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Technical Memorandum ERL ARL-79



A COMPARATIVE SYNOPSIS OF MODEL ATMOSPHERES FOR 1954, 1958,
1962, AND 1976 BELOW 47 KILOMETERS

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NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION /

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Research Laboratories

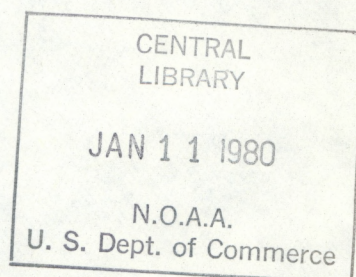
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SYMBOLLOGY

a	adopted value of lapse rate
b	subscript: layer designator
F_i	mole fractional volume
g	gravitational constant
g'_0	dimensional constant
H	geopotential height
H_b	height at layer boundary
$L_{M,b}$	temperature gradient (lapse rate)
M_i	any molecular weight
M_0	mean molecular weight (constant)
N	Newtons
P	pressure at height: H
P_b	pressure at layer boundary
R^*	universal gas constant
T	absolute temperature
T_M	molecular-scale absolute temperature at height H
$T_{M,b}$	temperature at boundary layer
Z	geometric height
ρ	density at height H

NOTE: In this report "constant" is used to designate a coefficient which remains unchanged for a given year's model.

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Research has refined atmospheric models over time. However, instruments used to explore atmospheric properties (natural constituents or man's pollutants) were often pushed to their useful limits, and, therefore, required calibration not only for the parameter of interest but also for altitude parameters which affected the primary measurement. The then current standard atmosphere was referenced for each set of measurements to compensate for the effects of pressures, density and temperature. Surviving documentation rarely specifies which year's model was used in calibration but often pressure versus altitude data are available. Also, reference to a subsequent year's model was then impossible but is now relevant. This report provides a simple means of comparing models to each other and to data records by reducing them to one equation for each parameter versus altitude. Constants and variables are tabulated by year and a computer program for generating the dependent variables is included. This work originated as a prelude to an error analysis of a family of turbine type flow sensors from 20-40 km from 1954 to the present.

1. INTRODUCTION

Since 1954, an interagency atmospheric sampling program has collected particulate matter on filter paper collection devices aboard aircraft below 20 km and above 20 km on balloon platforms [23]. In the balloon program, turbine flow sensors are used for calculating volumes required for determining particle concentrations. The period of sensor use overlaps the periods of several "standard atmospheres" [1 to 4]. Therefore, unless the relationship between calibration standards (the model atmospheres) were known, inconsistencies could exist within the data base.

To facilitate data comparisons, the four referenced standards were studied with respect to pressure, temperature, and density so that a unified approach could be applied to the group. The derivation of the general model was reviewed; pertinent constants and variables were tabulated by year; indirectly significant constants were likewise tabulated. Many properties and factors not relating to pressure, density or temperature are not considered in this comparison.

A simple program for machine generation of the models is presented. It can be used directly or as a subroutine in a larger program to implement a more complex generation and/or analysis.

2. MODEL

The equations used to calculate pressure, temperature, and density versus height in the four standard atmospheres [1 to 4] considered are equivalent but not identical. However, one set of equations can be used.

Since each year's equations were based on the same assumptions, they are all derived in the same way. The first assumption made was that air is a dry gas, obeying the perfect gas law [5].

$$\rho = \frac{M_0}{R^*} \cdot \frac{P}{T} \quad (1)$$

Second, the atmosphere is assumed to follow the hydrostatic equation [6].

$$dP = \rho g dZ \quad (2)$$

Empirical temperature versus height was then used to calculate pressure, P , and density, ρ [7,22]. Thus, the following set of equations, which were taken from the 1958 standard atmosphere [8], were adjusted to serve the altitude range of interest for any of the years

$$P = P_b \cdot \left[\frac{T_{M,b}}{T_{M,b} + L_{M,b} \cdot (H - H_b)} \right]^{\left(\frac{g'_0 \cdot M_0}{R^* \cdot L_{M,b}} \right)} \quad (3)$$

$$T_M = T_{M,b} + L_{M,b} (H - H_b) \quad (4)$$

$$\rho = \frac{P \cdot M_0}{R^* \cdot T_M} \quad (5)$$

The format of each of the above equations is different in 1954 because the lapse rate $L_{M,b}$ was defined differently [9,19]. Instead of the variable $L_{M,b}$, an adopted variable, a , was used, where,

$$a = \frac{-dT}{dH} \quad (6)$$

This was considered in formulating yearly tables of constants and variables for use with Eqs. 1 through 5.

3. CONSTANTS, REFERENCE LEVELS, AND ATMOSPHERIC COMPOSITION

The values for the variables, H_b , $L_{M,b}$, P_b , and $T_{M,b}$, were found in or calculated from the references and shown in Tables 1 through 4 for the four

standard atmospheres. Likewise, changes in the constants, R^* and M_0 , were noted. Tables 6 and 7 document the molecular weights M_i and the mole fractional volume F_i of each species for each year. These two values are used to calculate a mean molecular weight M_0 (see Table 5), thus explaining the variation in the constant. Table 6 lists a comparison of the other constants used.

3.1 Values Used Directly for Calculations

Table 1: Calculation Variables for 1954				
Subscript	Geopotential Height	Temperature Gradient	Pressure	Temperature
b	H_b	$L_{M,b}$ [10]	P_b [11]	$T_{M,b}$ [12]
unitless	km	$^{\circ}\text{K}/\text{km}$	mb	$^{\circ}\text{K}$
0	0	-6.5	1013.25	288.16
1	11	0.0	227.317	216.66
2	20		54.7478	216.66

Table 2. Calculation Variables for 1958 [13]				
Subscript	Geopotential Height	Temperature Gradient	Pressure	Temperature
b	H_b	$L_{M,b}$	P_b	$T_{M,b}$
unitless	km	$^{\circ}\text{K}/\text{km}$	mb	$^{\circ}\text{K}$
0	0	-6.5	1013.25	288.16
1	11	0.0	226.318	216.66
2	25	3.0	24.8861	216.66
3	47		1.20441	282.66

Table 3. Calculation Variables for 1962

Subscript	Geopotential Height	Temperature Gradient	Pressure	Temperature
b	H_b	$L_{M,b}$ [14]	P_b [15]	$T_{M,b}$ [14]
unitless	km	$^{\circ}\text{K}/\text{km}$	mb	$^{\circ}\text{K}$
0	0		1013.25	288.15
1	11	-6.5	226.321	216.65
2	20	0.0	54.7489	216.65
3	32	+1.0	8.68014	228.65
4	47	+2.8	1.10901	270.65

Table 4. Calculation Variables for 1976

Subscript	Geopotential Height	Temperature Gradient	Pressure	Temperature
b	H_b [16]	$L_{M,b}$ [16]	P_b [16]	$T_{M,b}$ [16]
unitless	km	$^{\circ}\text{K}/\text{km}$	mb	$^{\circ}\text{K}$
0	0		1013.25	288.15
1	11	-6.5	226.321	216.65
2	20	0.0	54.7489	216.65
3	32	+1.0	8.68014	228.65
4	47	+2.8	1.10901	270.65

Table 5. Adopted Constants					
symbol	units	1954	1958	1962	1976
M_O	kg/kmol	28.966	28.966	28.9644	28.9644
R^*	N·M/(kmol·K)	8.31436E03	8.31439E03	8.31432E03	8.31432E03
g_O'	---	9.80665	9.80665	9.80665	9.80665

3.2 Values Used Indirectly

Table 6. Adopted Constants					
symbol	units	YEAR			
		1954	1958	1962	1976
M_i	kg/kmol		See table 8		
F_i	---		See table 7		
k	N·M/k	----	----	----	1.380622E-26
N_A	kmol ⁻¹	----	6.02390E26	6.02257E26	6.022169E26
g_O	m/s ⁻²	9.80665	9.80665	9.80665	9.80665

Table 7. F_i , Fractional Volume (dimensionless)

species	YEAR			
	1954 [18]	1958 [19]	1962 [20]	1976 [16]
N ₂	0.7809	0.7809	0.78084	0.78084
O ₂	0.2095	0.2095	0.209476	0.209476
Ar	0.93E-02	0.93E-02	0.934E-02	0.934E-02
CO ₂	0.03E-02	0.03E-02	0.314E-02	0.314E-02
Ne	1.8E-05	1.8E-05	0.1818E-04	0.1818E-04
He	5.24E-06	5.24E-06	0.524E-05	0.524E-05
Kr	1.0E-06	1.0E-06	0.114E-05	0.114E-05
Xe	8.0E-08	8.0E-08	0.87E-07	0.87E-07
H ₂	5.0E-07	5.0E-07	0.50E-06	0.50E-06
CH ₄	-----	-----	0.20E-05	0.20E-05
N ₂ O	-----	-----	0.50E-06	-----
O ₃	1.0E-08	1.0E-08	0.10E-05	-----
SO ₂	-----	-----	0.10E-05	-----
NO ₂	-----	-----	0.20E-07	-----
NH ₃	-----	-----	0 to trace	-----
CO	-----	-----	0 to trace	-----
I ₂	-----	-----	0 to 0.10E-07	-----
Rn	6.0E-20	6.0E-20	-----	-----

Table 8. A Comparison of Molecular Weights (kg/kmol)

species	YEAR			
	1954 [21]	1958 [19]	1962 [20]	1976 [16]
N ₂	28.016	28.016	28.0134	28.0134
O ₂	32.000	32.000	31.9988	31.9988
Ar	39.944	39.944	39.948	39.948
CO ₂	44.010	44.010	44.00995	44.00995
Ne	20.183	20.183	20.183	20.183
He	4.003	4.003	4.0026	4.0026
Kr	83.7	83.7	83.80	83.80
Xe	131.3	131.3	131.30	131.30
H ₂	2.0160	2.0160	2.01594	2.01594
CH ₄	-----	-----	16.04303	16.04303
N ₂ O	-----	-----	44.0128	-----
O ₃	48.000	48.000	47.9982	-----
SO ₂	-----	-----	64.0628	-----
NO ₂	-----	-----	46.0055	-----
NH ₃	-----	-----	17.03061	-----
CO	-----	-----	28.01055	-----
I ₂	-----	-----	253.8088	-----
Rn	222	222	-----	-----

4. COMPUTER PROGRAM

4.1 Mnemonic Codes

BØ	dummy layer designator
G	dimensional constant
H	entered geopotential height
H (Y,BØ)	height at layer boundary
H1,...,H5	boundary test points
L (Y,BØ)	lapse rate
MØ (Y)	mean molecular weight
P	pressure at height H
P (Y,BØ)	reference pressure at layer boundary
RØ	density at height H
R (Y)	universal gas constant
T (Y,BØ)	temperature at layer boundary
TØ	temperature at altitude H
YØ	year

4.2 Discussion

The program reproduces the pressure (mb), density (kg/m^3), and temperature ($^{\circ}\text{K}$) printed in references [1] through [4]. It incorporates equations (1) through (5) with Tables 1 through 4 according to the following flow chart.

Two points are noteworthy. First, where the lapse rate equals zero, +0.0001 was used. Second, a hypothetical composite model facilitates handling any particular model atmosphere by having layer boundaries at every altitude having a boundary in all four models. Therefore, if in a particular model year the lapse rate $L_{M,b}$ doesn't change at the test point, then $L_{M,b}$, P_b , and $T_{M,b}$ are input at values calculated from the next lower (in height) boundary.

5. CONCLUSION

The objectives set forth in the introduction were met by several equations and tables. Supporting tables clarify some changes in the principle tables.

A computer program for generating pressure, density, and temperature versus altitude is attached. It can be used directly, as a subroutine, or restructured into a larger program for the purposes of interested parties.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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- [4] COESA, 1976: "U.S. Standard Atmosphere, 1976." U.S. Government Printing Office, Washington, DC.
- [5] Ref. [1], p. 4.
- [6] Ref. [1], p. 5.
- [7] Ref. [4], p. 23.
- [8] Ref. [2], p. 6,7.
- [9] Ref. [1], p. 9.
- [10] Ref. [1], p. 9,128.
- [11] Ref. [1], p. 128.
- [12] Ref. [1], p. 8,9.
- [13] Ref. [2], p. 6.
- [14] Ref. [3], p. 16.
- [15] Ref. [3], p. 4.
- [16] Ref. [4], p. 3.
- [17] Ref. [4], p. 4.

[18] Ref. [1], p. 2.

[19] Ref. [2], p. 5.

[20] Ref. [3], p. 9.

[21] Ref. [1], p. 3.

[22] Ref. [3], p. 19.

[23] Ashenfelter, T.E., 1966, "Summary of the Balloon Sampling Program for 1976," Health and Safety Laboratory Quarterly Summary Report, NASL-172, 19-22. Available from National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

APPENDIX
FLOW CHARTS AND PROGRAM

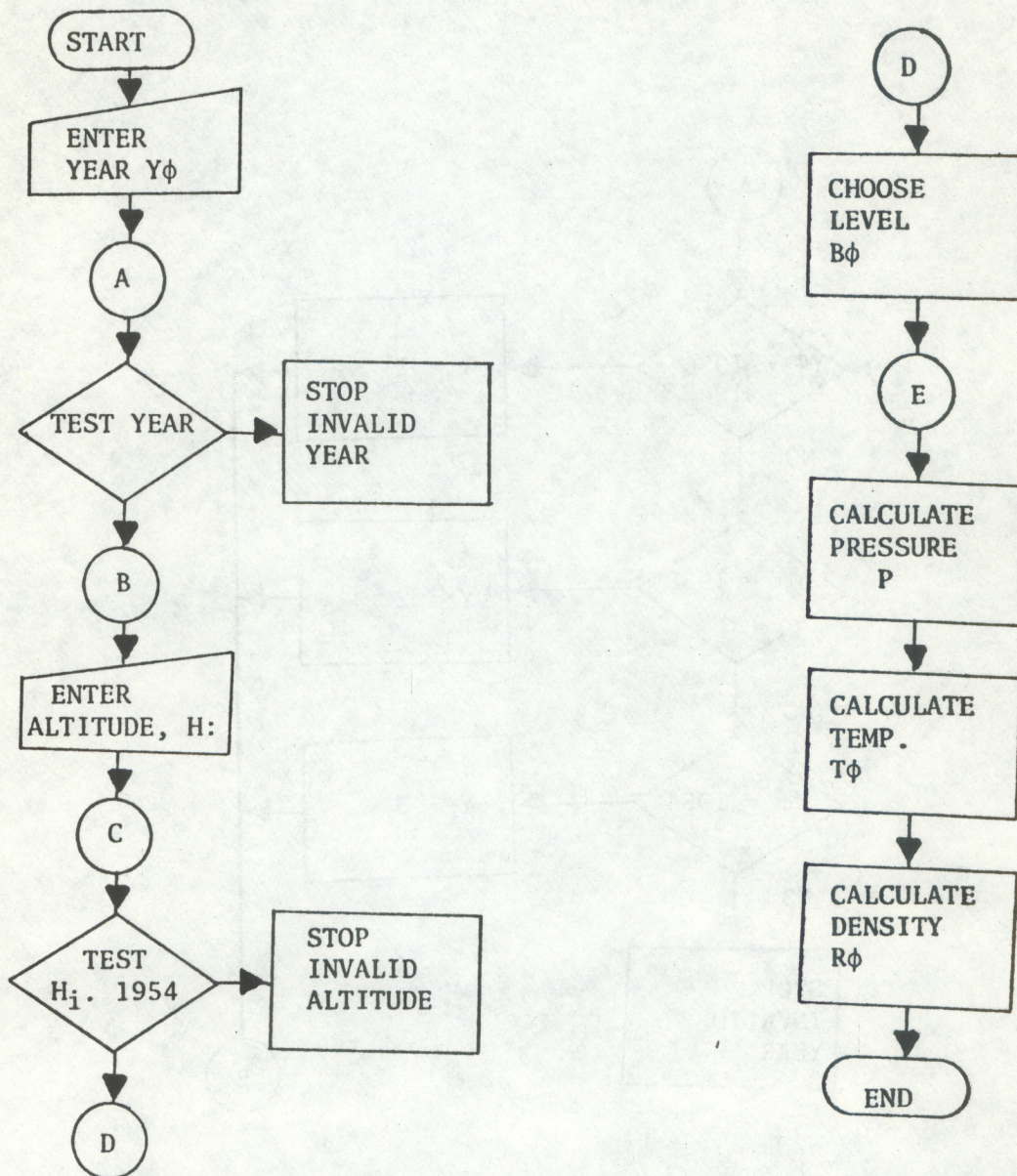


Figure 1. General Flow Chart.

*See detailed figures.

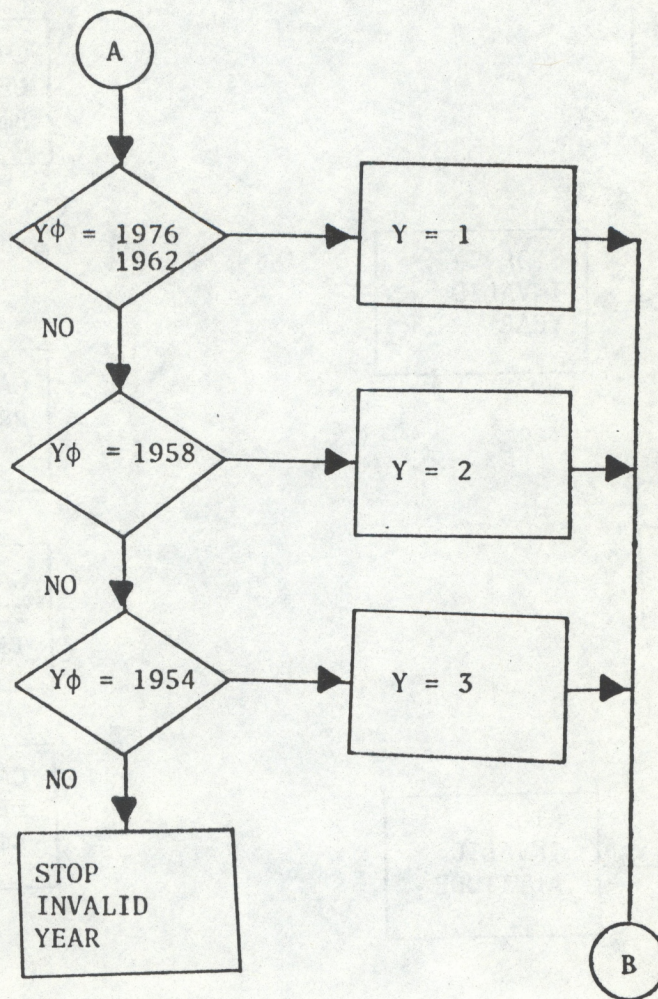


Figure 2. Detail of Year Test.

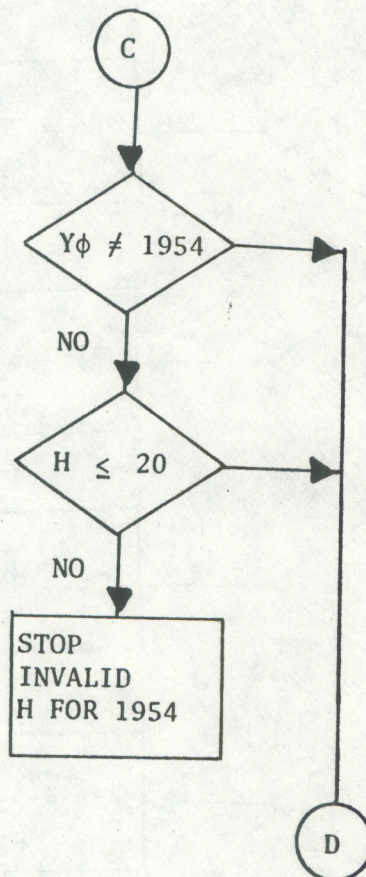


Figure 3. Detail of H Test for 1954.

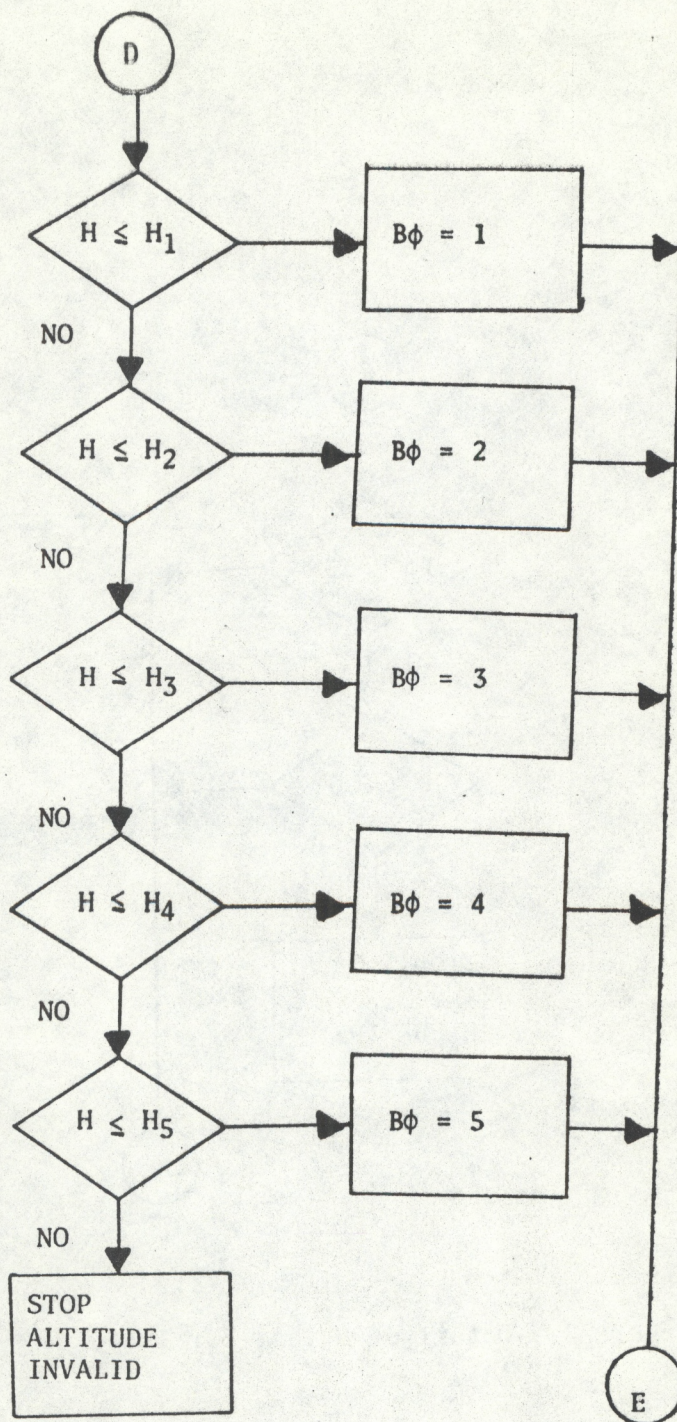


Figure 4. Detail of $B\phi$ Selection.


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10 REM "PRSALT01" THIS PROGRAM USES THE USSA OF 1976,1962,
1958,1954 TO RELATE PRESSURE,TEMPERATURE,AND DENSITY TO AN ENTER
ED GEOPOTENTIAL ALTITUDE
20 DIM L(3,5),T(3,5),P(3,5),H(3,5),R(3),M0(3)
30 L(1,1),L(2,1),L(3,1)=-6.5:L(1,2),L(2,2),L(3,2),L(2,3)=.0001
40 L(1,3),L(1,4)=1.0:L(2,4),L(2,5)=3.0:L(1,5)=2.8
50 T(1,1)=288.15:T(2,1),T(3,1)=288.16:T(1,2),T(1,3),T(1,4)=216.6
5:T(2,2),T(2,3),T(2,4),T(3,2)=216.66:T(1,5)=228.65:T(2,5)=237.66
60 P(1,1),P(2,1),P(3,1)=1013.25:P(1,2)=226.321:P(2,2)=226.3184
70 P(3,2)=226.3172:P(1,3),P(1,4)=54.7489:P(2,3)=54.7485
80 P(2,4)=24.88613:P(1,5)=8.68014:P(2,5)=8.6777
90 H(1,1),H(2,1),H(3,1)=0:H(1,2),H(2,2),H(3,2)=11:H(1,3),H(2,3),
H(1,4)=20:H(2,4)=25:H(2,5),H(1,5)=32
100 R(1)=8.31432:R(2)=8.31439:R(3)=8.31436
110 M0(1)=28.9644:M0(2),M0(3)=28.966: G=9.80665
120 INPUT "ENTER YEAR",Y0
130 INPUT "WILL THE YEAR REMAIN CONSTANT (YES=1,NO=0)",D0
140 IF Y0=1976 THEN 180: IF Y0=1962 THEN 180
150 IF Y0=1958 THEN 200: IF Y0=1954 THEN 220
160 STOP "--INVALID YEAR--"
170 GOTO 120
180 Y=1
190 GOTO 230
200 Y=2
210 GOTO 230
220 Y=3
230 INPUT "GEOPOTENTIAL HEIGHT IN KM",H
240 IF Y0<>1954 THEN 280
250 IF H<=20 THEN 280
260 STOP "--INPUT ALTITUDE INVALID IN 1954--"
270 GOTO 120
280 H1=11:H2=20:H3=25:H4=32:H5=47
290 IF H<=H1 THEN 340: IF H<=H2 THEN 350
300 IF H<=H3 THEN 360: IF H<=H4 THEN 370
310 IF H<=H5 THEN 380
320 STOP "--THE INPUT ALTITUDE EXCEEDS 47KM--"
330 GOTO 120
340 B0=1:GOTO 390
350 B0=2:GOTO 390
360 B0=3:GOTO 390
370 B0=4:GOTO 390
380 B0=5
390 P=P(Y,B0)*(T(Y,B0)/(T(Y,B0)+L(Y,B0)*(H-H(Y,B0))))^(G*M0(Y)/(
R(Y)*L(Y,B0))): PRINT "PRESSURE IN MB P=";P
400 T0=T(Y,B0)+L(Y,B0)*(H-H(Y,B0)): PRINT "TEMP IN K T0=";T0
410 R0=P*M0(Y)/(R(Y)*T0*10): PRINT "DENSITY IN KG/ME3 R0=";R0
420 IF D0=1 THEN 230: GOTO 120
430 END

```