349
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)
C
C     UPPER SURFACE TOPOGRAPHY    350-374
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)
C     PLOT ENHANCEMENTS CONTROL PARAMETERS
C
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)
C     ABSORPTION          500-524
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)
C
C     DELTA ABSORPTION          525-549
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)
C
C     PRESSURE          550-574
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)
C
C     DELTA PRESSURE          575-599
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)
C
C     COMMON DECK "B5" INSERTED HERE
      INTEGER TMX,TNTBL,TITBL,TFRMTBL,IDST(10)
      COMMON/B5/TMX,TNTBL(10),TITBL(10),TFRMTBL(10),TGP(262)
      EQUIVALENCE (TGP,IDST),(ANT,TGP(11))
C
      DATA RECOGT/0.0/
      DATA TMX/1/
      DATA TNTBL/1,11,8*0/
```

```
CWW3    5
CWW3    6
CWW3    7
CWW3    8
CWW3    9
CWW3   10
CWW3   11
CWW3   12
CWW3   13
CWW3   14
CWW3   15
CWW3   16
CWW3   17
CWW3   18
CWW3   19
CWW3   20
CWW3   21
CWW3   22
CWW3   23
CWW3   24
CWW3   25
CWW3   26
CWW3   27
CWW3   28
CWW3   29
CWW3   30
CWW3   31
CWW3   32
CWW3   33
CWW3   34
CWW3   35
CWW3   36
CWW3   37
CWW3   38
CWW3   39
CWW3   40
CWW3   41
CWW3   42
CWW3   43
CWW3   44
CWW3   45
CWW3   46
CWW3   47
CWW3   48
CWW3   49
CWW3   50
CWW3   51
CB5     2
CB5     4
CB5     5
CB5     6
NTEMP  14
NTEMP  15
NMPBL   2
NMPBL   3
```

```
      DATA TITBL/1,9*0/                                                  NMPBL  4
      DATA TFRMTBL/1,9*0/                                                NMPBL  5
C                                                                        NTEMP 18
      ENTRY ITEMP                                                        NTEMP 19
      IF(RECOGT .NE. TMODEL)                                             NTEMP 20
     1    CALL RERROR('TEMP  ','WRNG MODEL',RECOGT)                       NTEMP 21
C                                                                        NTEMP 22
      MODT(1)=5HNTEMP                                                    NTEMP 23
      MODT(2)=DTID                                                       NTEMP 24
      RETURN                                                             NTEMP 25
C                                                                        NTEMP 26
      ENTRY TEMP                                                         NTEMP 27
      RETURN                                                             NTEMP 28
      END                                                                NTEMP 29
```

```
      SUBROUTINE TBLOB2                                                  TBLOB2 8
C     TEMPERATURE PERTURBATION MODEL                                     TBLOB2 9
C     MULTIPLICATIVE PERTURBATION WITH EXPONENTIALLY DECAYING            TBLOB210
C     EFFECT IN ALL THREE DIRECTIONS. GIVE LATITUDE                      TBLOB211
C     INSTEAD OF CO-LATITUDE.                                            TBLOB212
C     COMMON DECK "CONST" INSERTED HERE                                  CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                      CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                          CCONST 5
C     COMMON DECK "RKAM" INSERTED HERE                                   RKAMCOM2
      REAL KR,KTH,KPH                                                    RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)        RKAMCOM5
C     COMMON DECK "B6" INSERTED HERE                                     CB6    2
      INTEGER DTMX,DTNTBL,DTITBL,DTFRMTB,IDSDT(10)                       CB6    4
      COMMON/B6/DTMX,DTNTBL(10),DTITBL(10),DTFRMTB(10),DTGP(10)          CB6    5
      EQUIVALENCE (DTGP,IDSDT)                                           CB6    6
C                                                                        TBLOB216
C     COMMON DECK "TT" INSERTED HERE                                     CTT    2
      REAL MODT                                                          CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                             CTT    5
C     COMMON DECK "WW" INSERTED HERE                                     CWW    2
      PARAMETER (NWARSZ=1000)                                            CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                    CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                 CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),     CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),       CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),           CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),          CWW2   6
     8 (RCVRH,W(20)),                                                    CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                       CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                       CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                      CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),        CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))         CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),         CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))               CWW2  15
```

```
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                    CWW2  16
      REAL MMODEL,MFORM,MID                                              CWW3   2
C                                                                        CWW3   3
C     WIND          100-124                                            CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)            CWW3   5
C                                                                        CWW3   6
C     DELTA WIND          125-149                                        CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)         CWW3   8
C                                                                        CWW3   9
C     SOUND SPEED 150-174                                                CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)            CWW3  11
      EQUIVALENCE (W(153),REFC)                                          CWW3  12
C                                                                        CWW3  13
C     DELTA SOUND SPEED 175-199                                          CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)         CWW3  15
C                                                                        CWW3  16
C     TEMPERATURE     200-224                                            CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)            CWW3  18
C                                                                        CWW3  19
C     DELTA TEMPERATURE     225-249                                      CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)         CWW3  21
C                                                                        CWW3  22
C     MOLECULAR   250-274                                                CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)            CWW3  24
C                                                                        CWW3  25
C     RECEIVER HEIGHT   275-299                                          CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)            CWW3  27
C                                                                        CWW3  28
C     TOPOGRAPHY    300-324                                              CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)            CWW3  30
C                                                                        CWW3  31
C     DELTA TOPOGRAPHY    325-349                                        CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)         CWW3  33
C                                                                        CWW3  34
C     UPPER SURFACE TOPOGRAPHY    350-374                                CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)            CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                               CWW3  37
C                                                                        CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                        CWW3  39
C     ABSORPTION          500-524                                        CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)            CWW3  41
C                                                                        CWW3  42
C     DELTA ABSORPTION          525-549                                  CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)         CWW3  44
C                                                                        CWW3  45
C     PRESSURE          550-574                                          CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)            CWW3  47
C                                                                        CWW3  48
C     DELTA PRESSURE          575-599                                    CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)         CWW3  50
C                                                                        CWW3  51
C                                                                       TBLOB219
      EQUIVALENCE (C0,W(228)), (Z0,W(229)),(TBTH0,W(230))               TBLOB220
      EQUIVALENCE (PH0,W(231)),(WZ,W(232)),(WTH,W(233)),(WPH,W(234))    TBLOB221
C                                                                       TBLOB222
```

```
      DATA RECOGDT/2.0/                                                  TBLOB223
      DATA DTMX/1/                                                       TOB2BL 2
      DATA DTNTBL/1,11,8*0/                                              TOB2BL 3
      DATA DTITBL/1,9*0/                                                 TOB2BL 4
      DATA DTFRMTB/1,9*0/                                                TOB2BL 5
C                                                                        TBLOB226
      ENTRY IPTEMP                                                       TBLOB227
      IF(RECOGDT .NE. DTMODEL)                                           TBLOB228
     1    CALL RERROR('DTEMP   ','WRNG MODEL',RECOGDT)                  TBLOB229
C                                                                        TBLOB230
C                                                                        TBLOB231
      MODT(3)=6HTBLOB2                                                   TBLOB232
      MODT(4)=DTID                                                       TBLOB233
C                                                                        TBLOB234
C                                                                        TBLOB235
      FWZ=0.0                                                            TBLOB236
      FWTH=0.0                                                           TBLOB237
      FWPH=0.0                                                           TBLOB238
      TH0= PID2-TBTH0                                                    TBLOB239
      IF(WZ.NE.0.0) FWZ=2.0/WZ/WZ                                        TBLOB240
      IF(WTH.NE.0.0) FWTH=2.0/WTH/WTH                                    TBLOB241
      IF(WPH.NE.0.0) FWPH=2.0/WPH/WPH                                    TBLOB242
      RETURN                                                             TBLOB243
C                                                                        TBLOB244
      ENTRY PTEMP                                                        TBLOB245
C                                                                        TBLOB246
      IF(C0.EQ.0.0) RETURN                                               TBLOB247
C                                                                        TBLOB248
      DZ=R-EARTHR-Z0                                                     TBLOB249
      DTH=TH-TH0                                                         TBLOB250
      DPH=PH-PH0                                                         TBLOB251
      DEXPO=0.0                                                          TBLOB252
      EXPO=-0.5*(DZ*DZ*FWZ+DTH*DTH*FWTH+DPH*DPH*FWPH)                    TBLOB253
      IF(EXPO .GT. -200.0) DEXPO=C0*EXP(EXPO)                            TBLOB254
      DEL=1.0+DEXPO                                                      TBLOB255
C                                                                        TBLOB256
      PTR=PTR*DEL-T*DEXPO*FWZ*DZ                                         TBLOB257
      PTTH=PTTH*DEL-T*DEXPO*FWTH*DTH                                     TBLOB258
      PTPH=PTPH*DEL-T*DEXPO*FWPH*DPH                                     TBLOB259
      T=T*DEL                                                            TBLOB260
      RETURN                                                             TBLOB261
      END
```

```
      SUBROUTINE NPTEMP                                                  NPTEMP 8
C     DO-NOTHING TEMPERATURE PERTURBATION MODEL                          NPTEMP 9
C     COMMON DECK "TT" INSERTED HERE                                     CTT    2
      REAL MODT                                                          CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                             CTT    5
C     COMMON DECK "WW" INSERTED HERE                                     CWW    2
      PARAMETER (NWARSZ=1000)                                            CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                    CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                 CWW2   2
```

```
 EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),     CWW2    3
1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),       CWW2    4
2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),           CWW2    5
3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),          CWW2    6
8 (RCVRH,W(20)),                                                    CWW2    7
4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2    8
5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                       CWW2    9
6 (HMIN,W(27)),(RGMAX,W(28)),                                       CWW2   10
8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                      CWW2   11
6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),        CWW2   12
7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))         CWW2   13
9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),         CWW2   14
1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))               CWW2   15
2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                    CWW2   16
      REAL MMODEL,MFORM,MID                                         CWW3    2
C                                                                   CWW3    3
C     WIND         100-124                                          CWW3    4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)       CWW3    5
C                                                                   CWW3    6
C     DELTA WIND         125-149                                    CWW3    7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)    CWW3    8
C                                                                   CWW3    9
C     SOUND SPEED 150-174                                           CWW3   10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)       CWW3   11
      EQUIVALENCE (W(153),REFC)                                     CWW3   12
C                                                                   CWW3   13
C     DELTA SOUND SPEED 175-199                                     CWW3   14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)    CWW3   15
C                                                                   CWW3   16
C     TEMPERATURE    200-224                                        CWW3   17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)       CWW3   18
C                                                                   CWW3   19
C     DELTA TEMPERATURE    225-249                                  CWW3   20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)    CWW3   21
C                                                                   CWW3   22
C     MOLECULAR   250-274                                           CWW3   23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)       CWW3   24
C                                                                   CWW3   25
C     RECEIVER HEIGHT   275-299                                     CWW3   26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)       CWW3   27
C                                                                   CWW3   28
C     TOPOGRAPHY    300-324                                         CWW3   29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)       CWW3   30
C                                                                   CWW3   31
C     DELTA TOPOGRAPHY    325-349                                   CWW3   32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)    CWW3   33
C                                                                   CWW3   34
C     UPPER SURFACE TOPOGRAPHY    350-374                           CWW3   35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)       CWW3   36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                          CWW3   37
C                                                                   CWW3   38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                   CWW3   39
C     ABSORPTION          500-524                                   CWW3   40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)       CWW3   41
C                                                                   CWW3   42
```

```
C       DELTA ABSORPTION          525-549                                       CWW3   43
        EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)              CWW3   44
C                                                                               CWW3   45
C       PRESSURE          550-574                                               CWW3   46
        EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)                 CWW3   47
C                                                                               CWW3   48
C       DELTA PRESSURE          575-599                                         CWW3   49
        EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)              CWW3   50
C                                                                               CWW3   51
C                                                                               NPTEMP12
C       COMMON DECK "B6" INSERTED HERE                                          CB6     2
        INTEGER DTMX,DTNTBL,DTITBL,DTFRMTB,IDSDT(10)                            CB6     4
        COMMON/B6/DTMX,DTNTBL(10),DTITBL(10),DTFRMTB(10),DTGP(10)               CB6     5
        EQUIVALENCE (DTGP,IDSDT)                                                CB6     6
C                                                                               NPTEMP14
        DATA DTMX/1/                                                            NEMPBL  2
        DATA DTNTBL/1,11,8*0/                                                   NEMPBL  3
        DATA DTITBL/1,9*0/                                                      NEMPBL  4
        DATA DTFRMTB/1,9*0/                                                     NEMPBL  5
C                                                                               NPTEMP17
        DATA RECOGDT/0.0/                                                       NPTEMP18
C                                                                               NPTEMP19
        ENTRY IPTEMP                                                            NPTEMP20
        IF(RECOGDT .NE. DTMODEL)                                                NPTEMP21
     1     CALL RERROR('DTEMP   ','WRNG MODEL',RECOGDT)                         NPTEMP22
C                                                                               NPTEMP23
        MODT(3)=6HNPTEMP                                                        NPTEMP24
        MODT(4)=DTID                                                            NPTEMP25
        RETURN                                                                  NPTEMP26
C                                                                               NPTEMP27
        ENTRY PTEMP                                                             NPTEMP28
        RETURN                                                                  NPTEMP29
        END                                                                     NPTEMP30
```

```
        SUBROUTINE MCONST                                                       MCONST  8
C       CONSTANT MOLECULAR WEIGHT MODEL                                         MCONST  9
C       COMMON DECK "WW" INSERTED HERE                                          CWW     2
        PARAMETER (NWARSZ=1000)                                                 CWW1    3
        COMMON/WW/ID(10),MAXW,W(NWARSZ)                                         CWW1    4
        REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                      CWW2    2
        EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),          CWW2    3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),              CWW2    4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                  CWW2    5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),                 CWW2    6
                                                                               CWW2    7
     8 (RCVRH,W(20)),                                                          CWW2    8
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))       CWW2    9
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                             CWW2   10
     6 (HMIN,W(27)),(RGMAX,W(28)),                                             CWW2   11
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                            CWW2   12
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),              CWW2   13
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))               CWW2   14
```

```
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),      CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))            CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                 CWW2  16
      REAL MMODEL,MFORM,MID                                           CWW3   2
C                                                                     CWW3   3
C     WIND          100-124                                           CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)         CWW3   5
C                                                                     CWW3   6
C     DELTA WIND          125-149                                     CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)      CWW3   8
C                                                                     CWW3   9
C     SOUND SPEED 150-174                                             CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)         CWW3  11
      EQUIVALENCE (W(153),REFC)                                       CWW3  12
C                                                                     CWW3  13
C     DELTA SOUND SPEED 175-199                                       CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)      CWW3  15
C                                                                     CWW3  16
C     TEMPERATURE     200-224                                         CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)         CWW3  18
C                                                                     CWW3  19
C     DELTA TEMPERATURE     225-249                                   CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)      CWW3  21
C                                                                     CWW3  22
C     MOLECULAR   250-274                                             CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)         CWW3  24
C                                                                     CWW3  25
C     RECEIVER HEIGHT   275-299                                       CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)         CWW3  27
C                                                                     CWW3  28
C     TOPOGRAPHY    300-324                                           CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)         CWW3  30
C                                                                     CWW3  31
C     DELTA TOPOGRAPHY    325-349                                     CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)      CWW3  33
C                                                                     CWW3  34
C     UPPER SURFACE TOPOGRAPHY    350-374                             CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)         CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                            CWW3  37
C                                                                     CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                     CWW3  39
C     ABSORPTION          500-524                                     CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)         CWW3  41
C                                                                     CWW3  42
C     DELTA ABSORPTION          525-549                               CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)      CWW3  44
C                                                                     CWW3  45
C     PRESSURE          550-574                                       CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)         CWW3  47
C                                                                     CWW3  48
C     DELTA PRESSURE          575-599                                 CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)      CWW3  50
C                                                                     CWW3  51
C     COMMON DECK "MM" INSERTED HERE                                  CMM   2
      REAL M,MODM                                                     CMM   4
```

```
      COMMON/MM/MODM(4),M,PMT,PMR,PMTH,PMPH                                  CMM    5
      REAL  MLCNST                                                           MCONST12
      EQUIVALENCE (W(253),MLCNST)                                            MCONST13
C     COMMON DECK "B7" INSERTED HERE                                         CB7    2
      INTEGER MMX,MNTBL,MITBL,MFRMTBL,IDSM(10)                               CB7    4
      REAL MGP                                                               CB7    5
      COMMON/B7/MMX,MNTBL(10),MITBL(10),MFRMTBL(10),MGP(10)                  CB7    6
      EQUIVALENCE (MGP,IDSM)                                                 CB7    7
      DATA RECOGM/1.0/                                                       MCONST15
      DATA MMX/1/                                                            MNSTBL 2
      DATA MNTBL/1,11,8*0/                                                   MNSTBL 3
      DATA MITBL/1,9*0/                                                      MNSTBL 4
      DATA MFRMTBL/1,9*0/                                                    MNSTBL 5
C                                                                            MCONST18
      ENTRY IMOLWT                                                           MCONST19
C                                                                            MCONST20
      IF(RECOGM .NE. MMODEL)                                                 MCONST21
     1    CALL RERROR('IMOLWT ','WRNG MODEL',RECOGM)                         MCONST22
C                                                                            MCONST23
      MODM(1)=6HMCONST                                                       MCONST24
      MODM(2)=MID                                                            MCONST25
C                                                                            MCONST26
      RETURN                                                                 MCONST27
C                                                                            MCONST28
      ENTRY MOLWT                                                            MCONST29
      M=MLCNST                                                               MCONST30
      CALL CLEAR(PMT,4)                                                      MCONST31
      END                                                                    MCONST32
```

```
      SUBROUTINE GHORIZ                                                      GHORIZ 8
C     TERRAIN MODEL USING FIXED OFFSET TO EARTHR'S SURFACE                   GHORIZ 9
C     COMMON DECK "GG" INSERTED HERE                                         CGG    2
      REAL MODG                                                              CGG    4
      COMMON/GG/MODG(4)                                                      CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                       CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME                 CGG    7
C     COMMON DECK "WW" INSERTED HERE                                         CWW    2
      PARAMETER (NWARSZ=1000)                                                CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                        CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                     CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),         CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),           CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),               CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),              CWW2   6
     8 (RCVRH,W(20)),                                                        CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))     CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                           CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                           CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                          CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),            CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))             CWW2   13
```

```
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),          CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                     CWW2  16
      REAL MMODEL,MFORM,MID                                               CWW3   2
C                                                                         CWW3   3
C     WIND          100-124                                             CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)             CWW3   5
C                                                                         CWW3   6
C     DELTA WIND          125-149                                         CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)          CWW3   8
C                                                                         CWW3   9
C     SOUND SPEED 150-174                                                 CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)             CWW3  11
      EQUIVALENCE (W(153),REFC)                                           CWW3  12
C                                                                         CWW3  13
C     DELTA SOUND SPEED 175-199                                           CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)          CWW3  15
C                                                                         CWW3  16
C     TEMPERATURE     200-224                                             CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)             CWW3  18
C                                                                         CWW3  19
C     DELTA TEMPERATURE     225-249                                       CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)          CWW3  21
C                                                                         CWW3  22
C     MOLECULAR   250-274                                                 CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)             CWW3  24
C                                                                         CWW3  25
C     RECEIVER HEIGHT   275-299                                           CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)             CWW3  27
C                                                                         CWW3  28
C     TOPOGRAPHY    300-324                                               CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)             CWW3  30
C                                                                         CWW3  31
C     DELTA TOPOGRAPHY    325-349                                         CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)          CWW3  33
C                                                                         CWW3  34
C     UPPER SURFACE TOPOGRAPHY    350-374                                 CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)             CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                CWW3  37
C                                                                         CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                         CWW3  39
C     ABSORPTION          500-524                                         CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)             CWW3  41
C                                                                         CWW3  42
C     DELTA ABSORPTION          525-549                                   CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)          CWW3  44
C                                                                         CWW3  45
C     PRESSURE          550-574                                           CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)             CWW3  47
C                                                                         CWW3  48
C     DELTA PRESSURE          575-599                                     CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)          CWW3  50
C                                                                         CWW3  51
C     COMMON DECK "RKAM" INSERTED HERE                                    RKAMCOM2
      REAL KR,KTH,KPH                                                     RKAMCOM4
```

```
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)        RKAMCOM5
C                                                                        GHORIZ13
      EQUIVALENCE (W(303), Z0)                                           GHORIZ14
C                                                                        GHORIZ15
C     COMMON DECK "B9" INSERTED HERE                                     CB8    2
      INTEGER GMX,GNTBL,GITBL,GFRMTBL,IDSG(10)                           CB8    4
      COMMON/B9/GMX,GNTBL(10),GITBL(10),GFRMTBL(10),GGP(113)             CB8    5
      EQUIVALENCE (GGP,IDSG),(ANG,GGP(11))                               CB8    6
C                                                                        GHORIZ17
      DATA RECOGG/1.0/                                                   GHORIZ18
C                                                                        GHORIZ19
      DATA GMX/1/                                                        GRIZBL 2
      DATA GNTBL/1,11,8*0/                                               GRIZBL 3
      DATA GITBL/1,9*0/                                                  GRIZBL 4
      DATA GFRMTBL/1,9*0/                                                GRIZBL 5
C                                                                        GHORIZ22
      ENTRY ITOPOG                                                       GHORIZ23
      IF(RECOGG .NE. GMODEL)                                             GHORIZ24
     1    CALL RERROR('GHORIZ ','WRNG MODEL',RECOGG)                     GHORIZ25
      MODG(1)=6HGHORIZ                                                   GHORIZ26
      MODG(2)=GID                                                        GHORIZ27
      RETURN                                                             GHORIZ28
      ENTRY TOPOG                                                        GHORIZ29
      G=R-W(1)-Z0                                                        GHORIZ30
      PGR=1.0                                                            GHORIZ31
      CALL CLEAR(PGRR,8)                                                 GHORIZ32
      END                                                                GHORIZ33
```

```
      SUBROUTINE GLORENZ                                                 GLORENZ8
C     TERRAIN MODEL USING LORENZIAN SHAPED HORIZONTAL SURFACE LOCATED A  GLORENZ9
C     ARBITRARY GEOGRAPHICAL LOCATION.                                   GLOREN10
C                                                                        GLOREN11
C     COMMON DECK "CONST" INSERTED HERE                                  CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                      CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                          CCONST 5
C     COMMON DECK "B9" INSERTED HERE                                     CB8    2
      INTEGER GMX,GNTBL,GITBL,GFRMTBL,IDSG(10)                           CB8    4
      COMMON/B9/GMX,GNTBL(10),GITBL(10),GFRMTBL(10),GGP(113)             CB8    5
      EQUIVALENCE (GGP,IDSG),(ANG,GGP(11))                               CB8    6
C     COMMON DECK "RKAM" INSERTED HERE                                   RKAMCOM2
      REAL KR,KTH,KPH                                                    RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)        RKAMCOM5
C     COMMON DECK "GG" INSERTED HERE                                     CGG    2
      REAL MODG                                                          CGG    4
      COMMON/GG/MODG(4)                                                  CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                   CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME             CGG    7
C     COMMON DECK "B10" INSERTED HERE                                    CB9    2
      INTEGER DGMX,DGNTBL,DGITBL,DGFRMTB,IDSDG(10)                       CB9    4
      COMMON/B10/DGMX,DGNTBL(10),DGITBL(10),DGFRMTB(10),DGGP(10)         CB9    5
      EQUIVALENCE (DGGP,IDSDG)                                           CB9    6
```

```
C       COMMON DECK "WW" INSERTED HERE                                          CWW     2
        PARAMETER (NWARSZ=1000)                                                 CWW1    3
        COMMON/WW/ID(10),MAXW,W(NWARSZ)                                         CWW1    4
        REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                      CWW2    2
        EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),          CWW2    3
       1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),            CWW2    4
       2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                CWW2    5
       3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),               CWW2    6
       8 (RCVRH,W(20)),                                                         CWW2    7
       4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))      CWW2    8
       5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                            CWW2    9
       6 (HMIN,W(27)),(RGMAX,W(28)),                                            CWW2   10
       8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                           CWW2   11
       6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),             CWW2   12
       7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))              CWW2   13
       9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),              CWW2   14
       1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                    CWW2   15
       2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                         CWW2   16
        REAL MMODEL,MFORM,MID                                                   CWW3    2
C                                                                               CWW3    3
C       WIND          100-124                                                   CWW3    4
        EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)                 CWW3    5
C                                                                               CWW3    6
C       DELTA WIND          125-149                                             CWW3    7
        EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)              CWW3    8
C                                                                               CWW3    9
C       SOUND SPEED 150-174                                                     CWW3   10
        EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                 CWW3   11
        EQUIVALENCE (W(153),REFC)                                               CWW3   12
C                                                                               CWW3   13
C       DELTA SOUND SPEED 175-199                                               CWW3   14
        EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)              CWW3   15
C                                                                               CWW3   16
C       TEMPERATURE     200-224                                                 CWW3   17
        EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                 CWW3   18
C                                                                               CWW3   19
C       DELTA TEMPERATURE     225-249                                           CWW3   20
        EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)              CWW3   21
C                                                                               CWW3   22
C       MOLECULAR   250-274                                                     CWW3   23
        EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                 CWW3   24
C                                                                               CWW3   25
C       RECEIVER HEIGHT   275-299                                               CWW3   26
        EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                 CWW3   27
C                                                                               CWW3   28
C       TOPOGRAPHY    300-324                                                   CWW3   29
        EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)                 CWW3   30
C                                                                               CWW3   31
C       DELTA TOPOGRAPHY    325-349                                             CWW3   32
        EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)              CWW3   33
C                                                                               CWW3   34
C       UPPER SURFACE TOPOGRAPHY    350-374                                     CWW3   35
        EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)                 CWW3   36
C       PLOT ENHANCEMENTS CONTROL PARAMETERS                                    CWW3   37
C                                                                               CWW3   38
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      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                        CWW3  39
C     ABSORPTION          500-524                                        CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)            CWW3  41
C                                                                        CWW3  42
C     DELTA ABSORPTION          525-549                                  CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)         CWW3  44
C                                                                        CWW3  45
C     PRESSURE          550-574                                          CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)            CWW3  47
C                                                                        CWW3  48
C     DELTA PRESSURE          575-599                                    CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)         CWW3  50
C                                                                        CWW3  51
      EQUIVALENCE (GCZAMP,W(303))                                        GLOREN18
      EQUIVALENCE (GCLAMZ,W(304)) ,(GCTHDL,W(305))                       GLOREN19
      EQUIVALENCE (GCBASE,W(306))                                        GLOREN20
C                                                                        GLOREN21
      DATA RECOGG/4.0/                                                   GLOREN22
      DATA GMX/1/                                                        GRENZBL2
      DATA GNTBL/1,11,8*0/                                               GRENZBL3
      DATA GITBL/1,9*0/                                                  GRENZBL4
      DATA GFRMTBL/1,9*0/                                                GRENZBL5
C                                                                        GLOREN25
C                                                                        GLOREN26
      ENTRY ITOPOG                                                       GLOREN27
C                                                                        GLOREN28
      IF(RECOGG .NE. GMODEL)                                             GLOREN29
     1    CALL RERROR('GROUND ','WRNG MODEL',RECOGG)                     GLOREN30
      MODG(1)=7HGLORENZ                                                  GLOREN31
      MODG(2)=GID                                                        GLOREN32
C                                                                        GLOREN33
      GCTH0=PID2-GCLAMZ                                                  GLOREN34
      GCINV=1.0/GCTHDL                                                   GLOREN35
      CALL IPTOPOG                                                       GLOREN36
      RETURN                                                             GLOREN37
C                                                                        GLOREN38
      ENTRY TOPOG                                                        GLOREN39
C                                                                        GLOREN40
      CALL CLEAR(PGRTH,7)                                                GLOREN41
C                                                                        GLOREN42
      ETA=(TH-GCTH0)*GCINV                                               GLOREN43
      ETA2=ETA*ETA                                                       GLOREN44
      GBINOM=1.0/(1.0 + ETA2)                                            GLOREN45
      Z=GCZAMP*GBINOM                                                    GLOREN46
      G=R-EARTHR-Z-GCBASE                                                GLOREN47
C                                                                        GLOREN48
      PGR=1.0                                                            GLOREN49
      GBINOMB=GBINOM*GCINV                                               GLOREN50
      PGTH=2.0*Z*ETA*GBINOMB                                             GLOREN51
      PGTHTH=2.0*Z*GBINOMB*GBINOMB*(1.0-3.0*ETA2)                        GLOREN52
C                                                                        GLOREN53
      RETURN                                                             GLOREN54
      END                                                                GLOREN55
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      SUBROUTINE GTANH                                                  GTANH  8
C     TERRAIN PROFILE REPRESENTED BY A SEQUENCE OF LINEAR SEGMENTS      GTANH  9
C     SMOOTHLY JOINED BY HYPERBOLIC FUNCTIONS. PARAMETERS ARE INPUT     GTANH 10
C     AS TABULAR DATA WITH SLOPES COMPUTED FROM TERRAIN DATA.           GTANH 11
C     COMMON DECK "CONST" INSERTED HERE                                 CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                     CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                         CCONST 5
C     TERRAIN MODEL                                                     GTANH 13
      REAL C(49), LAM0,LMI,LMIM1,LM(49), DL(49),ALC(50)                 GTANH 14
C     COMMON DECK "RKAM" INSERTED HERE                                  RKAMCOM2
      REAL KR,KTH,KPH                                                   RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)       RKAMCOM5
C     COMMON DECK "GG" INSERTED HERE                                    CGG    2
      REAL MODG                                                         CGG    4
      COMMON/GG/MODG(4)                                                 CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                  CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME            CGG    7
C     COMMON DECK "B9" INSERTED HERE                                    CB8    2
      INTEGER GMX,GNTBL,GITBL,GFRMTBL,IDSG(10)                          CB8    4
      COMMON/B9/GMX,GNTBL(10),GITBL(10),GFRMTBL(10),GGP(113)            CB8    5
      EQUIVALENCE (GGP,IDSG),(ANG,GGP(11))                              CB8    6
C     COMMON DECK "WW" INSERTED HERE                                    CWW    2
      PARAMETER (NWARSZ=1000)                                           CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         CWW2   6
     8 (RCVRH,W(20)),                                                   CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))        CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),        CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))              CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                   CWW2  16
      REAL MMODEL,MFORM,MID                                             CWW3   2
C                                                                       CWW3   3
C     WIND          100-124                                           CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)           CWW3   5
C                                                                       CWW3   6
C     DELTA WIND          125-149                                       CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)        CWW3   8
C                                                                       CWW3   9
C     SOUND SPEED 150-174                                               CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)           CWW3  11
      EQUIVALENCE (W(153),REFC)                                         CWW3  12
C                                                                       CWW3  13
C     DELTA SOUND SPEED 175-199                                         CWW3  14
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      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)          CWW3  15
C                                                                         CWW3  16
C     TEMPERATURE    200-224                                              CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)             CWW3  18
C                                                                         CWW3  19
C     DELTA TEMPERATURE    225-249                                        CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)          CWW3  21
C                                                                         CWW3  22
C     MOLECULAR   250-274                                                 CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)             CWW3  24
C                                                                         CWW3  25
C     RECEIVER HEIGHT   275-299                                           CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)             CWW3  27
C                                                                         CWW3  28
C     TOPOGRAPHY   300-324                                                CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)             CWW3  30
C                                                                         CWW3  31
C     DELTA TOPOGRAPHY   325-349                                          CWW3  32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)          CWW3  33
C                                                                         CWW3  34
C     UPPER SURFACE TOPOGRAPHY   350-374                                  CWW3  35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)             CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                CWW3  37
C                                                                         CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                         CWW3  39
C     ABSORPTION         500-524                                          CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)             CWW3  41
C                                                                         CWW3  42
C     DELTA ABSORPTION         525-549                                    CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)          CWW3  44
C                                                                         CWW3  45
C     PRESSURE         550-574                                            CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)             CWW3  47
C                                                                         CWW3  48
C     DELTA PRESSURE         575-599                                      CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)          CWW3  50
C                                                                         CWW3  51
      EQUIVALENCE (LAM0,GGP(12)),(Z0,GGP(62)),(DL0,GGP(112))              GTANH 19
      EQUIVALENCE (LM,GGP(13)),(C,GGP(63)),(DL,GGP(113))                  GTANH 20
C                                                                         GTANH 21
      DATA RECOGG/3.0/                                                    GTANH 22
      DATA ANG/0.0/                                                       GNHBL  2
      DATA GMX/2/                                                         GNHBL  3
      DATA GNTBL/1,11,162,7*0/                                            GNHBL  4
      DATA GITBL/1,50,8*0/                                                GNHBL  5
      DATA GFRMTBL/1,2,8*0/                                               GNHBL  6
C                                                                         GTANH 25
      ENTRY ITOPOG                                                        GTANH 26
C                                                                         GTANH 27
      CALL IPTOPOG                                                        GTANH 28
C                                                                         GTANH 29
C     IF HAD PREVIOUS CALL BUT NOTHING THIS TIME, EXIT NOW                GTANH 30
C     RETAINING PREVIOUS TABULAR DATA COUNT                               GTANH 31
      IF(N.GT.0 .AND. ANG.EQ.0.0) RETURN                                  GTANH 32
C                                                                         GTANH 33
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      IF(RECOGG .NE. GMODEL)                                            GTANH 34
     1    CALL RERROR('TOPO    ','WRNG MODEL',RECOGG)                  GTANH 35
      MODG(1)=5HGTANH                                                   GTANH 36
      MODG(2)=GID                                                       GTANH 37
      N=ANG/3                                                           GTANH 38
      IF(ANG.NE.3*N.OR.N.LE.0)                                          GTANH 39
     1     CALL RERROR('GTANH','BAD NUMBER',ANG+2.0)                    GTANH 40
      N=N-2                                                             GTANH 41
      ANG=0.0                                                           GTANH 42
C                                                                       GTANH 43
C                                                                       GTANH 44
C     CONVERT 'Z' ARRAY INPUT(OVERLAYS 'C' ARRAY) TO 'C' ARRAY          GTANH 45
C                                                                       GTANH 46
      ZM1=Z0                                                            GTANH 47
      LAM0=PID2-LAM0                                                    GTANH 48
      LMIM1=LAM0                                                        GTANH 49
      NP1=N+1                                                           GTANH 50
      DO 10 I=1,NP1                                                     GTANH 51
         Z=C(I)                                                         GTANH 52
         LMI=PID2-LM(I)                                                 GTANH 53
         LM(I)=LMI                                                      GTANH 54
         ALC(I)=ALCOSH((LMI-LAM0) / DL(I))                              GTANH 55
         C(I)=(Z-ZM1)/(LMI-LMIM1)                                       GTANH 56
         ZM1=Z                                                          GTANH 57
10       LMIM1=LMI                                                      GTANH 58
C                                                                       GTANH 59
      RETURN                                                            GTANH 60
C                                                                       GTANH 61
      ENTRY TOPOG                                                       GTANH 62
C                                                                       GTANH 63
      IF(N.LE.0)                                                        GTANH 64
     1    CALL RERROR('GTANH','BAD N VALUE',FLOAT(N))                   GTANH 65
C                                                                       GTANH 66
      SUM = 0.                                                          GTANH 67
      DO 1 I = 1, N                                                     GTANH 68
    1 SUM = SUM + DL(I) * (C(I + 1) - C(I)) / 2. *(ALCOSH(((TH-LM       GTANH 69
     1(I)) / DL(I))) - ALC(I))                                          GTANH 70
      Z = Z0 - SUM + (C(1) + C(N + 1)) * (TH-LAM0) / 2.                 GTANH 71
      G=R-EARTHR-Z                                                      GTANH 72
      PGR=1.0                                                           GTANH 73
C                                                                       GTANH 74
      PGTH = C(1)                                                       GTANH 75
      DO 2 I = 1, N                                                     GTANH 76
    2 PGTH= PGTH+ (C(I + 1) - C(I)) / 2. * (1. + TANH ((LM(I)- TH) /DL  GTANH 77
     1 (I)))                                                            GTANH 78
      PGTH=-PGTH                                                        GTANH 79
      PGTHTH=0.0                                                        GTANH 80
      DO 3 I=1,N                                                        GTANH 81
3     PGTHTH=PGTHTH+                                                    GTANH 82
     1    (C(I+1)-C(I))/2.*(1.0-TANH((LM(I)-TH)/DL(I))**2)/DL(I)        GTANH 83
C                                                                       GTANH 84
      CALL PTOPOG                                                       GTANH 85
      RETURN                                                            GTANH 86
      END                                                               GTANH 87
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      SUBROUTINE NPTERR                                                 NPTERR 8
C     DO-NOTHING TERRAIN PERTURBATION MODEL                             NPTERR 9
C      COMMON DECK "GG" INSERTED HERE                                   CGG    2
      REAL MODG                                                         CGG    4
      COMMON/GG/MODG(4)                                                 CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                  CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME            CGG    7
C                                                                       NPTERR11
C      COMMON DECK "B10" INSERTED HERE                                  CB9    2
      INTEGER DGMX,DGNTBL,DGITBL,DGFRMTB,IDSDG(10)                      CB9    4
      COMMON/B10/DGMX,DGNTBL(10),DGITBL(10),DGFRMTB(10),DGGP(10)        CB9    5
      EQUIVALENCE (DGGP,IDSDG)                                          CB9    6
C                                                                       NPTERR13
      DATA DGMX/1/                                                      NERRBL 2
      DATA DGNTBL/1,11,8*0/                                             NERRBL 3
      DATA DGITBL/1,9*0/                                                NERRBL 4
      DATA DGFRMTB/1,9*0/                                               NERRBL 5
C                                                                       NPTERR16
      ENTRY IPTOPOG                                                     NPTERR17
C                                                                       NPTERR18
      MODG(3)=6HNPTERR                                                  NPTERR19
      ENTRY PTOPOG                                                      NPTERR20
      END                                                               NPTERR21
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      SUBROUTINE MUARDC                                                 MUARDC 8
C     ARDC BACKGROUND ABSORPTION FORMULA                                MUARDC 9
C                                                                       MUARDC10
C      COMMON DECK "WW" INSERTED HERE                                   CWW    2
      PARAMETER (NWARSZ=1000)                                           CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         CWW2   6
     8 (RCVRH,W(20)),                                                   CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))        CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),        CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))              CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                   CWW2  16
      REAL MMODEL,MFORM,MID                                             CWW3   2
C                                                                       CWW3   3
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C       WIND          100-124                                                  CWW3    4
        EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)                CWW3    5
C                                                                              CWW3    6
C       DELTA WIND          125-149                                            CWW3    7
        EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)             CWW3    8
C                                                                              CWW3    9
C       SOUND SPEED 150-174                                                    CWW3   10
        EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                CWW3   11
        EQUIVALENCE (W(153),REFC)                                              CWW3   12
C                                                                              CWW3   13
C       DELTA SOUND SPEED 175-199                                              CWW3   14
        EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)             CWW3   15
C                                                                              CWW3   16
C       TEMPERATURE     200-224                                                CWW3   17
        EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                CWW3   18
C                                                                              CWW3   19
C       DELTA TEMPERATURE     225-249                                          CWW3   20
        EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)             CWW3   21
C                                                                              CWW3   22
C       MOLECULAR   250-274                                                    CWW3   23
        EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                CWW3   24
C                                                                              CWW3   25
C       RECEIVER HEIGHT   275-299                                              CWW3   26
        EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                CWW3   27
C                                                                              CWW3   28
C       TOPOGRAPHY   300-324                                                   CWW3   29
        EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)                CWW3   30
C                                                                              CWW3   31
C       DELTA TOPOGRAPHY   325-349                                             CWW3   32
        EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)             CWW3   33
C                                                                              CWW3   34
C       UPPER SURFACE TOPOGRAPHY   350-374                                     CWW3   35
        EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)                CWW3   36
C       PLOT ENHANCEMENTS CONTROL PARAMETERS                                   CWW3   37
C                                                                              CWW3   38
        EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                            CWW3   39
C       ABSORPTION          500-524                                            CWW3   40
        EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)                CWW3   41
C                                                                              CWW3   42
C       DELTA ABSORPTION          525-549                                      CWW3   43
        EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)             CWW3   44
C                                                                              CWW3   45
C       PRESSURE          550-574                                              CWW3   46
        EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)                CWW3   47
C                                                                              CWW3   48
C       DELTA PRESSURE          575-599                                        CWW3   49
        EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)             CWW3   50
C                                                                              CWW3   51
C                                                                              MUARDC12
        EQUIVALENCE (W(503),BETAV),(W(504),SUTH),(W(505),PRNDTL)               MUARDC13
C                                                                              MUARDC14
C       COMMON DECK "RINREAL" INSERTED HERE                                    CRINREA2
        LOGICAL SPACE                                                          CRINREA4
        REAL LPOLAR,LPOLRI,KPHK,KPHKI,KAY2,KAY2I                               CRINREA5
        CHARACTER DISPM*6                                                      CRINREA6
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      COMMON/RINPL/DISPM                                                CRINREA7
      COMMON /RIN/ MODRIN(8),RAYNAME(2,3),TYPE(3),SPACE                 CRINREA8
      COMMON/RIN/OMEGMIN,OMEGMAX,KAY2,KAY2I,                            CRINREA9
     1             H,HI,PHT,PHTI,PHR,PHRI,PHTH,PHTHI,PHPH,PHPHI       CRINRE10
     2, PHOW,PHOWI,PHKR,PHKRI,PHKTH,PHKTI, PHKPH,PHKPI                  CRINRE11
     3 ,KPHK,KPHKI,POLAR,POLARI,LPOLAR,LPOLRI,SGN                       CRINRE12
C     COMMON DECK "CONST" INSERTED HERE                                 CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                     CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                         CCONST 5
C     COMMON DECK "TT" INSERTED HERE                                    CTT    2
      REAL MODT                                                         CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                            CTT    5
C     COMMON DECK "AA" INSERTED HERE                                    CAA    2
      REAL MODA                                                         CAA    4
      REAL MU,MUPT,MUPR,MUPTH,MUPPH                                     CAA    5
      REAL KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                                CAA    6
      COMMON/AA/MODA(4),MU,MUPT,MUPR,MUPTH,MUPPH                        CAA    7
      COMMON/AA/KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                           CAA    8
C                                                                       MUARDC19
C     COMMON DECK "MM" INSERTED HERE                                    CMM    2
      REAL M,MODM                                                       CMM    4
      COMMON/MM/MODM(4),M,PMT,PMR,PMTH,PMPH                             CMM    5
C                                                                       MUARDC21
C     COMMON DECK "CB17" INSERTED HERE                                  CB17   2
      INTEGER VMX,VNTBL,VITBL,VFRMTBL,IDSV(10)                          CB17   4
      COMMON/B17/VMX,VNTBL(10),VITBL(10),VFRMTBL(10),VGP(53)            CB17   5
      EQUIVALENCE (VGP,IDSV),(ANV,VGP(11))                              CB17   6
C                                                                       MUARDC23
      DATA VMX/1/                                                       MRDCBL 2
      DATA VNTBL/1,11,8*0/                                              MRDCBL 3
      DATA VITBL/1,9*0/                                                 MRDCBL 4
      DATA VFRMTBL/1,9*0/                                               MRDCBL 5
      DATA RECOGA/1.0/                                                  MUARDC26
C                                                                       MUARDC27
      ENTRY IABSRP                                                      MUARDC28
      IF(RECOGA .NE. AMODEL)                                            MUARDC29
     1    CALL RERROR('ABSRP ','WRNG MODEL',RECOGA)                     MUARDC30
      MODA(1)=6HMUARDC                                                  MUARDC31
      MODA(2)=AID                                                       MUARDC32
C     SET ALL VICOSITY/CONDUCTIVITY VALUES TO ZERO                      MUARDC33
C     INITIALLY                                                         MUARDC34
      CALL CLEAR(MU,10)                                                 MUARDC35
      CALL IPABSRP                                                      MUARDC36
      RETURN                                                            MUARDC37
C                                                                       MUARDC38
      ENTRY ABSRP                                                       MUARDC39
      MU=BETAV*T**1.5/(SUTH+T)                                          MUARDC40
      KAP=GAMMA*RGAS*MU/((GAMMA-1.0)*M*PRNDTL)                          MUARDC41
      CALL PABSRP                                                       MUARDC42
      END                                                               MUARDC43
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      SUBROUTINE NPABSR                                                 NPABSR 8
C     DO-NOTHING ABSORPTION PERTURBATION MODEL                          NPABSR 9
C     COMMON DECK "WW" INSERTED HERE                                    CWW    2
      PARAMETER (NWARSZ=1000)                                           CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         CWW2   6
     8 (RCVRH,W(20)),                                                  CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                     CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                    CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),      CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))       CWW2   13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),       CWW2   14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))             CWW2   15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                  CWW2   16
      REAL MMODEL,MFORM,MID                                             CWW3   2
C                                                                       CWW3   3
C     WIND          100-124                                           CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)           CWW3   5
C                                                                       CWW3   6
C     DELTA WIND          125-149                                       CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)        CWW3   8
C                                                                       CWW3   9
C     SOUND SPEED 150-174                                               CWW3   10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)           CWW3   11
      EQUIVALENCE (W(153),REFC)                                         CWW3   12
C                                                                       CWW3   13
C     DELTA SOUND SPEED 175-199                                         CWW3   14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)        CWW3   15
C                                                                       CWW3   16
C     TEMPERATURE     200-224                                           CWW3   17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)           CWW3   18
C                                                                       CWW3   19
C     DELTA TEMPERATURE     225-249                                     CWW3   20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)        CWW3   21
C                                                                       CWW3   22
C     MOLECULAR   250-274                                               CWW3   23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)           CWW3   24
C                                                                       CWW3   25
C     RECEIVER HEIGHT   275-299                                         CWW3   26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)           CWW3   27
C                                                                       CWW3   28
C     TOPOGRAPHY    300-324                                             CWW3   29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)           CWW3   30
C                                                                       CWW3   31
C     DELTA TOPOGRAPHY    325-349                                       CWW3   32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)        CWW3   33
C                                                                       CWW3   34
C     UPPER SURFACE TOPOGRAPHY    350-374                               CWW3   35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)           CWW3   36
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C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                  CWW3  37
C                                                                           CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                           CWW3  39
C     ABSORPTION          500-524                                           CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)               CWW3  41
C                                                                           CWW3  42
C     DELTA ABSORPTION          525-549                                     CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)            CWW3  44
C                                                                           CWW3  45
C     PRESSURE          550-574                                           CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)               CWW3  47
C                                                                           CWW3  48
C     DELTA PRESSURE          575-599                                       CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)            CWW3  50
C                                                                           CWW3  51
C     COMMON DECK "AA" INSERTED HERE                                        CAA    2
      REAL MODA                                                             CAA    4
      REAL MU,MUPT,MUPR,MUPTH,MUPPH                                         CAA    5
      REAL KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                                    CAA    6
      COMMON/AA/MODA(4),MU,MUPT,MUPR,MUPTH,MUPPH                            CAA    7
      COMMON/AA/KAP,KAPPT,KAPPR,KAPPTH,KAPPPH                               CAA    8
C                                                                           NPABSR12
C     COMMON DECK "CB18" INSERTED HERE                                      CB18   2
      INTEGER DVMX,DVNTBL,DVITBL,DVFRMTB,IDSDV(10)                          CB18   4
      COMMON/B18/DVMX,DVNTBL(10),DVITBL(10),DVFRMTB(10),DVGP(11)            CB18   5
      EQUIVALENCE (DVGP,IDSDV),(ANDV,DVGP(11))                              CB18   6
C                                                                           NPABSR14
      DATA DVMX/1/                                                          NBSRBL 2
      DATA DVNTBL/1,11,8*0/                                                 NBSRBL 3
      DATA DVITBL/1,9*0/                                                    NBSRBL 4
      DATA DVFRMTB/1,9*0/                                                   NBSRBL 5
C                                                                           NPABSR17
      DATA RECOGDA/0.0/                                                     NPABSR18
C                                                                           NPABSR19
      ENTRY IPABSRP                                                         NPABSR20
      IF(RECOGDA .NE. DAMODEL)                                              NPABSR21
     1    CALL RERROR('DABSRP ','WRNG MODEL',RECOGDA)                       NPABSR22
      MODA(3)=6HNPABSR                                                      NPABSR23
      MODA(4)=DAID                                                          NPABSR24
      RETURN                                                                NPABSR25
C                                                                           NPABSR26
      ENTRY PABSRP                                                          NPABSR27
      RETURN                                                                NPABSR28
      END                                                                   NPABSR29



      SUBROUTINE PEXP                                                       PEXP   8
C                                                                           PEXP   9
C     SCALE HEIGHT PRESSURE MODEL                                           PEXP  10
C                                                                           PEXP  11
C     COMMON DECK "WW" INSERTED HERE                                        CWW    2
      PARAMETER (NWARSZ=1000)                                               CWW1   3
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      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                    CWW1    4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                 CWW2    2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),     CWW2    3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),       CWW2    4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),           CWW2    5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),          CWW2    6
     8 (RCVRH,W(20)),                                                    CWW2    7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2    8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                       CWW2    9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                       CWW2   10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                      CWW2   11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),        CWW2   12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))         CWW2   13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),         CWW2   14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))               CWW2   15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                    CWW2   16
      REAL MMODEL,MFORM,MID                                              CWW3    2
C                                                                        CWW3    3
C     WIND         100-124                                             CWW3    4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)            CWW3    5
C                                                                        CWW3    6
C     DELTA WIND         125-149                                         CWW3    7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)         CWW3    8
C                                                                        CWW3    9
C     SOUND SPEED 150-174                                                CWW3   10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)            CWW3   11
      EQUIVALENCE (W(153),REFC)                                          CWW3   12
C                                                                        CWW3   13
C     DELTA SOUND SPEED 175-199                                          CWW3   14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)         CWW3   15
C                                                                        CWW3   16
C     TEMPERATURE    200-224                                             CWW3   17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)            CWW3   18
C                                                                        CWW3   19
C     DELTA TEMPERATURE    225-249                                       CWW3   20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)         CWW3   21
C                                                                        CWW3   22
C     MOLECULAR   250-274                                                CWW3   23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)            CWW3   24
C                                                                        CWW3   25
C     RECEIVER HEIGHT   275-299                                          CWW3   26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)            CWW3   27
C                                                                        CWW3   28
C     TOPOGRAPHY   300-324                                               CWW3   29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)            CWW3   30
C                                                                        CWW3   31
C     DELTA TOPOGRAPHY   325-349                                         CWW3   32
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)         CWW3   33
C                                                                        CWW3   34
C     UPPER SURFACE TOPOGRAPHY   350-374                                 CWW3   35
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)            CWW3   36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                               CWW3   37
C                                                                        CWW3   38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                        CWW3   39
C     ABSORPTION         500-524                                         CWW3   40
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      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)          CWW3  41
C                                                                      CWW3  42
C     DELTA ABSORPTION         525-549                                 CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)       CWW3  44
C                                                                      CWW3  45
C     PRESSURE         550-574                                         CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)          CWW3  47
C                                                                      CWW3  48
C     DELTA PRESSURE         575-599                                   CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)       CWW3  50
C                                                                      CWW3  51
C     COMMON DECK "RKAM" INSERTED HERE                                 RKAMCOM2
      REAL KR,KTH,KPH                                                  RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)      RKAMCOM5
C     COMMON DECK "CONST" INSERTED HERE                                CCONST 2
      COMMON/PCONST/CREF,RGAS,GAMMA                                    CCONST 4
      COMMON/MCONST/PI,PIT2,PID2,DEGS,RAD,ALN10                        CCONST 5
C     COMMON DECK "PP" INSERTED HERE                                   CPP    2
      REAL MODP                                                        CPP    4
      COMMON/PP/MODP(4),P,PPT,PPR,PPTH,PPPH                            CPP    5
C     COMMON DECK "TT" INSERTED HERE                                   CTT    2
      REAL MODT                                                        CTT    4
      COMMON/TT/MODT(4), T,PTT,PTR,PTTH,PTPH                           CTT    5
C     COMMON DECK "MM" INSERTED HERE                                   CMM    2
      REAL M,MODM                                                      CMM    4
      COMMON/MM/MODM(4),M,PMT,PMR,PMTH,PMPH                            CMM    5
C                                                                      PEXP  18
      EQUIVALENCE (W(553),P0),(W(554),HSCALE)                          PEXP  19
C                                                                      PEXP  20
C     COMMON DECK "CB19" INSERTED HERE                                 CB19   2
      INTEGER PRMX,PRNTBL,PRITBL,PRFRMTB,IDSPR(10)                     CB19   4
      COMMON/B19/PRMX,PRNTBL(10),PRITBL(10),PRFRMTB(10),PRGP(11)       CB19   5
      EQUIVALENCE (PRGP,IDSPR),(ANP,PRGP(11))                          CB19   6
C                                                                      PEXP  22
      DATA PRMX/1/                                                     PPBL   2
      DATA PRNTBL/1,11,8*0/                                            PPBL   3
      DATA PRITBL/1,9*0/                                               PPBL   4
      DATA PRFRMTB/1,9*0/                                              PPBL   5
      DATA RECOGP/1.0/                                                 PEXP  25
C                                                                      PEXP  26
      ENTRY IPRES                                                      PEXP  27
      IF(RECOGP .NE. PMODEL)                                           PEXP  28
     1    CALL RERROR('PRESUR ','WRNG MODEL',RECOGP)                   PEXP  29
      MODP(1)=4HPEXP                                                   PEXP  30
      MODP(2)=PID                                                      PEXP  31
      CALL IPPRES                                                      PEXP  32
      RETURN                                                           PEXP  33
C                                                                      PEXP  34
      ENTRY PRES                                                       PEXP  35
      Z=R-EARTHR                                                       PEXP  36
      EX=-Z/HSCALE                                                     PEXP  37
      P=P0*EXP(EX)                                                     PEXP  38
      PPT=0.0                                                          PEXP  39
      PPR=P*EX/Z                                                       PEXP  40
      PPTH=0.0                                                         PEXP  41
```

```
      PPPH=0.0                                                                  PEXP  42
      CALL PPRES                                                                PEXP  43
      RETURN                                                                    PEXP  44
      END                                                                       PEXP  45



      SUBROUTINE NPPRES                                                         NPPRES 8
C     DO-NOTHING PRESSURE PERTURBATION MODEL                                    NPPRES 9
C     COMMON DECK "WW" INSERTED HERE                                            CWW    2
      PARAMETER (NWARSZ=1000)                                                   CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                           CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                        CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),            CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),              CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                  CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),                 CWW2   6
     8 (RCVRH,W(20)),                                                           CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))        CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                              CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                              CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                             CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),               CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))                CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),                CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                      CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                           CWW2  16
      REAL MMODEL,MFORM,MID                                                     CWW3   2
C                                                                               CWW3   3
C     WIND          100-124                                                     CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)                   CWW3   5
C                                                                               CWW3   6
C     DELTA WIND          125-149                                               CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)                CWW3   8
C                                                                               CWW3   9
C     SOUND SPEED 150-174                                                       CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                   CWW3  11
      EQUIVALENCE (W(153),REFC)                                                 CWW3  12
C                                                                               CWW3  13
C     DELTA SOUND SPEED 175-199                                                 CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)                CWW3  15
C                                                                               CWW3  16
C     TEMPERATURE     200-224                                                   CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                   CWW3  18
C                                                                               CWW3  19
C     DELTA TEMPERATURE     225-249                                             CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)                CWW3  21
C                                                                               CWW3  22
C     MOLECULAR   250-274                                                       CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                   CWW3  24
C                                                                               CWW3  25
C     RECEIVER HEIGHT   275-299                                                 CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                   CWW3  27
```

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C                                                                       CWW3  28
C                                                                       CWW3  29
C     TOPOGRAPHY   300-324                                              CWW3  30
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)           CWW3  31
C                                                                       CWW3  32
C     DELTA TOPOGRAPHY   325-349                                        CWW3  33
      EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)        CWW3  34
C                                                                       CWW3  35
C     UPPER SURFACE TOPOGRAPHY   350-374                                CWW3  36
      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)           CWW3  37
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                              CWW3  38
C                                                                       CWW3  39
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                       CWW3  40
C     ABSORPTION         500-524                                        CWW3  41
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)           CWW3  42
C                                                                       CWW3  43
C     DELTA ABSORPTION         525-549                                  CWW3  44
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)        CWW3  45
C                                                                       CWW3  46
C     PRESSURE         550-574                                          CWW3  47
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)           CWW3  48
C                                                                       CWW3  49
C     DELTA PRESSURE         575-599                                    CWW3  50
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)        CWW3  51
C                                                                       CPP    2
C     COMMON DECK "PP" INSERTED HERE                                    CPP    4
      REAL MODP                                                         CPP    5
      COMMON/PP/MODP(4),P,PPT,PPR,PPTH,PPPH                             NPPRES12
C                                                                       CB20   2
C     COMMON DECK "CB20" INSERTED HERE                                  CB20   4
      INTEGER DPMX,DPNTBL,DPITBL,DPFRMTB,IDSDP(10)                      CB20   5
      COMMON/B20/DPMX,DPNTBL(10),DPITBL(10),DPFRMTB(10),DPGP(11)        CB20   6
      EQUIVALENCE (DPGP,IDSDP),(ANDP,DPGP(11))                          NPPRES14
C                                                                       NRESBL 2
      DATA DPMX/1/                                                      NRESBL 3
      DATA DPNTBL/1,11,8*0/                                             NRESBL 4
      DATA DPITBL/1,9*0/                                                NRESBL 5
      DATA DPFRMTB/1,9*0/                                               NPPRES17
C                                                                       NPPRES18
      DATA RECOGDP/0.0/                                                 NPPRES19
C                                                                       NPPRES20
      ENTRY IPPRES                                                      NPPRES21
      IF(RECOGDP .NE. DPMODEL)                                          NPPRES22
     1    CALL RERROR('DPPRES ','WRNG MODEL',RECOGDP)                   NPPRES23
      MODP(3)=6HNPPRES                                                  NPPRES24
      MODP(4)=DPID                                                      NPPRES25
      RETURN                                                            NPPRES26
C                                                                       NPPRES27
      ENTRY PPRES                                                       NPPRES28
      RETURN                                                            NPPRES29
      END
```

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      SUBROUTINE RHORIZ                                                 RHORIZ 8
C     RECEIVER MODEL USING FIXED OFFSET TO EARTHR'S SURFACE.            RHORIZ 9
C     COMMON DECK "RR" INSERTED HERE                                    CRR    2
      REAL MODREC                                                       CRR    4
      COMMON/RR/ MODREC(4)                                              CRR    5
      COMMON/RR/F,PFR,PFRR,PFRTH,PFRPH                                  CRR    6
      COMMON/RR/PFTH,PFPH,PFTHTH,PFPHPH,PFTHPH,FSELECT,FTIME            CRR    7
C     COMMON DECK "WW" INSERTED HERE                                    CWW    2
      PARAMETER (NWARSZ=1000)                                           CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         CWW2   6
     8 (RCVRH,W(20)),                                                   CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))        CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),        CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))              CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                   CWW2  16
      REAL MMODEL,MFORM,MID                                             CWW3   2
C                                                                       CWW3   3
C     WIND         100-124                                            CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)           CWW3   5
C                                                                       CWW3   6
C     DELTA WIND         125-149                                        CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)        CWW3   8
C                                                                       CWW3   9
C     SOUND SPEED 150-174                                               CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)           CWW3  11
      EQUIVALENCE (W(153),REFC)                                         CWW3  12
C                                                                       CWW3  13
C     DELTA SOUND SPEED 175-199                                         CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)        CWW3  15
C                                                                       CWW3  16
C     TEMPERATURE    200-224                                            CWW3  17
      EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)           CWW3  18
C                                                                       CWW3  19
C     DELTA TEMPERATURE    225-249                                      CWW3  20
      EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)        CWW3  21
C                                                                       CWW3  22
C     MOLECULAR   250-274                                               CWW3  23
      EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)           CWW3  24
C                                                                       CWW3  25
C     RECEIVER HEIGHT   275-299                                         CWW3  26
      EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)           CWW3  27
C                                                                       CWW3  28
C     TOPOGRAPHY   300-324                                              CWW3  29
      EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)           CWW3  30
C                                                                       CWW3  31
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C       DELTA TOPOGRAPHY    325-349                                          CWW3  32
        EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)           CWW3  33
C                                                                            CWW3  34
C       UPPER SURFACE TOPOGRAPHY    350-374                                  CWW3  35
        EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)              CWW3  36
C       PLOT ENHANCEMENTS CONTROL PARAMETERS                                 CWW3  37
C                                                                            CWW3  38
        EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                          CWW3  39
C       ABSORPTION          500-524                                          CWW3  40
        EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)              CWW3  41
C                                                                            CWW3  42
C       DELTA ABSORPTION          525-549                                    CWW3  43
        EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)           CWW3  44
C                                                                            CWW3  45
C       PRESSURE          550-574                                            CWW3  46
        EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)              CWW3  47
C                                                                            CWW3  48
C       DELTA PRESSURE          575-599                                      CWW3  49
        EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)           CWW3  50
C                                                                            CWW3  51
C       COMMON DECK "RKAM" INSERTED HERE                                     RKAMCOM2
        REAL KR,KTH,KPH                                                      RKAMCOM4
        COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)          RKAMCOM5
C                                                                            RHORIZ13
C       COMMON DECK "B8" INSERTED HERE                                       CB10   2
        INTEGER RMX,RNTBL,RITBL,RFRMTBL,IDSR(10)                             CB10   4
        COMMON/B8/RMX,RNTBL(10),RITBL(10),RFRMTBL(10),RGP(10)                CB10   5
        EQUIVALENCE (RGP,IDSR)                                               CB10   6
C                                                                            RHORIZ15
        DATA RECORR/1.0/                                                     RHORIZ16
        DATA RMX/1/                                                          RRIZBL 2
        DATA RNTBL/1,11,8*0/                                                 RRIZBL 3
        DATA RITBL/1,9*0/                                                    RRIZBL 4
        DATA RFRMTBL/1,9*0/                                                  RRIZBL 5
C                                                                            RHORIZ19
        ENTRY IRECVR                                                         RHORIZ20
C                                                                            RHORIZ21
        IF(RECORR .NE. RMODEL)                                               RHORIZ22
       1    CALL RERROR('RECEIVR','WRNG MODEL',RECORR)                       RHORIZ23
C                                                                            RHORIZ24
        MODREC(1)=6HRHORIZ                                                   RHORIZ25
        MODREC(2)=RID                                                        RHORIZ26
        RETURN                                                               RHORIZ27
        ENTRY RECEVER                                                        RHORIZ28
        F=R-W(1)-W(20)                                                       RHORIZ29
        PFR=1.0                                                              RHORIZ30
        CALL CLEAR(PFRR,8)                                                   RHORIZ31
        END                                                                  RHORIZ32


        SUBROUTINE RTERR                                                     RTERR  8
C       RECEIVER MODEL USING FIXED OFFSET TO TERRAIN HEIGHT                  RTERR  9
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C      COMMON DECK "RKAM" INSERTED HERE                                        RKAMCOM2
       REAL KR,KTH,KPH                                                         RKAMCOM4
       COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)             RKAMCOM5
C      COMMON DECK "WW" INSERTED HERE                                          CWW    2
       PARAMETER (NWARSZ=1000)                                                 CWW1   3
       COMMON/WW/ID(10),MAXW,W(NWARSZ)                                         CWW1   4
       REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                      CWW2   2
       EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),          CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),             CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),                 CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),                CWW2   6
     8 (RCVRH,W(20)),                                                          CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))       CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                             CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                             CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                            CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),              CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))               CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),               CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                     CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                          CWW2  16
       REAL MMODEL,MFORM,MID                                                   CWW3   2
C                                                                              CWW3   3
C      WIND          100-124                                                   CWW3   4
       EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)                 CWW3   5
C                                                                              CWW3   6
C      DELTA WIND          125-149                                             CWW3   7
       EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)              CWW3   8
C                                                                              CWW3   9
C      SOUND SPEED 150-174                                                     CWW3  10
       EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)                 CWW3  11
       EQUIVALENCE (W(153),REFC)                                               CWW3  12
C                                                                              CWW3  13
C      DELTA SOUND SPEED 175-199                                               CWW3  14
       EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)              CWW3  15
C                                                                              CWW3  16
C      TEMPERATURE     200-224                                                 CWW3  17
       EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                 CWW3  18
C                                                                              CWW3  19
C      DELTA TEMPERATURE     225-249                                           CWW3  20
       EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)              CWW3  21
C                                                                              CWW3  22
C      MOLECULAR   250-274                                                     CWW3  23
       EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                 CWW3  24
C                                                                              CWW3  25
C      RECEIVER HEIGHT    275-299                                              CWW3  26
       EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                 CWW3  27
C                                                                              CWW3  28
C      TOPOGRAPHY    300-324                                                   CWW3  29
       EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)                 CWW3  30
C                                                                              CWW3  31
C      DELTA TOPOGRAPHY    325-349                                             CWW3  32
       EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)              CWW3  33
C                                                                              CWW3  34
C      UPPER SURFACE TOPOGRAPHY    350-374                                     CWW3  35
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      EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)                CWW3  36
C     PLOT ENHANCEMENTS CONTROL PARAMETERS                                   CWW3  37
C                                                                            CWW3  38
      EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                            CWW3  39
C     ABSORPTION          500-524                                            CWW3  40
      EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)                CWW3  41
C                                                                            CWW3  42
C     DELTA ABSORPTION          525-549                                      CWW3  43
      EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)             CWW3  44
C                                                                            CWW3  45
C     PRESSURE          550-574                                            CWW3  46
      EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)                CWW3  47
C                                                                            CWW3  48
C     DELTA PRESSURE          575-599                                      CWW3  49
      EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)             CWW3  50
C                                                                            CWW3  51
C     COMMON DECK "RR" INSERTED HERE                                         CRR    2
      REAL MODREC                                                            CRR    4
      COMMON/RR/ MODREC(4)                                                   CRR    5
      COMMON/RR/F,PFR,PFRR,PFRTH,PFRPH                                       CRR    6
      COMMON/RR/PFTH,PFPH,PFTHTH,PFPHPH,PFTHPH,FSELECT,FTIME                 CRR    7
C     COMMON DECK "GG" INSERTED HERE                                         CGG    2
      REAL MODG                                                              CGG    4
      COMMON/GG/MODG(4)                                                      CGG    5
      COMMON/GG/G,PGR,PGRR,PGRTH,PGRPH                                       CGG    6
      COMMON/GG/PGTH,PGPH,PGTHTH,PGPHPH,PGTHPH,GSELECT,GTIME                 CGG    7
C                                                                            RTERR 14
C     COMMON DECK "B8" INSERTED HERE                                         CB10   2
      INTEGER RMX,RNTBL,RITBL,RFRMTBL,IDSR(10)                               CB10   4
      COMMON/B8/RMX,RNTBL(10),RITBL(10),RFRMTBL(10),RGP(10)                  CB10   5
      EQUIVALENCE (RGP,IDSR)                                                 CB10   6
C                                                                            RTERR 16
      DATA RMX/1/                                                            RRBL   2
      DATA RNTBL/1,11,8*0/                                                   RRBL   3
      DATA RITBL/1,9*0/                                                      RRBL   4
      DATA RFRMTBL/1,9*0/                                                    RRBL   5
C                                                                            RTERR 19
      DATA RECORR/2.0/                                                       RTERR 20
C                                                                            RTERR 21
      ENTRY IRECVR                                                           RTERR 22
C                                                                            RTERR 23
      IF(RECORR .NE. RMODEL)                                                 RTERR 24
     1    CALL RERROR('RECEIVR','WRNG MODEL',RECORR)                         RTERR 25
      MODREC(1)=5HRTERR                                                      RTERR 26
      MODREC(2)=RID                                                          RTERR 27
      RETURN                                                                 RTERR 28
C                                                                            RTERR 29
      ENTRY RECEVER                                                          RTERR 30
C     GET CURRENT TERRAIN HEIGHT(MUST USE GET1 TO AVOID RECURSION            RTERR 31
C     SINCE WE ARE PROBABLY BEING CALLED BY GET RIGHT NOW)                   RTERR 32
      F=GET1(G)-W(20)                                                        RTERR 33
      CALL RMOVE(PFR,PGR,9)                                                  RTERR 34
      END                                                                    RTERR 35
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      SUBROUTINE RVERT                                                      RVERT  8
C     VERTICAL(CONICAL) RECEIVER SURFACE AT A FIXED RADIUS FROM             RVERT  9
C     A SPECIFIED ORIGIN.                                                   RVERT 10
C                                                                           RVERT 11
C     COMMON DECK "RKAM" INSERTED HERE                                      RKAMCOM2
      REAL KR,KTH,KPH                                                       RKAMCOM4
      COMMON//R,TH,PH,KR,KTH,KPH,RKVARS(14),TPULSE,CSTEP,DRDT(20)           RKAMCOM5
C     COMMON DECK "RR" INSERTED HERE                                        CRR    2
      REAL MODREC                                                           CRR    4
      COMMON/RR/ MODREC(4)                                                  CRR    5
      COMMON/RR/F,PFR,PFRR,PFRTH,PFRPH                                      CRR    6
      COMMON/RR/PFTH,PFPH,PFTHTH,PFPHPH,PFTHPH,FSELECT,FTIME                CRR    7
C     COMMON DECK "B8" INSERTED HERE                                        CB10   2
      INTEGER RMX,RNTBL,RITBL,RFRMTBL,IDSR(10)                              CB10   4
      COMMON/B8/RMX,RNTBL(10),RITBL(10),RFRMTBL(10),RGP(10)                 CB10   5
      EQUIVALENCE (RGP,IDSR)                                                CB10   6
C     COMMON DECK "GAMANG" INSERTED HERE                                    CGAMANG2
      COMMON/SPHGAM/SINLM0,COSLM0,GPH0,COSPHD,SINTH,COSTH                   CGAMANG4
      COMMON/SPHGAM/GAMFUN,PGMTH,PGMPH,PGMTHTH,PGMPHPH,PGMTHPH              CGAMANG5
C     COMMON DECK "WW" INSERTED HERE                                        CWW    2
      PARAMETER (NWARSZ=1000)                                               CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                       CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                    CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),        CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),          CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),              CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),             CWW2   6
     8 (RCVRH,W(20)),                                                       CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))    CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                          CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                          CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                         CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),           CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))            CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),            CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))                  CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                       CWW2  16
      REAL MMODEL,MFORM,MID                                                 CWW3   2
C                                                                           CWW3   3
C     WIND          100-124                                                 CWW3   4
      EQUIVALENCE (W(100),UMODEL),(W(101),UFORM),(W(102),UID)               CWW3   5
C                                                                           CWW3   6
C     DELTA WIND          125-149                                           CWW3   7
      EQUIVALENCE (W(125),DUMODEL),(W(126),DUFORM),(W(127),DUID)            CWW3   8
C                                                                           CWW3   9
C     SOUND SPEED 150-174                                                   CWW3  10
      EQUIVALENCE (W(150),CMODEL),(W(151),CFORM),(W(152),CID)               CWW3  11
      EQUIVALENCE (W(153),REFC)                                             CWW3  12
C                                                                           CWW3  13
C     DELTA SOUND SPEED 175-199                                             CWW3  14
      EQUIVALENCE (W(175),DCMODEL),(W(176),DCFORM),(W(177),DCID)            CWW3  15
C                                                                           CWW3  16
```

```
C       TEMPERATURE     200-224                                                 CWW3  17
        EQUIVALENCE (W(200),TMODEL),(W(201),TFORM),(W(202),TID)                 CWW3  18
C                                                                               CWW3  19
C       DELTA TEMPERATURE     225-249                                           CWW3  20
        EQUIVALENCE (W(225),DTMODEL),(W(226),DTFORM),(W(227),DTID)              CWW3  21
C                                                                               CWW3  22
C       MOLECULAR    250-274                                                    CWW3  23
        EQUIVALENCE (W(250),MMODEL),(W(251),MFORM),(W(252),MID)                 CWW3  24
C                                                                               CWW3  25
C       RECEIVER HEIGHT    275-299                                              CWW3  26
        EQUIVALENCE (W(275),RMODEL),(W(276),RFORM),(W(277),RID)                 CWW3  27
C                                                                               CWW3  28
C       TOPOGRAPHY    300-324                                                   CWW3  29
        EQUIVALENCE (W(300),GMODEL),(W(301),GFORM),(W(302),GID)                 CWW3  30
C                                                                               CWW3  31
C       DELTA TOPOGRAPHY    325-349                                             CWW3  32
        EQUIVALENCE (W(325),GUMODEL),(W(326),GUFORM),(W(327),GUID)              CWW3  33
C                                                                               CWW3  34
C       UPPER SURFACE TOPOGRAPHY    350-374                                     CWW3  35
        EQUIVALENCE (W(350),SMODEL),(W(351),SFORM),(W(352),SID)                 CWW3  36
C       PLOT ENHANCEMENTS CONTROL PARAMETERS                                    CWW3  37
C                                                                               CWW3  38
        EQUIVALENCE (W(490),XFQMDL),(W(491),YFQMDL)                             CWW3  39
C       ABSORPTION          500-524                                             CWW3  40
        EQUIVALENCE (W(500),AMODEL),(W(501),AFORM),(W(502),AID)                 CWW3  41
C                                                                               CWW3  42
C       DELTA ABSORPTION          525-549                                       CWW3  43
        EQUIVALENCE (W(525),DAMODEL),(W(526),DAFORM),(W(527),DAID)              CWW3  44
C                                                                               CWW3  45
C       PRESSURE          550-574                                               CWW3  46
        EQUIVALENCE (W(550),PMODEL),(W(551),PFORM),(W(552),PID)                 CWW3  47
C                                                                               CWW3  48
C       DELTA PRESSURE          575-599                                         CWW3  49
        EQUIVALENCE (W(575),DPMODEL),(W(576),DPFORM),(W(577),DPID)              CWW3  50
C                                                                               CWW3  51
        EQUIVALENCE (RVALPH0,W(278)) ,(RVLAMZ,W(279)), (RVPH0,W(280))           RVERT 17
C                                                                               RVERT 18
        DATA RMX/1/                                                             RRTBL  2
        DATA RNTBL/1,11,8*0/                                                    RRTBL  3
        DATA RITBL/1,9*0/                                                       RRTBL  4
        DATA RFRMTBL/1,9*0/                                                     RRTBL  5
        DATA RECORR/1.0/                                                        RVERT 21
C                                                                               RVERT 22
C                                                                               RVERT 23
        ENTRY IRECVR                                                            RVERT 24
C                                                                               RVERT 25
        IF(RECORR .NE. RMODEL)                                                  RVERT 26
     1    CALL RERROR(7HRECEIVR   ,10HWRNG MODEL ,RECORR)                       RVERT 27
        MODREC(1)=7HRVERT                                                       RVERT 28
        MODREC(2)=RID                                                           RVERT 29
C                                                                               RVERT 30
        SINLMZ=SIN(RVLAMZ)                                                      RVERT 31
        COSLMZ=COS(RVLAMZ)                                                      RVERT 32
        COSALP=COS(RVALPH0)                                                     RVERT 33
C                                                                               RVERT 34
```

```
      RETURN                                                            RVERT 35
C                                                                       RVERT 36
      ENTRY RECEVER                                                     RVERT 37
C                                                                       RVERT 38
      SINLM0=SINLMZ                                                     RVERT 39
      COSLM0=COSLMZ                                                     RVERT 40
      GPH0=RVPH0                                                        RVERT 41
C                                                                       RVERT 42
      CALL GAMANG(TH,PH)                                                RVERT 43
C                                                                       RVERT 44
      F=GAMFUN-COSALP                                                   RVERT 45
      PFR=0.0                                                           RVERT 46
      CALL RMOVE(PFTH,PGMTH,5)                                          RVERT 47
C                                                                       RVERT 48
      RETURN                                                            RVERT 49
      END                                                               RVERT 50
```

```
      SUBROUTINE SMPANN                                                 SMPANN 9
C     ANNOTATION MODEL FOR MINIMUM GRAPHICS SUPPORT                     SMPANN10
C                                                                       SMPANN11
      CHARACTER*(*) S,C                                                 SMPANN12
C                                                                       SMPANN13
C     INITIALIZES PLOT IN DRAFT MODE(DOES NOT REQUIRE DISSPLA)          SMPANN14
C                                                                       SMPANN15
C     COMMON DECK "WWR" INSERTED HERE                                   CWWR   2
      PARAMETER (NWARSZ=1000)                                           CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                   CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                                CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),    CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),      CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),          CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),         CWW2   6
     8 (RCVRH,W(20)),                                                   CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2   8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                      CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                      CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                     CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),       CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))        CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),        CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))              CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                   CWW2  16
C     COMMON DECK "ANNOT" INSERTED HERE                                 ANNOT  2
      CHARACTER*10 ANOTES,HNOTES                                        ANNOT  4
      COMMON/ANNCTL/LENA(4),LENHA(3)                                    ANNOT  5
      COMMON/ANNCTC/ANOTES(2,4),HNOTES(4,3)                             ANNOT  6
C                                                                       SMPANN18
      DATA LENA,ANOTES                                                  SANNBL 2
     1  /2*1,2*2,'DEPTH (M)',' ','DEPTH (KM)',' ',                      SANNBL 3
     2 'HEIGHT (M)',' ','HEIGHT (KM',')'/                              SANNBL 4
C                                                                       SANNBL 5
```

```
      DATA LENHA,HNOTES                                                 SANNBL 6
     1  /3,2,3, 'RANGE AT S','EA LEVEL (','KM)',' '                    SANNBL 7
     2        ,'RANGE (DEG',')',2*' '                                  SANNBL 8
     3        ,'CROSS RANG','E AT SEA L','EVEL (KM)',' '/              SANNBL 9
C                                                                      SMPANN21
      ENTRY SETANN                                                     SMPANN22
C                                                                      SMPANN23
      RETURN                                                           SMPANN24
C                                                                      SMPANN25
      ENTRY ANNFIL(S,C)                                                SMPANN26
      CALL SFILTR(S,C,'#!')                                            SMPANN27
      END                                                              SMPANN28
```

```
      SUBROUTINE FULANN                                                FULANN 9
C     ANNOTATION MODEL SUITED FOR PUBLICATION QUALITY LETTERING        FULANN10
C                                                                      FULANN11
      CHARACTER*(*) S,C                                                FULANN12
C                                                                      FULANN13
C     INITIALIZES PLOT IN PUBLICATION-QUALITY MODE(REQUIRES DISSPLA)   FULANN14
C                                                                      FULANN15
C     COMMON DECK "WWR" INSERTED HERE                                  CWWR   2
      PARAMETER (NWARSZ=1000)                                          CWW1   3
      COMMON/WW/ID(10),MAXW,W(NWARSZ)                                  CWW1   4
      REAL MAXSTP,MAXERR,INTYP,LLAT,LLON                               CWW2   2
      EQUIVALENCE (EARTHR,W(1)),(RAY,W(2)),(XMTRH,W(3)),(TLAT,W(4)),   CWW2   3
     1 (TLON,W(5)),(OW,W(6)),(FBEG,W(7)),(FEND,W(8)),(FSTEP,W(9)),     CWW2   4
     2 (AZ1,W(10)),(AZBEG,W(11)),(AZEND,W(12)),(AZSTEP,W(13)),         CWW2   5
     3 (BETA,W(14)),(ELBEG,W(15)),(ELEND,W(16)),(ELSTEP,W(17)),        CWW2   6
     8 (RCVRH,W(20)),                                                 CWW2   7
     4 (ONLY,W(21)),(HOP,W(22)),(MAXSTP,W(23)),(PLAT,W(24)),(PLON,W(25))CWW2  8
     5,(HMAX,W(26)),(RAYFNC,W(29)),(EXTINC,W(33)),                    CWW2   9
     6 (HMIN,W(27)),(RGMAX,W(28)),                                    CWW2  10
     8 (INTYP,W(41)),(MAXERR,W(42)),(ERATIO,W(43)),                   CWW2  11
     6 (STEP1,W(44)),(STPMAX,W(45)),(STPMIN,W(46)),(FACTR,W(47)),     CWW2  12
     7 (SKIP,W(71)),(RAYSET,W(72)),(PRTSRP,W(74)),(HITLET,W(75))      CWW2  13
     9 ,(BINRAY,W(76)),(PAGLN,W(77)),(PLT,W(81)),(PFACTR,W(82)),      CWW2  14
     1 (LLAT,W(83)),(LLON,W(84)),(RLAT,W(85)),(RLON,W(86))            CWW2  15
     2,(TIC,W(87)),(HB,W(88)),(HT,W(89)),(TICV,W(96))                 CWW2  16
C     COMMON DECK "ANNOT" INSERTED HERE                                ANNOT  2
      CHARACTER*10 ANOTES,HNOTES                                       ANNOT  4
      COMMON/ANNCTL/LENA(4),LENHA(3)                                   ANNOT  5
      COMMON/ANNCTC/ANOTES(2,4),HNOTES(4,3)                            ANNOT  6
C                                                                      FULANN18
      DATA LENA,ANOTES                                                 FANNBL 2
     1  /4*2,'DEPTH (#M!',')','DEPTH (#KM','!)',                       FANNBL 3
     2'HEIGHT (#M',')','HEIGHT (#K','M!)'/                            FANNBL 4
      DATA LENHA,HNOTES                                                FANNBL 5
     1  /3,2,4, 'RANGE AT S','EA LEVEL (','#KM!)',' '                  FANNBL 6
     2        ,'RANGE (#DE','G!)',2*' '                                FANNBL 7
     3        ,'CROSS RANG','E AT SEA L','EVEL (#KM!',')'/             FANNBL 8
      ENTRY SETANN                                                     FULANN21
```

```
C
      PRINT *,'FULL ANNOTATION MODEL'                                   FULANN22
C                                                                       FULANN23
      CALL SCMPLX                                                       FULANN24
      CALL MX1ALF('STAND','!')                                          FULANN25
      CALL MX2ALF('L/CSTD','#')                                         FULANN26
      CALL HEIGHT(HITLET)                                               FULANN27
      RETURN                                                            FULANN28
C                                                                       FULANN29
      ENTRY ANNFIL(S,C)                                                 FULANN30
      C=S                                                               FULANN31
      END                                                               FULANN32
                                                                        FULANN33
```

DDSPLA -- Programs for reading Graphics Output File (Tape File 6)

```
      PROGRAM DDSPLA(TAPE5,INPUT,OUTPUT,TAPE9)                          DDSPLA 3
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                               DDSPLA 4
      COMMON/SUPNEG/IDEL,NMBS                                           DDSPLA 5
C                                                                       DDSPLA 6
      PARAMETER (LIMPTS=700)                                            DDSPLA 7
      REAL XV(LIMPTS),YV(LIMPTS)                                        DDSPLA 8
      INTEGER A(4),C(4),E(4)                                            DDSPLA 9
      LOGICAL COMPCL                                                    DDSPLA10
      CHARACTER LINE*72,TEXT*80,S*10                                    DDSPLA11
      EQUIVALENCE (IX,XXX),(IY,YYY)                                     DDSPLA12
      DATA COMPCL/.TRUE./                                               DDSPLA13
      DATA KNT/0/                                                       DDSPLA14
C                                                                       DDSPLA15
      REWIND 5                                                          DDSPLA16
10    READ(5,END=100,ERR=100) IT,IX,IY                                  DDSPLA17
C      IF(IT.GT.29) PRINT *,IT,IX,IY,XXX,YYY                            DDSPLA18
      IF(IT.GT.20) THEN                                                 DDSPLA19
         IF(COMPCL) THEN                                                DDSPLA20
            WRITE(LINE,'(A,3(I4,1X),2G13.6)')                           DDSPLA21
     1         'NO CALL TO ''COMPRS'' BEFORE---',IT,IX,IY,XXX,YYY       DDSPLA22
            CALL SYSTEM(52,LINE)                                        DDSPLA23
            ENDIF                                                       DDSPLA24
      ENDIF                                                             DDSPLA25
      IF(IT.LT.-2 .OR. IT.GT.38) STOP 'CODE>38'                         DDSPLA26
      KNT=KNT+1                                                         DDSPLA27
      IF(IT.EQ.-1) THEN                                                 DDSPLA28
         CALL DDEND                                                     DDSPLA29
      ELSEIF(IT.EQ.-2) THEN                                             DDSPLA30
         CALL DDFR                                                      DDSPLA31
      ELSEIF(IT.EQ.0) THEN                                              DDSPLA32
         READ(5) N,M,(TEXT(I:I),I=1,M)                                  DDSPLA33
         CALL DDINIT(N,TEXT)                                            DDSPLA34
      ELSEIF(IT.EQ.1) THEN                                              DDSPLA35
         CALL DDBP                                                      DDSPLA36
      ELSEIF(IT.EQ.2) THEN                                              DDSPLA37
         CALL DDVC                                                      DDSPLA38
      ELSEIF(IT.EQ.10) THEN                                             DDSPLA39
         CALL SCMPLX                                                    DDSPLA40
      ELSEIF(IT.EQ.11) THEN                                             DDSPLA41
         CALL MX1ALF(IX,IY)                                             DDSPLA42
      ELSEIF(IT.EQ.12) THEN                                             DDSPLA43
         CALL MX2ALF(IX,IY)                                             DDSPLA44
      ELSEIF(IT.EQ.13) THEN                                             DDSPLA45
         IF(XXX.LE.0.0) THEN                                            DDSPLA46
            PRINT *,'HEIGHT OF ZERO!!'                                  DDSPLA47
            XXX=.15                                                     DDSPLA48
         ENDIF                                                          DDSPLA49
         CALL HEIGHT(XXX)                                               DDSPLA50
C                                                                       DDSPLA51
      ELSEIF(IT.EQ.20) THEN                                             DDSPLA52
         COMPCL=.FALSE.                                                 DDSPLA53
         CALL COMPRS                                                    DDSPLA54
      ELSEIF(IT.EQ.21) THEN                                             DDSPLA55
         CALL GRACE(IX,IY)                                              DDSPLA56
      ELSEIF(IT.EQ.22) THEN                                             DDSPLA57
```

```
   CALL PHYSOR(IX,IY)                                                    DDSPLA58
ELSEIF(IT.EQ.23) THEN                                                    DDSPLA59
   CALL PAGE(IX,IY)                                                      DDSPLA60
ELSEIF(IT.EQ.24) THEN                                                    DDSPLA61
   CALL SCLPIC(IX)                                                       DDSPLA62
ELSEIF(IT.EQ.25) THEN                                                    DDSPLA63
   IF(IX.NE.0 .OR. IY.NE.0) STOP 'ERROR 1'                               DDSPLA64
   READ(5) A,B,C,D,E,F,XAXIS,YAXIS                                       DDSPLA65
   CALL XREVTK                                                           DDSPLA66
   CALL YREVTK                                                           DDSPLA67
   CALL INTAXS                                                           DDSPLA68
   CALL TITLE(A,B,C,D,E,F,XAXIS,YAXIS)                                   DDSPLA69
ELSEIF(IT.EQ.26) THEN                                                    DDSPLA70
   CALL FRAME                                                            DDSPLA71
ELSEIF(IT.EQ.27) THEN                                                    DDSPLA72
   READ(5) W,X,Y,Z                                                       DDSPLA73
   CALL GRAFB(IX,IY,W,X,Y,Z,XAXIS,YAXIS)                                 DDSPLA74
ELSEIF(IT.EQ.28) THEN                                                    DDSPLA75
   CALL MARKER(IX)                                                       DDSPLA76
ELSEIF(IT.EQ.29) THEN                                                    DDSPLA77
   IF(IX.GT.LIMPTS) CALL SYSTEM(52,'N>LIMPTS')                           DDSPLA78
   READ(5) (XV(I),I=1,IX),(YV(I),I=1,IX)                                 DDSPLA79
   CALL CURVE(XV,YV,IX,IY)                                               DDSPLA80
ELSEIF(IT.EQ.30) THEN                                                    DDSPLA81
   CALL ENDPL(IX)                                                        DDSPLA82
ELSEIF(IT.EQ.31) THEN                                                    DDSPLA83
   CALL DONEPL                                                           DDSPLA84
ELSEIF(IT.EQ.32) THEN                                                    DDSPLA85
   CALL XTICKS(IX)                                                       DDSPLA86
ELSEIF(IT.EQ.33) THEN                                                    DDSPLA87
   CALL YTICKS(IX)                                                       DDSPLA88
ELSEIF(IT.EQ.34) THEN                                                    DDSPLA89
   CALL MYJACT(IX)                                                       DDSPLA90
ELSEIF(IT.EQ.35) THEN                                                    DDSPLA91
   CALL MYJACT('NUMBERS')                                                DDSPLA92
   IDEL=IX                                                               DDSPLA93
   NMBS=IY                                                               DDSPLA94
ELSEIF(IT.EQ.36) THEN                                                    DDSPLA95
   CALL NOBRDR                                                           DDSPLA96
ELSEIF(IT.EQ.37) THEN                                                    DDSPLA97
   CALL DASH                                                             DDSPLA98
ELSEIF(IT.EQ.38) THEN                                                    DDSPLA99
   READ(5) S                                                             DDSPL100
   CALL RESET(S)                                                         DDSPL101
ENDIF                                                                    DDSPL102
ENDIF                                                                    DDSPL103
C                                                                        DDSPL104
   IF(IT.NE.3) GO TO 10                                                  DDSPL105
   READ(5) IOR,N,M,(TEXT(I:I),I=1,M)                                     DDSPL106
   CALL DDTEXT(N,TEXT)                                                   DDSPL107
C   PRINT 20,(TEXT(I),I=1,N)                                             DDSPL108
20 FORMAT(8A10)                                                          DDSPL109
   GO TO 10                                                              DDSPL110
C                                                                        DDSPL111
100 PRINT *,'NUMBER OF VECTORS=',KNT,IT                                  DDSPL112
```

```
      STOP                                                              DDSPL113
      END                                                               DDSPL114


      SUBROUTINE MYJSUB(IPAR,ITY,IMYJ)                                  DDSPL115
      COMMON/SUPNEG/IDEL,NMBS                                           DDSPL116
      DATA IDEL,NMBS/0,100000/                                          DDSPL117
C                                                                       DDSPL118
C  WE ARE INTERESTED ONLY IN NUMERICAL VALUES CAUSED BY                 DDSPL119
C  A CALL MYJACT('NUMBERS')(IMYJ=5)                                     DDSPL120
C                                                                       DDSPL121
      IF(ITY.GE.0 .OR. IMYJ.NE.5) RETURN                                DDSPL122
C                                                                       DDSPL123
      IF(IDEL.GT.0) IDEL=IDEL-1                                         DDSPL124
C                                                                       DDSPL125
      IF(IDEL.LE.0.AND.NMBS.GT.0) THEN                                  DDSPL126
         NMBS=NMBS-1                                                    DDSPL127
         IPAR=IABS(IPAR)                                                DDSPL128
      ENDIF                                                             DDSPL129
      END                                                               DDSPL130


      SUBROUTINE DDINIT(N,TEXT)                                         DDSPL131
C                                                                       DDSPL132
      COMMON/PLOTCN/NPLOT,INABLE,FX,FY,OFFX,OFFY                        CPLOT  2
      DATA OFFX,OFFY/0.0,0.0/                                           DDSPL134
      DATA NPLOT,INABLE,PLOTSZ,XAXIS,YAXIS/0,0,7.5,11.,8.5/             DDSPL135
C                                                                       DDSPL136
C     NO RE-INITIALIZATIONS BEFORE ENDPL'S                              DDSPL137
      IF(INABLE.GT.0) RETURN                                            DDSPL138
C                                                                       DDSPL139
      IF(NPLOT.GT.0) GO TO 10                                           DDSPL140
C                                                                       DDSPL141
       CALL COMPRS                                                      DDSPL142
      FY=PLOTSZ/1024.                                                   DDSPL143
      FX=FY                                                             DDSPL144
C                                                                       DDSPL145
10    NPLOT=NPLOT+1                                                     DDSPL146
      INABLE=1                                                          DDSPL147
      CALL NOBRDR                                                       DDSPL148
      CALL PAGE(XAXIS,YAXIS)                                            DDSPL149
      CALL PHYSOR(0.0,0.0)                                              DDSPL150
      CALL AREA2D(XAXIS,YAXIS)                                          DDSPL151
      CALL GRACE(0.0)                                                   DDSPL152
      RETURN                                                            DDSPL153
      END                                                               DDSPL154
```

```
      SUBROUTINE DDBP                                                    DDSPL155
      COMMON/PLOTCN/NPLOT,INABLE,FX,FY,OFFX,OFFY                         CPLOT  2
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                                CDDCOM 2
C                                                                        DDSPL158
C     "DDPLOT" DOES NOT REQUIRE RE-INITIALIZATION AFTER EACH FRAME       DDSPL159
C     BUT "DISPLA" DOES SO WE USE THE STATUS OF "INABLE" TO TELL US      DDSPL160
C     WHERE WE ARE.                                                      DDSPL161
      IF(INABLE.EQ.0) CALL DDINIT(-1,0)                                  DDSPL162
      CALL STRTPT(OFFX+IX*FX,OFFY+IY*FY)                                 DDSPL163
      RETURN                                                             DDSPL164
      END                                                                DDSPL165

      SUBROUTINE DDVC                                                    DDSPL166
      COMMON/PLOTCN/NPLOT,INABLE,FX,FY,OFFX,OFFY                         CPLOT  2
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                                CDDCOM 2
C                                                                        DDSPL169
C     SEE "DDBP" FOR THE REASON FOR THIS TEST.                           DDSPL170
      IF(INABLE.EQ.0) CALL DDINIT(-1,0)                                  DDSPL171
      CALL CONNPT(OFFX+IX*FX,OFFY+IY*FY)                                 DDSPL172
      RETURN                                                             DDSPL173
      END                                                                DDSPL174

      SUBROUTINE DDEND                                                   DDSPL175
      COMMON/PLOTCN/NPLOT,INABLE,FX,FY,OFFX,OFFY                         CPLOT  2
C     CHECK SYNCH, DDFR SHOULD HAVE BEEN CALLED BY NOW                   DDSPL177
      IF(INABLE.GT.0) CALL ENDPL(0)                                      DDSPL178
C                                                                        DDSPL179
      CALL DONEPL                                                        DDSPL180
C                                                                        DDSPL181
      INABLE=0                                                           DDSPL182
      RETURN                                                             DDSPL183
      END                                                                DDSPL184

      SUBROUTINE DDTEXT(N,TEXT)                                          DDSPL185
      COMMON/PLOTCN/NPLOT,INABLE,FX,FY,OFFX,OFFY                         CPLOT  2
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                                CDDCOM 2
C                                                                        DDSPL188
      IF(INABLE.EQ.0) CALL DDINIT(-1,0)                                  DDSPL189
      IF(IOR.EQ.0) CALL ANGLE(0.0)                                       DDSPL190
      IF(IOR.NE.0) CALL ANGLE(90.0)                                      DDSPL191
      CALL MESSAG(TEXT,N*10,OFFX+IX*FX,OFFY+IY*FY)                       DDSPL192
```

```
      RETURN                                                            DDSPL193
      END                                                               DDSPL194


      SUBROUTINE DDTAB                                                  DDSPL195
      RETURN                                                            DDSPL196
      END                                                               DDSPL197


      SUBROUTINE DDFR                                                   DDSPL198
      COMMON/PLOTCN/NPLOT,INABLE,FX,FY,OFFX,OFFY                        CPLOT  2
      IF(INABLE.GT.0) CALL ENDPL(0)                                     DDSPL200
      INABLE=0                                                          DDSPL201
      RETURN                                                            DDSPL202
      END                                                               DDSPL203


      SUBROUTINE SETDDOF(IXF,IYF)                                       DDSPL204
C     SETS RASTOR RANGE TO: -IXF TO 1023-IXF                            DDSPL205
C     AND -IYF TO 1023-IYF.                                             DDSPL206
      COMMON/PLOTCN/NPLOT,INABLE,FX,FY,OFFX,OFFY                        CPLOT  2
      OFFX=IXF*FX                                                       DDSPL208
      OFFY=IYF*FY                                                       DDSPL209
      END                                                               DDSPL210


      SUBROUTINE GRAFB(XORIG,XSTP,XMAX,YORIG,YSTP,YMAX,XAXIS,YAXIS)     DDSPL211
C                                                                       DDSPL212
      CALL GRAF(XORIG,XSTP,XMAX,YORIG,YSTP,YMAX)                        DDSPL213
      CALL XNONUM                                                       DDSPL214
      CALL YNONUM                                                       DDSPL215
      CALL XGRAXS(XORIG,XSTP,XMAX,XAXIS,' ',-1,0.0,YAXIS)               DDSPL216
      XR=XMAX-XORIG                                                     DDSPL217
      XAX=AINT(XR/XSTP)*XSTP*(XAXIS/XR)                                 DDSPL218
      PRINT *,XORIG,XMAX,XSTP,XAXIS,XAX                                 DDSPL219
      CALL YGRAXS(YORIG,YSTP,YMAX,YAXIS,' ',-1,XAX,0.0)                 DDSPL220
      CALL RESET('XNONUM')                                              DDSPL221
      CALL RESET('YNONUM')                                              DDSPL222
      END                                                               DDSPL223
```

```
      SUBROUTINE TITLEW(A,B,C,D,E,F,G,H)                                    DDSPL224
C     DUMMY ROUTINE ALLOWING SUBSTITUTION OF ALTERNATE TITLE PROGRAMS       DDSPL225
      CALL TITLE(A,B,C,D,E,F,G,H)                                           DDSPL226
      END                                                                   DDSPL227
```

DDALT -- Skeleton routines for reading Graphics Output File (Tape File 7)

```
      PROGRAM DDALT(TAPE5,OUTPUT)                                        DDALT
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                                DDALT
      COMMON/SUPNEG/IDEL,NMBS                                            DDALT
C                                                                        DDALT
      PARAMETER (LIMPTS=700)                                             DDALT
      REAL XV(LIMPTS),YV(LIMPTS)                                         DDALT
      INTEGER A(4),C(4),E(4)                                             DDALT
      LOGICAL COMPCL                                                     DDALT
      CHARACTER LINE*72,TEXT*80                                          DDALT
      EQUIVALENCE (IX,XXX),(IY,YYY)                                      DDALT
      DATA COMPCL/.TRUE./                                                DDALT
      DATA KNT/0/                                                        DDALT
C                                                                        DDALT
      REWIND 5                                                           DDALT
10    READ(5,END=100,ERR=100) IT,IX,IY                                   DDALT
      IF(IT.LT.-2 .OR. IT.GT.24) STOP 'PLOTTING CODE>24'                 DDALT
      KNT=KNT+1                                                          DDALT
      IF(IT.EQ.-1) THEN                                                  DDALT
         CALL DDEND                                                      DDALT
      ELSEIF(IT.EQ.-2) THEN                                              DDALT
         CALL DDFR                                                       DDALT
      ELSEIF(IT.EQ.0) THEN                                               DDALT
         READ(5) N,M,(TEXT(I:I),I=1,M)                                   DDALT
         CALL DDINIT(N,TEXT)                                             DDALT
      ELSEIF(IT.EQ.1) THEN                                               DDALT
         CALL DDBP                                                       DDALT
      ELSEIF(IT.EQ.2) THEN                                               DDALT
         CALL DDVC                                                       DDALT
      ELSEIF(IT.EQ.3) THEN                                               DDALT
         READ(5) IOR,N,M,(TEXT(I:I),I=1,M)                               DDALT
         PRINT *,N,M,' ',TEXT(:M)                                        DDALT
         CALL DDTEXT(N,TEXT)                                             DDALT
      ENDIF                                                              DDALT
      GO TO 10                                                           DDALT
C                                                                        DDALT
100   PRINT *,'NUMBER OF VECTORS=',KNT,IT                                DDALT
      STOP                                                               DDALT
      END                                                                DDALT
```

```
      SUBROUTINE DDINIT(N,ID)                                            DDALT
C     INSERT YOUR OWN ROUTINE TO INITIALIZE PLOTTING PROCESS             DDALT
C     ID IS A STRING OF CHARACTERS IDENTIFYING THE PERSON                DDALT
CGETTING THE PLOT, PHONE NUMBER, ETC.                                    DDALT
CN IS THE NUMBER OF CHARACTERS IN THE STRING "ID"                        DDALT
      RETURN                                                             DDALT
      END                                                                DDALT
```

```
      SUBROUTINE DDBP                                                   DDALT
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                               DDALT
C     INSERT YOUR OWN ROUTINE TO DEFINE A VECTOR ORIGIN AT IX,IY        DDALT
      RETURN                                                            DDALT
      END                                                               DDALT



      SUBROUTINE DDVC                                                   DDALT
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                               DDALT
CINSERT YOUR OWN ROUTINE TO PLOT A STRAIGHT LINE WITH INTENSITY         DDALT
C"IN" FROM THE ORIGIN TO THE END POSITION IX,IY.  A SINGLE CALL         DDALT
CTO DDBP FOLLOWED BY SUCCESSIVE CALLS TO DDVC (CHANGING IX,IY)          DDALT
CPLOTS CONNECTED VECTORS.                                               DDALT
      RETURN                                                            DDALT
      END                                                               DDALT



      SUBROUTINE DDEND                                                  DDALT
C     CHECK SYNCH, DDFR SHOULD HAVE BEEN CALLED BY NOW                  DDALT
CINSERT YOUR OWN ROUTINE TO EMPTY THE PLOT BUFFER AND RELEASE           DDALT
CTHE PLOTTING COMMAND FILE TO YOUR PLOTTING DEVICE.                     DDALT
      RETURN                                                            DDALT
      END                                                               DDALT



      SUBROUTINE DDTEXT(N,NT)                                           DDALT
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                               DDALT
CINSERT YOUR OWN ROUTINE TO PLOT A GIVEN ARRAY IN A TABULAR MODE        DDALT
CAFTER INITIALIZING TABULAR PLOTTING WITH DDTAB. NT IS AN ARRAY OF      DDALT
CLENGTH N, CONTAINING "TEXT" FOR TABULAR PLOTTING. SEE APPENDIX C.      DDALT
      RETURN                                                            DDALT
      END                                                               DDALT



      SUBROUTINE DDTAB                                                  DDALT
      COMMON/DD/IN,IOR,IT,IS,IC,ICC,IX,IY                               DDALT
CINSERT YOUR OWN ROUTINE TO INITIALIZE TABULAR TEXT PLOTTING            DDALT
C        SPECIFY IOR,IS,IX,IY.  TEXT WILL BEGIN AT IX,IY.               DDALT
      RETURN                                                            DDALT
      END                                                               DDALT
```

```
      SUBROUTINE DDFR                                                   DDALT
CINSERT YOUR OWN ROUTINE TO ADVANCE ONE PLOTTING FRAME, WHEN            DDALT
CPLOTTING IS COMPLETED.                                                 DDALT
      RETURN                                                            DDALT
      END                                                               DDALT
```

APPENDIX E. ERRATA FOR NOAA TECH. MEMO. ERL-WPL 103

A versatile three-dimensional Hamiltonian ray-tracing computer program for acoustic waves in the atmosphere.

by R. M. Jones, J. P. Riley, and T. M. Georges

NOAA Tech. Memo. ERL WPL-103

On page 9, the term k_ϕ r sin $d\phi/dP'$ in equation (3.17) should read k_ϕ r sinθ $d\phi/dP'$.

On page 10, the denominator in the last fraction in equation (3.18) should be C_{ref} $\partial H/\partial\omega$ instead of C $\partial H/\partial\omega$.

On page 16, $\partial\omega/\partial r$ in (4.27) should be $\partial\Omega/\partial r$.

On page 45, the last line in the caption for Figure 9 should read:
****See Table 29 for details.

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