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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey

# A User's Guide to a Computer Program for Harmonic Analysis of Data at Tidal Frequencies

R. E. DENNIS AND E. E. LONG

ROCKVILLE, MD.
July 1971

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R. E. DENNIS AND E. E. LONG

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# A User's Guide to a Computer Program for Harmonic Analysis of Data at Tidal Frequencies

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ABSTRACT. This report describes a FORTRAN-IV program for the harmonic analysis of a series of 15 or 29 days of uniformly spaced tidal data (observations). The program is usable with minor modifications on any computer with a 140K memory which accepts FORTRAN input. The mathematical basis and equations for the determina tion of tidal constants from observational data are given. This report should be u sed with Manual of Harmonic Analysis and Prediction of Tides, C&GS Special Publication No. 98, Revised (1940) Edition, published in 1941, for reference to formulas and tables.

It was recognized in ancient time that tides follow a relatively regular cycle, recurring periodically. Since any periodic motion or oscillation can be resolved into components consisting of simple harmonic motions, a method for reducing tidal motions to these components was inevitable. Lord Kelvin devised such a method about 1867. His method followed the suggestions and speculations made by Laplace, Young, and Airy during the earlier part of the 19th century, but full credit belongs to Kelvin for making such analysis practical. In the late 19th century and early 20th century, William Ferrel and Rollin A. Harris of the U.S. Coast and Geodetic Survey both made important contributions to harmonic analysis of tides and interpretation of the results.

In 1885, Leland P. Shidy of the U.S. Coast and Geodetic Survey designed a set of stencils for the "Standard Method" of harmonic analysis of observational data (Report of the U.S. Coast and Geodetic Survey, 1893, Vol. 1, p. 108). A stencil with apertures was fitted over tabulations of observed data to obtain sums for computing the harmonic constants of the tidal constituents. Only after this —a process involving computation of values for about 20 coefficients for use in the tide equations—could the tide prediction begin. Operational harmonic analysis was continued by hand until the presently used computer system was implemented in 1965.

The original version of this program for the standard harmonic analysis of tidal data was completed in 1965. Since then, improvements in the method and refinements in programing have yielded a program that can analyze the observational data for a station in as little as 1.5 seconds on a CDC-6600 computer.

## BASIC HARMONIC EQUATION AND DETERMINATION OF TIDAL CONSTANTS FROM OBSERVATIONAL DATA

For analyzing equally spaced short-period data (15 days or 29 days), this program utilizes the standard Fourier analysis and traditional methods of the former Coast and Geodetic Survey described by Schureman (1941) with extracts from Doodson (1924) and Harris (1897) reports on tidal analysis.

Harmonic analysis of tidal data entails three basic processes:

1. Initial separation of the tidal constituents from the data
2. Orientation of the constituent tides with the astronomical elements
3. Elimination from each constituent sought of effects of other tidal constituents

The equation

$$h = H_0 + \sum_n f_n H_n \cos [a_n t - (\kappa_n - [V_0 + u]_n)] \tag{1}$$

describes the height of tide at any time for which

$H_0$—mean value of tide for observations

$$H_0 = \frac{1}{N} \sum_{i=0}^{N-1} h_i$$

$t$—time reckoned from some arbitrary point

$f_n$—node factor of constituent

$H_n$—mean amplitude of the constituent

$a_n$—speed of constituent

$\kappa_n$—epoch of the constituent at $t = 0$ for period of observation

$(V_0+u)_n$—value of argument of constituent at $t = 0$ for period of observation

$n$—any particular constituent being computed

$N$—total number of data values used in analysis

The factor $H_n$ is the mean amplitude of constituent, $n$, for an entire nodal period, whereas the adjustment using the node factor $f_n$, denoted

$$R_n = f_n H_n \tag{2}$$

is the amplitude pertaining to a particular time. The amplitudes $R_n$ are derived from observational data.

Although the constant $\kappa_n$ is used ultimately to characterize the constituent, the quantity $\kappa_n - (V_0+u)_n$ may be designated

$$\zeta_n = \kappa_n - (V_0+u)_n \tag{3}$$

where $\zeta_n$ is derived from the data. $\zeta_n$ represents the phase of the constituent at $t = 0$ for a particular series of observations.

To use the tidal equation in harmonic form we follow Schureman's (1941) discussion of the Fourier series technique. The curve described by

$$h = H_0 + C_1 \cos \Theta + C_2 \cos 2\Theta + \ldots C_k \cos k\Theta + S_1 \sin \Theta + S_2 \sin 2\Theta + \ldots S_l \sin l\Theta \tag{4}$$

will pass through the $N$ coordinates given by ordinates $h_0$, $h_1$, $h_2$, $h_3$, . . ., $h_{N-1}$ and abscissas O, $\delta$, $2\delta$, . . ., $(N-1)\delta$ where $N\delta = 2\pi$ provided that

$$C_p = \frac{2}{N} \sum_{i=0}^{N-1} h_i \cos ip\delta \tag{5}$$

and

$$S_p = \frac{2}{N} \sum_{i=0}^{N-1} h_i \sin ip\delta \tag{6}$$

Since the limits of $k$ and $l$ are

$$\text{for } N \text{ even,} \begin{cases} \lim k = \dfrac{N}{2} \\ \lim l = \dfrac{N}{2} - 1 \end{cases}$$

$$\text{for } N \text{ odd, } \lim k = \lim l = \frac{N-1}{2}$$

the limit of $p$ is correspondingly always less than $\frac{N}{2}$.

When $\Theta$ represents the constituent day, $C_1$ and $S_1$ corresponding to $p = 1$ represent the diurnal constituents, and $C_2$, $S_2$ corresponding to $p = 2$ represent the semidiurnal constituents. For tidal work values of $p$ greater than 8 are seldom used, so the limit of $N/2$ has no significance.

Using the notation

$a$ = speed of constituent sought in degrees per solar hour

$\delta$ = length of sampling period in solar hours

the coefficient equations may be written more exactly for real data:

$$C_p = \frac{2}{N} \sum_{i=1}^{N} h_i \cos\left[(i-1)\left(\frac{\pi}{180} a\delta p\right)\right] \tag{7}$$

$$S_p = \frac{2}{N} \sum_{i=1}^{N} h_i \sin\left[(i-1)\left(\frac{\pi}{180} a\delta p\right)\right] \tag{8}$$

From the Fourier coefficients in equations (7) and (8) desired harmonic constants are defined:

$$\zeta'(A) = \tan^{-1}\left(\frac{S_p}{C_p}\right) \tag{9}$$

$$R'(A) = (S_p^2 + C_p^2)^{1/2} \tag{10}$$

The quantity $\zeta'(A)$ is the phase at $t = 0$, and $R'(A)$ the amplitude for the constituent during the particular series of observations. Both symbols are primed, designating that the effects of other constituents have not been removed. For each constituent the quantity $p$ in the coefficient equations equals the coefficient of the hour angle of the mean sun, $T$, in the equilibrium argument of that constituent.

Subroutine FORAN in the program does the entire Fourier summation for each desired constituent. $R'$ and $\zeta'$ are determined from the original series for five major constituents $M_2$, $S_2$, $N_2$, $O_1$, and $K_1$ and the harmonics $M_4$, $M_6$, $M_8$, $S_4$, and $S_6$. In the case of a 15-day series of observations, the $N_2$ constituent is approximated from the constants for $M_2$.

### Astronomical Adjustments

Modifications of $R'$ and $\zeta'$ must be made to reduce these constants from the particular time of observation to mean values for an entire nodal period. The epochs of each constituent $(V_0 + u)_n$ must be computed to adjust $\zeta'_n$ to $\kappa'_n$ and node factors $f_n$ determined to resolve $R'_n$ to $H'_n$ for the entire nodal period.

### Calculation of Orbital Functions

Prior to either adjustment, certain orbital elements and functions of these elements must be calculated. These are:

*Primary Orbital Elements*

$s$—mean longitude of the moon
$p$—mean longitude of lunar perigee
$h$—mean longitude of the sun
$p_1$—mean longitude of solar perigee
$N$—longitude of ascending lunar node
$\iota$—inclination of moon's orbit to plane of ecliptic
$\omega$—obliquity of the ecliptic

*Secondary Orbital Functions*

$I$—obliquity of the moon's orbit
$\nu$—longitude in the celestial equator (right ascension) of the moon's intersection with the equator
$\xi$—longitude in the moon's orbit of the moon's intersection with the celestial equator
$\nu'$—a function of the moon's orbit (this term appears in the argument of lunisolar constituent $K_1$)
$2\nu''$—another function of the moon's orbit (this term appears in the argument of lunisolar constituent $K_2$)
$P$—mean longitude of lunar perigee reckoned from lunar intersection in the celestial equator

Each of the orbital elements must be calculated for the beginning of the series before the epochs can be computed. The subroutines ASTRO and ORBIT compute these elements. Formulas for their determination used in the program and found in table 1 are compiled from Newcomb (1912) and Doodson (1924). Detailed discussion of these elements can be found in these references and in other works on celestial mechanics.

Computation of the secondary orvital functions are based on the assumption $\iota$ and $\omega$ are constant. This assumption may be reliable for as much as 4 centuries prior to or after the year 1900, as $\omega$ is defined by the function

$$\omega = 23.45229444° - 0.0130125°T - 0.000001638°T^2$$

and varies only 0.1 degree in 4 centuries. ($T$ defined in table 1.) Formulas for the secondary orbital functions are given in table 2, based on Baird (1886) and Schureman (1924).

### Computation of the Equilibrium Arguments

Equilibrium arguments $(V + u)$ are combinations of the lunar and solar elements in the tidal equations derived from lunar and solar motion and are denoted by the symbol $E$(A). They serve to identify the constituent and determine its speed and period, fixing times of extrema for the corresponding tidal force. When referring the argument $E$ to the time at the beginning of a particular series, the argument becomes $V_0 + u$. The basic equations for computing the equilibrium arguments are taken from Schureman (1924). Equilibrium arguments for $(MK)_3$, $(2MK)_3$, $(MN)_4$, $(MS)_4$, $(2SM)_2$, Mf, MSf, Mm, Sa, and Ssa are omitted because they have negligible effect upon the maxima and minima for a short-period analysis. $M_3$ and $S_1$ are also omitted because their effects cannot be determined from a short period analysis.

### Computation of Node Factors

The ratio of the true obliquity of the moon's orbit for any particular value of $I$ to the mean value of the obliquity over an entire nodal period is called the *node factor*. This factor applied to the mean constituent amplitude for a nodal period yields the amplitude for the constituent at that particular value of $I$. Conversely, the reciprocal of the node factor applied to the tidal coefficients determined from a particular series reduces them to a mean value for the constituent for all positions of the lunar node. Equations used for computation of the node factors were extracted from Harris (1897) and Schureman (1941) and are shown in table 3.

TABLE 1.—*Formulas for computation of orbital elements*

**Formulas for adjustment of orbital elements to beginning of century:**

$$s' = 270.43742222° + 307.892°T + 0.002525°T^2 + 0.00000189°T^3 + s_o z$$

$$p' = 334.32801944° + 109.0322055°T - 0.01034444°T^2 - 0.0000125°T^3 + p_o z$$

$$h' = 279.69667778° + 0.768925°T + 0.0003025°T^2 + h_o z$$

$$p_1' = 281.22083333° + 1.719175°T + 0.00045278°T^2 + 0.00000333°T^3 + p_{1o} z$$

$$N' = 259.18253333° - 134.1423972°T + 0.00210556°T^2 + 0.00000222°+T^3 + N_o z$$

**Formulas for adjustment of orbital elements to beginning of observations:**

[For beginning of the series]

$$s = s' + 129.38482032\,[Y-C] + 13.176396768\,[D_s+X] + 0.549016532 \quad \text{[grbs]}$$

$$p = p' + 40.66246584\,[Y-C] + 0.111404016\,[D_s+X] + 0.004641834 \quad \text{[grbs]}$$

$$h = h' - 0.238724988\,[Y-C] + 0.9856473288\,[D_s+X] + 0.0410686387 \quad \text{[grbs]}$$

$$p_1 = p_1' + 0.1717836\,[Y-C] + 0.000047064\,[D_s+X] + 0.000001961 \quad \text{[grbs]}$$

[For middle of series]

$$p = p' + 40.66246584\,[Y-C] + 0.111404016\,[D_m+X] + 0.004641834 \quad \text{[grms]}$$

$$N = N' + 19.328185764\,[Y-C] - 0.0529539336\,[D_m+X] - 0.0022064139 \quad \text{[grms]}$$

$s_o, p_o, h_o, p_{1o}, N_o$—Speeds of the elements (degrees/solar day)

$s', p', h', p_1', N'$—Values of the elements at the beginning of any century

$s, p, h, p_1, N$—Values of the elements at any given time

$T$—Nearest whole number of Julian centuries (36525 days,) from Greenwich Mean Noon, December 31, 1899, on the Gregorian Calendar to the beginning of the century for observations

$Y$—The exact year in which observations are recorded

$C$—The century during which observations are recorded

$z$—A factor representing the time difference (in solar days) formed between the Gregorian calendar date and the time $T$ as calculated in Julian centuries

$D_s$—The day of the year during which observations begin

$D_m$—The day of the year upon which the midpoint of the series falls

$X$—Correction for leap years

$$X = 0.25\,[Y-(c+1)]$$

truncated to no decimals

grbs—Greenwich hour at the beginning of the series

grms—Greenwich hour at the middle of the series

TABLE 2.—*Formulas for secondary orbital functions*

$$I = \cos^{-1}[0.9136949 - 0.0356926 \cos N]^*$$

$$\nu = \sin^{-1}[0.0897056 \sin N / \sin I]^*$$

$$\xi = \tan^{-1}\left[\frac{(0.206727 \sin N)(1 - 0.0194926 \cos N)}{0.9979852 + 0.206727 \cos N - 0.0020148 \cos 2N}\right]^{**}$$

$$\nu' = \tan^{-1}\left[\sin \nu \div \left(\cos \nu + \frac{0.334766}{\sin 2I}\right)\right]^{**}$$

$$2\nu'' = \tan^{-1}\left[\sin 2\nu \div \left(\cos 2\nu + \frac{0.0726184}{\sin^2 I}\right)\right]^{**}$$

$$P = [p \text{ (for middle of series)} - \xi]^*$$

$$u \text{ of } L_2 = 2(\xi - \nu) - R \pm 180°^*$$

where $$R = \tan^{-1}[\sin 2P / \{(\cos^2 0.5I / 6 \sin^2 0.5I) - \cos 2P\}]$$

$$u \text{ of } M_1 = (\xi - \nu) + Q + 90°^*$$

where $$Q = \tan^{-1}[\{(5 \cos I - 1) / (7 \cos I + 1)\} \tan P]$$

---

*Schureman (1924)
**Baird (1886)

TABLE 3.—*Formulas for calculation of node factor reciprocals*

$$F(\mathrm{A}) \cdot f(\mathrm{A}) = 1.000$$

$$f(\mathrm{A}) = \text{node factor of constituent A.}$$

$$F(\mathrm{M}_2) = (0.91544) \div (\cos^4 0.5\, I)$$

$$F(\mathrm{S}_2) = F(\mathrm{R}_2) = F(\mathrm{T}_2) = F(\mathrm{P}_1) = F(\mathrm{S}_4) = F(\mathrm{S}_6) = 1.000$$

$$F(\mathrm{O}_1) = (0.37988) \div (\sin I \cos^2 0.5\, I)$$

$$F(\mathrm{K}_1) = (0.8965 \sin^2 2I + 0.6001 \sin 2I \cos \nu + 0.1006)^{-1/2}$$

$$F(\mathrm{K}_2) = (19.0444 \sin^4 I + 2.7702 \sin^2 I \cos 2\nu + 0.0981)^{-1/2}$$

$$F(\mathrm{L}_2) = F(\mathrm{M}_2) \times [1 - (12 \sin^2 0.5\, I \cos 2P) \div (\cos^2 0.5\, I) + (36 \sin^4 0.5\, I) \div (\cos^4 0.5\, I)]^{-1/2}$$

$$F(\mathrm{J}_1) = (0.72137) \div \sin 2I$$

$$F(\mathrm{M}_1) = F(\mathrm{O}_1) \times (2.310 + 1.435 \cos 2P)^{-1/2}$$

$$F(\mathrm{OO}) = (0.016358) \div (\sin I \sin^2 0.5\, I)$$

$$F(\mathrm{N}_2) = F(2\mathrm{N}) = F(\lambda_2) = F\mu_2) = F(\nu_2) = F(\mathrm{M}_2)$$

$$F(\mathrm{Q}_1) = F(2\mathrm{Q}) = F(\mathrm{P}_1) = F(\mathrm{O}_1)$$

$$F(\mathrm{M}_4) = F^2(\mathrm{M}_2)$$

$$F(\mathrm{M}_6) = F^3(\mathrm{M}_2)$$

$$F(\mathrm{M}_8) = F^4(\mathrm{M}_2)$$

### Inference of $R'$, $\kappa'$, $\zeta'$ for Secondary Constituents

Following the discussion of Schureman, the relations existing between observational constants of similar constituents are assumed the same as those existing between the corresponding theoretical values. Since values for only 10 constituents are sought ($M_2$, $S_2$, $N_2$, $O_1$, $K_1$, $M_4$, $M_6$, $M_8$, $S_4$, $S_6$), the other constituents, although minor in effect, must be approximate before the process of elimination can be applied to the major constituents. In the program this is done using the formulas given by Schureman (1941).

### Elimination of Perturbations From Secondary Constituents

The disturbing effects upon $S_2$ by $K_2$ and $T_2$ and on $K_1$ by $P_1$ may be considerable in a short series owing to the small differences in frequencies of the respective constituents. To correct for this, account is taken of the phase displacement and augmentation of amplitude in the major constituents $S_2$ and $K_1$ by the respective minor constituent disturbances. This process is described by Schureman (1941) and performed by the computer using the imbedded data from tables 21-26 from the *Manual of Harmonic Analysis and Prediction of Tides.*

The final process of elimination frees the constituents from the disturbing effects of the other constituents. The constituents sought are $M_2$, $N_2$, $S_2$, $O_1$, $K_1$. Only constituents with the same coefficient for the factor $T$ in their equilibrium argument are considered interfering, that is, effects of diurnal upon semidiurnal and vice versa are negligible.

Complete discussion of constituent interference is found in Schureman (1941). The program completes the elimination process, using tables prepared from equations 389, 390 from Schureman (1941, table 29).

### Harmonic Constants

Inference of secondary constituents from primary constituents utilizes the ratios derived by Schureman (1941) and shown in table 4.

Table 4.—*Formulas for inference of secondary constituents*

Diurnal constituents

$$H(J_1) = 0.079\, H(O_1); \quad \kappa(J_1) = \kappa(K_1) + 0.496\, [\kappa(K_1) - \kappa(O_1)]$$
$$H(M_1) = 0.071\, H(O_1); \quad \kappa(M_1) = \kappa(K_1) - 0.500\, [\kappa(K_1) - \kappa(O_1)]$$
$$H(OO) = 0.043\, H(O_1); \quad \kappa(OO) = \kappa(K_1) + 1.000\, [\kappa(K_1) - \kappa(O_1)]$$
$$H(P_1) = 0.331\, H(K_1); \quad \kappa(P_1) = \kappa(K_1) - 0.075\, [\kappa(K_1) - \kappa(O_1)]$$
$$H(Q_1) = 0.194\, H(O_1); \quad \kappa(Q_1) = \kappa(K_1) - 1.496\, [\kappa(K_1) - \kappa(O_1)]$$
$$H(2Q) = 0.026\, H(O_1); \quad \kappa(2Q) = \kappa(K_1) - 1.992\, [\kappa(K_1) - \kappa(O_1)]$$
$$H(\rho_1) = 0.038\, H(O_1); \quad \kappa(\rho_1) = \kappa(K_1) - 1.429\, [\kappa(K_1) - \kappa(O_1)]$$

Semidiurnal constituents

$$H(K_2) = 0.272\, H(S_2); \quad \kappa(K_2) = \kappa(S_2) + 0.081\, [\kappa(S_2) - \kappa(M_2)]$$
$$H(L_2) = 0.028\, H(M_2); \quad \kappa(L_2) = \kappa(S_2) - 0.464\, [\kappa(S_2) - \kappa(M_2)]$$
$$= 0.143\, H(N_2); \quad = \kappa(M_2) + 1.000\, [\kappa(M_2) - \kappa(N_2)]$$
$$H(N_2) = 0.194\, H(M_2); \quad \kappa(N_2) = \kappa(S_2) - 1.536\, [\kappa(S_2) - \kappa(M_2)]$$
$$H(2N) = 0.026\, H(M_2); \quad \kappa(2N) = \kappa(S_2) - 2.072\, [\kappa(S_2) - \kappa(M_2)]$$
$$= 0.133\, H(N_2); \quad = \kappa(M_2) - 2.000\, [\kappa(M_2) - \kappa(N_2)]$$
$$H(R_2) = 0.008\, H(S_2); \quad \kappa(R_2) = \kappa(S_2) + 0.040\, [\kappa(S_2) - \kappa(M_2)]$$
$$H(T_2) = 0.059\, H(S_2); \quad \kappa(T_2) = \kappa(S_2) - 0.040\, [\kappa(S_2) - \kappa(M_2)]$$
$$H(\lambda_2) = 0.007\, H(M_2); \quad \kappa(\lambda_2) = \kappa(S_2) - 0.536\, [\kappa(S_2) - \kappa(M_2)]$$
$$H(\mu_2) = 0.024\, H(M_2); \quad \kappa(\mu_2) = \kappa(S_2) - 2.000\, [\kappa(S_2) - \kappa(M_2)]$$
$$H(\nu_2) = 0.038\, H(M_2); \quad \kappa(\nu_2) = \kappa(S_2) - 1.464\, [\kappa(S_2) - \kappa(M_2)]$$
$$= 0.194\, H(N_2); \quad = \kappa(M_2) - 0.866\, [\kappa(M_2) - \kappa(N_2)]$$

## USERS' GUIDE TO PROGRAM

The present program is written in FORTRAN-IV, executable with minor adjustments on any compatible machine having a 140K memory and access to arcsine and arccosine systems functions. Computing time is approximately 1.5 seconds on the CDC-6600.

Either a vector (polar form) or scalar variable may be analyzed. For vector series, the program allows either a major-minor axis analysis or a north-east component approach. No data series may exceed 7,000 terms without redimensioning in the program, and no series of other than 15 or 29 days of uniformly spaced data can be analyzed.

The program accepts input via magnetic tape or punched cards in any format with the restriction that, for vectors with magnitude and direction in the same record, the angles must precede the amplitudes in the record. For vectors specified by one file of amplitudes and one file of directions, the amplitude file must be read first.

Output comprises the mean amplitudes and phases of 26 tidal constituents.

### Explanation of Control Cards

The order of the control cards (fig. 1) input to the machine is of utmost importance. The discussion of each card or set of cards is in the order in which they are read. The master job control card appears only once, whereas all other cards appear for each new data series.

#### Master Job Control Card

Immediately following the program deck must be a card containing the quantity NJ. This specifies the number of different jobs to be done.

```
      READ 221, NJ
221 FORMAT (I5)
```

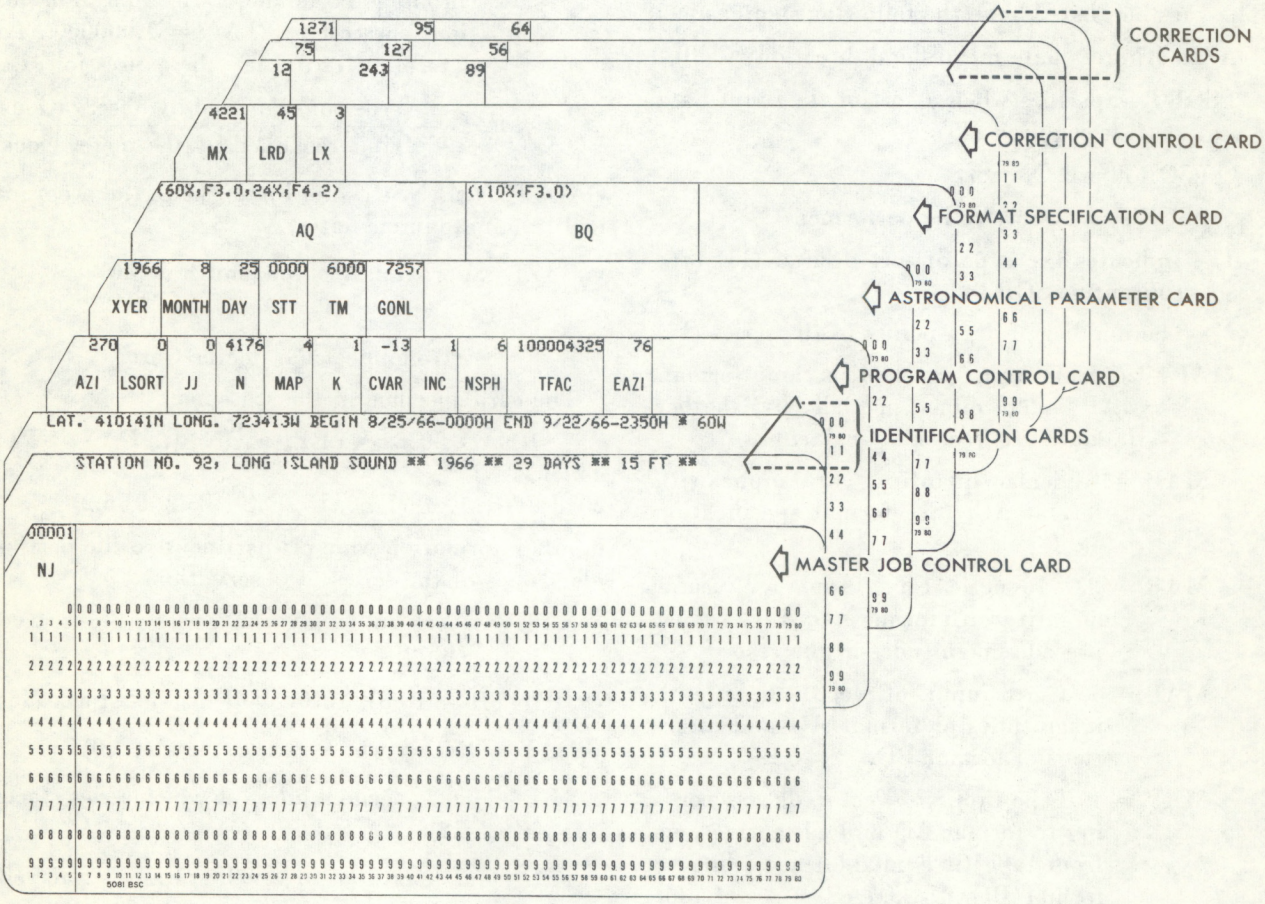


FIGURE 1.—Order of control cards. If data are on cards, data deck(s) follow the format specification card and the correction cards are not applicable.

### Identification Cards

These two cards follow the master job control card and are read by the statement.

READ 808, IDENS
808 FORMAT (9A8/9A8)

The purpose of these cards is to introduce any desired alphanumeric information to be used as identifications. Contents of these two cards will be printed *verbatim* immediately preceding final results. Only columns 1–72 of each card will be printed.

### Program Control Card

The program card specifies the operations to be performed on the data series, the mode of input for data series, and any adjustments which are to be made to the data. The variables are read by the statement

READ 76, AZI, LSORT, JJ, N, MAP, K, CVAR, INC, NSPH, TFAC, EAZI
76 FORMAT (F5.0, 5I5, F5.0, 2I5, F10.8, F5.0)

The variables listed have the following significance:

AZI—Approximate mean flood direction (F5.0)

LSORT—Specifies when a sort of the input data is required (I5)

LSORT = 0. No sort

LSORT = 1. Sort to be performed

JJ—Indicates the type of sort desired (I5) (See subroutine SORT)

N—The number of data points in the series (I5)

MAP—Controls input mechanism and format. MAP is determined partially by whether the data are vector or scalar. (I5)

MAP = 1. Scalar quantity, card input with format AQ. (See format specification card)

MAP = 2. Magnetic tape input for vector quantity with format AQ. Angles must precede magnitudes in the record

MAP = 3. Card input of vector data with magnitudes of format AQ and directions of format BQ.

MAP = 4. Tape input of vector data according to format AQ and tilt corrections from tape (if available) according to format BQ. Use MAP = 4 only for making corrections to data series. (See subroutine EDAT)

K—Indicates whether analysis by components is desired (I5)

K = 1. Major axis analysis only (use K = 1 for scalar)

K = 2. Minor axis analysis only

K = 3. Major and minor axis analysis

K = 4. North and east component analysis. In this case AZI = 0.00

CVAR—Compass variation of the vicinity. CVAR is negative when West and positive when EAST. (F5.0)

INC—Indicate if tilt corrections are to be applied. (See subroutine TILT) (I5)

INC = 0. No tilt corrections

INC = 1. Tilt corrections to be applied

NSPH—Number of samples of data per mean solar hour (I5)

TFAC—Time correction factor for a slow or fast chronometer in meters. (F10.8) For no time correction TFAC = 1.000000. To determine TFAC use the expression

$$\text{TFAC} = \frac{\text{True time covered by observations}}{\text{Time reckoned by the meter clock}}$$

CAUTION: If NSPH or TFAC is zero, the program will terminate immediately.

EAZI—approximate ebb azimuth (F5.0)

### Astronomical Parameter Card

The card specified in the statement

READ 2038, XYER, MONTH, DAY, STT, TM, GONL
2038 FORMAT (F5.0, I5, F5.0, F5.2, 2F6.2)

inputs information which is pertinent to the particular times of the series of observations.

XYER—Year in which the series is observed (F5.0)

MONTH—Month during which series starts (I5)

DAY—Day on which series starts (F5.0)

STT—Time in decimal hours at which series starts (F5.2)

TM—Time meridian to which station is referred (F6.2)

GONL—Longitude of the station (F6.2)

CAUTION: The convention of west longitude being positive and east longitude being negative is fol. lowed in entering the parameters TM and GONL-

### Format Specification Card

This card allows variability in the format of data on magnetic tape or cards. This card is read by the statement

```
    READ 2039, AQ, BQ
2039 FORMAT (4A8, 3A8)
```

The maximum field length of AQ is 32 characters and of BQ is 24 characters. The format specification BQ must always begin in column 33 of this card. Parenthesis must be punched and counted as part of the field length.

Limitations are according to the variable MAP:

MAP = 1. Assign AQ a card format; do not assign BQ.

MAP = 2. Assign AQ a tape format; do not assign BQ. Angle of vector must precede the magnitude in the record.

MAP = 3. Assign AQ and BQ formats for card reading. AQ must be magnitudes of the vectors and BQ must be directions.

MAP = 4. AQ and BQ must be as follows:
AQ = (60X, F3.0, 24X, F4.2)
BQ = (110X, F3.0)

This is necessary for tilt corrections.

### Correction Control Card

If data are on cards, data decks immediately follow the format specification card. For data read from magnetic tape, corrections can be made using the correction control card.

```
    READ 222, MX, LRD, LX
222 FORMAT (3I5)
```

MX—Total number of records which will be read to attain desired series
MX = N + LRD

LRD—Number of records at beginning of tape to be skipped

LX—Number of corrections to be read from cards and substituted in the series for those values found on the magnetic tape

Correction cards follow the correction control card and contain the interval number of the point to be changed and the desired angle and magnitude of the vector at that point. The statement

```
    READ 555, (ICOR (LY), CD (LY),
    CV (LY), LY = 1, LX)
555 FORMAT (I5, F10.0, F10.2)
```

reads these parameters.

## Explanation of Subroutines

The subroutines called in program CURAN can be grouped into three categories. The mathematical analysis and astronomical adjustments are performed in four basic subroutines—FORAN, ORBIT, ASTRO, SASTR. The subroutine DAYXX is a utility routine used for adjusting the time of beginning of series to astronomical reference frame (Greenwich Time Meridian). Operations peculiar to tidal currents are performed by subroutines AZIM, DETAZ, and TILT.

Utility routines which are called or in some cases are optional include SORT, EDAT, MEAN, TERPO, TEMP, FITAN, ONEPI, and TWOPI.

### Subroutine FORAN (SER, SP, RES, ZEP, N, M)

This subroutine is designed to determine the Fourier coefficients of the data (SER) for the first approximations of phases (ZEP) and amplitudes (RES) of the various constituents. The angular displacement per sampling period (SP) of the required constituent is computed in the subroutine according to the expression:

$$SP = \frac{\text{(Speed of the constituent in degrees per mean solar hour)}}{\text{(Number of samples per hour} \times 180)}$$

The numbers N and M represent the number of data points and the number of harmonics sought, respectively. The subroutine uses equations (289) and (292) from Schureman to obtain the Fourier coefficients.

### Subroutine SASTR

This subroutine calls as input the reciprocals (CF) of the node factors of the various constituents computed in the main program according to equations (73)-(80), (141)-(150), (207), (215), and (235). The input also comprises the node factor for $K_2$ (CKKF), the mean longitude of the sun (SL), the arguments

for $\nu'$, $\nu''$ (VP, VPP), and the mean longitude of solar perigee (PS). Tables 21-26 from Schureman are embedded in the program. The following effects of secondary constituents are computed:

ACS—Acceleration in $S_2$ from $K_2$ and $T_2$

APS—Augmentation of amplitude of $S_2$ from $K_2$ and $T_2$

ACK—Acceleration in $K_1$ from $P_1$

APK—Augmentation of amplitude of $K_1$ from $P_1$

This subroutine calls subroutine TERPO to interpolate the appropriate tables.

Subroutine ASTRO (XYER, DAYB, DAYM, GRBS, GRMS, JOBX)
COMMON/COSTX/CXX(30), OEX(5)

This subroutine uses input from subroutine DAYXX (DAYB, DAYM, GRBS, GRMS) with the input value XYER, the year in which observations begin, to compute the orbital elements $s$, $p$, $h$, $p_1$, $N$, $I$, $\nu$, $E$, $\nu'$, and $2\nu''$ (table 1) relative to the period of observation. The subprogram calls subroutine ORBIT to compute all values for the beginning of the century, then adjusts each to the time of the observed series. The array CXX are the appropriate values of the orbital elements. JOBX is the number of days in the data series.

Subroutine ORBIT (XCEN, XSX, SPX, SHX, XP1X, XNX, OEX, T, XYER, NNN)

This subroutine uses the value XYER to compute orbital elements (table 1) for the beginning of the century during which observations were taken. The elements are computed according to the expressions given by Newcomb and Schureman displayed in table 1. Values are computed in array OEX and transferred to the variables XSX, XPX, XHX, XP1X, XNX for convenience. XCEN, T, NNN are all internal variables.

Subroutine TERPO

This subprogram is a utility program designed to interpolate a table of figures in two directions.

Subroutine SORT (SORX, VK, KK, JJ)

This is designed to sort values from an array (SORX) forming a new array (VX) such that the new array consists of the first value and every JJth value thereafter of the original series. KK is internal and dimensions the new array VX.

Subroutine EDAT (MX, VIN, DIN, MA, LX, ICOR, CD, CV, LRD, XTEMP, INC)

This routine is available only to MAP = 4. It is designed for cases where polar vectors are input as data from magnetic tape, but either simple substitutions or tilt corrections need to be applied to the data series.

MX—MA + LRD

VIN—Magnitudes (corrected)

DIN—Directions (corrected)

MA—Total number of values desired in final data series

LX—Number of substitutions and inferences to be made within the series or at end of series

ICOR—Interval number in the list MX which is to be corrected

CD—Angle to be substituted for the value actually on tape

CV—Magnitude to be substituted for the value actually on tape

LRD—Number of records on tape to be skipped

XTEMP—Temporary storage for TILT values

INC—Integer indicating when tilt corrections are to be applied

CAUTION: If a magnitude or direction for a given interval need correcting, both magnitude and direction and interval number must be punched on a card. The program substitutes the entire record. Format for correction cards bearing ICOR, CD, CV is (I5, F10.0, F10.2). The number of substitutions used may not exceed 300.

If an inference of data is required to extend the series to the required length of 15 or 29 days, the magnitudes and directions must be punched on cards with the formats (24F3.2) and (24F3.0), respectively. These cards then follow any substitution cards in the data deck.

Subroutine XMEAN

This is a utility routine to compute the arithmetic mean of an array.

### Subroutine DAYXX

Computes the day of the year and the Greenwich hour for the beginning and middle of the data series.

### Subroutine TEMP

Provides temporary storage for any array so that operations can be performed on the array without loss of the original series.

### Subroutine FITAN

This subprogram finds the angle for a given value of the arctangent function.

### Subroutine ONEPI

This subroutine is designed to prevent the difference between two angles from exceeding 180 degrees or becoming negative.

### Subroutine TWOPI

This subroutine places a given angle in the proper quadrant.

### Subroutine AZIM (DX, VR, A, VN, K, J, COMPV)

This subprogram is designed to compute the vector components along major and minor axes or to determine north and east components.

DX, VR—Angles, magnitudes of popular vector

A—Azimuth (A = 0. North and east components)

VN—New component series which is formed

K—Indicates type of component formed

K = 1. Major axis; north component

K = 2. Minor axis; east component

J—Number of data values in series

COMPV—Magnetic variation in directions if the directions are not true readings

### Subroutine DETAZ

This routine is designed to compute a mean major axis azimuth for a given approximate azimuth which is input on the master job contol card.

### Subroutine TILT

This subroutine is designed for correcting erroneous tidal current velocities for instrumental tilt. It should be applied only to instruments having Savonius rotor current sensors with tilt meters. If the tilt reading exceeds 35 degrees, a manual inference will be required.

## REFERENCES


Baird, A. W., *A Manual for Tidal Observations and their Reduction by the Method of Harmonic Analysis*, Taylor and Francis, London, 1886.

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Newcomb, Simon, *Astronomical Papers for the American Ephemeris*, Vol. IX, Part I, 1912.

Schureman, P. W., *Manual of Harmonic Analysis and Prediction of Tides*, C&GS Special Publication No. 98, Revised (1940) Edition, U.S. Department of Commerce, Washington, D.C., 1941.

Schureman, P. W., *Manual of Harmonic Analysis and Prediction of Tides*, C&GS Special Publication No. 98, Serial No. 244, U.S. Department of Commerce, Washington, D.C., 1924.

# PROGRAM FOR HARMONIC ANALYSIS AT TIDAL FREQUENCIES

```
 ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION - C.+ G.S.
 FOURIER - HARMONIC ANALYSIS     PROJECT 131403    29 DAYS
 PROGRAM CURAN (INPUT'OUTPUT'TAPE9)
 DIMENSION  VIN(9000)'DIN(9000)'CHSIP(10)'CRP(10)'COVU(25)'CF(25)'
1TXXIX1( 5'20)' TXXIX2(5'20)'CKAPAP(20)' CKAP(20)' CHSI(20)'CR(20)'
2BELL(20)'BINGO(20)'G(5)'PAK(5)'D(24)'W(24)' ZETA(5)' CRC(5)
 DIMENSION RES(4)'ZEP(4)'XTEMP(9000)'VN(9000)'ITEMP(9000)
 DIMENSION CV(300)' CD(300)' ICOP(300)' IDENS(18)
 DIMENSION CXX(30)'DEG(40)' TAB1(40)' TAB2(40)' TAB3(40)' TAB4(40)
 DIMENSION TAB5(40)' TAB6(40)'AQ(4)' BQ(3)' OEX(5)
 DIMENSION TXXIXA(20)'TXXIXB(20)'TXXIXC(20)'TXXIXD(20)'TXXIXE(20)
 DIMENSION TXXIXF(20)'TXXIXG(20)'TXXIXH(20)'TXXIXI(20)'TXXIXJ(20)
 COMMON/FORT/AQ'BQ/COSTX/CXX'OEX/CONTT/NN
 COMMON / LEAPYR / DAY'MONTH


  SPEEDS OF CONSTITUENTS M(2)'N(2)'S(2)'O(1)'K(1)  FOR 1 SAMPLE/HR.

 DATA SXM2'SXS2'SXN2'SXO1'SXK1/0.1610228'0.1666667'0.1579985'0.0774
1613'0.0835615/


          TABLE XXIX FROM SCHUREMAN' S.P. 98   (1941)


          ACCELERATION IN EPOCH OF K(1) DUE TO P(1)' 29 DAYS

 DATA(TAB1(JZ)'JZs1'18)/11.4'16.4'18.3'17.6'15.2'11.7'7.4'2.7'-2.2'
1-6.9' 11.3'-14.9'-17.5'-18.3'-16.7'-12.1'-4.7'3.9/

          RATIO OF INCREASE IN AMPLITUDE OF K(1) DUE TO P(1)'29DAYS

 DATA(TAB2(JZ)'JZs1'18)/-0.26'-0.17'-0.06'0.04'0.14'0.23'0.28'0.31'
10.32' .29'0.23'0.15'0.05'-0.06'-0.16'-0.25'-0.30'-0.31/

          ACCELERATION IN EPOCH OF S(2) DUE TO K(2)' 29DAYS

 DATA(TAB3(JZ)'JZs1'18)/5.9'9.6'12.6'14.6'15.0'13.5'9.6'3.7'-3.0'-9
1.1'-13.2'-15.0'-14.7'-12.9'-10.0'-6.4'-2.3'1.9/

          RATIO OF INCREASE IN AMPLITUDE OF S(2) DUE TO K(2)'29DAYS

 DATA(TAB4(JZ)'JZs1'18)/0.24'0.19'0.12'0.04'-0.05'-0.14'-0.21'2*-0.
125'-0.21'-0.15'-0.06'0.03'0.11'0.18'0.23'2*0.26/

          ACCELERATION IN EPOCH OF S(2) DUE TO T(2)' 29 DAYS

 DATA(TAB5(JZ)'JZs1'37)/-0.8'-1.3'-1.8'-2.2'-2.6'-2.9'-3.2'3*-3.3'-
13.1'-2.8'-2.5'-2.0'-1.5'-0.9'-0.3'0.3'0.9'1.5'2.0'2.4'2.8'3.1'3*3.
23'3.2'3.0'2.7'2.3'1.9'1.4'0.8'0.3'-0.2'-0.8/

          RESULTANT AMPLITUDE IN S(2) DUE TO T(2)' 29 DAYS

 DATA(TAB6(JZ)'JZs1'37)/1.06'2*1.05'1.04'2*1.03'1.02'1.01'1.00'0.99
1'0.98'0.97'0.96'2*0.95'4*0.94'2*0.95'0.96'0.97'0.98'0.99'1.00'1.01
2'1.02'2*1.03'1.04'2*1.05'4*1.06/


          AMPLITUDE EFFECT OF CONSTITUENTS ON M(2)' 29 DAYS

 DATA(TXXIXA( J )'Js1'20)/0.0'0.050'0.018'2*0.0'0.056'0.050'0.049'0
1.021' .060'0.096'0.018'0.096'7*0.0/

          AMPLITUDE EFFECT OF CONSTITUENTS ON N(2)' 29 DAYS

 DATA(TXXIXB( J )'Js1'20)/0.050'0.00'0.005'2*0.0'0.052'0.049'0.050'
10.031'0.021'0.018'0.096'0.968'7*0.0/
```

```
            AMPLITUDE EFFECT OF CONSTITUENTS ON S(2)' 29 DAYS

     DATA(TXXIXC( J )'Js1'20)/0.018'0.005'3*0.0'0.959'0.096'0.017'2*0.9
    190'0. 50'0.018'0.042'7*0.0/

            AMPLITUDE EFFECT OF CONSTITUENTS ON O(1)' 29 DAYS

     DATA(TXXIXD( J )'Js1'20)/4*0.0'0.056'8*0.0'0.052'0.065'0.052'0.018
    1'0.05 '0.049'0.096/
            AMPLITUDE EFFECT OF CONSTITUENTS ON K(1)' 29 DAYS

     DATA(TXXIXE( J )'Js1'20)/3*0.0'0.056'9*0.0'2*0.050'0.056'0.959'0.0
    152'0. 49'0.011/
            PHASE EFFECT OF CONSTITUENTS ON M(2)' 29 DAYS
     DATA(TXXIXF( J )'Js1'20)/0.0'351.'174.'2*0.0'22.'9.'341.'8.'159.'1
    164.'186.'196.'7*0.0/
            PHASE EFFECT OF CONSTITUENTS ON N(2)' 29 DAYS
     DATA(TXXIXG( J )'Js1'20)/9.'0.0'3.'2*0.0'32.'19.'351.'17.'169.'174
    1.'196.'25.'7*0.0/
            PHASE EFFECT OF CONSTITUENTS ON S(2)'29 DAYS
     DATA(TXXIXH( J )'Js1'20)/186.'357.'3*0.0'29.'196.'348.'14.'346.'35
    11.'193.'202.'7*0.0/
            PHASE EFFECT OF CONSTITUENTS ON O(1)' 29 DAYS
     DATA(TXXIXI( J )'Js1'20)/4*0.0'22.'8*0.0'32.'13.'44.'174.'351.'341
    1.'196./
            PHASE EFFECT OF CONSTITUENTS ON K(1)' 29 DAYS
     DATA(TXXIXJ( J )'Js1'20)/3*0.0'338.'9*0.0'9.'351.'22.'331.'328.'31
    19.'354./


  LOADING OF  TABLES INTO PROPER ARRAYS


     DO 80 8 MAXJ s 1'20
     TXXIX1(1'MAXJ) s TXXIXA(MAXJ)
     TXXIX1(2'MAXJ) s TXXIXB(MAXJ)
     TXXIX1(3'MAXJ) s TXXIXC(MAXJ)
     TXXIX1(4'MAXJ) s TXXIXD(MAXJ)
     TXXIX1(5'MAXJ) s TXXIXE(MAXJ)
     TXXIX2(1'MAXJ) s TXXIXF(MAXJ)
     TXXIX2(2'MAXJ) s TXXIXG(MAXJ)
     TXXIX2(3'MAXJ) s TXXIXH(MAXJ)
     TXXIX2(4'MAXJ) s TXXIXI(MAXJ)
8008 TXXIX2(5'MAXJ) s TXXIXJ(MAXJ)


     CONTROL CARDS ENTERED


     READ 221'NJ
     DO 1111 JN s 1'NJ
     READ 808'(IDENS(JK)'JK s 1'18)
     READ 76' AZI'LSORT'JJ'N'MAP'K'CVAR'INC'NSPH'TFAC'EAZI
     READ 2038'XYER'MONTH'DAY'STT'TM'GONL
     READ 2039' AQ' BQ
     IF(NSPH.EQ.0.OR.TFAC.EQ.0.0) GO TO 8356


     DATA INPUT LOOP BEGINS


     GO TO (101'102'103'660'661)'MAP
 661 READ AQ'(DIN(KX)'VIN(KX)'KX s 1'N)
     GO TO 104
 101 READ AQ'(VIN(I)'I s 1'N)
     GO TO 123
 103 READ AQ' (VIN(I)' I s 1'N)
     IF(AZI.EQ.0.0.AND.K.EQ.0) GO TO 123
     READ BQ'(DIN(I)' I s 1'N)
     GO TO 104
 123 IF(LSORT - 1) 120'121'121
 120 CALL TEMP(VIN'XTEMP'N)
     GO TO 108
```

```
121 CALL SORT(VIN'XTEMP'N'JJ)
    N s NN
    GO TO 108
102 READ(9'AQ)(DIN(I)' VIN(I)'I s 1'N)
    IF(K.EQ.5) GO TO 120
    GO TO 104
660 READ 222'MX'LRD'LX
    IF(LX.EQ.0) GO TO 666
    READ 555'(ICOR(LY)'CD(LY)'CV(LY)'LY s 1'LX)
666 CALL EDAT(MX'VIN'DIN'N'LX'ICOR'CD'CV'LRD'XTEMP'INC)
104 NECOM s 1
    IF(K.EQ.3) NECOM s 3
    IF(K.EQ.4) NECOM s 4
    IF(NECOM.EQ.3.OR.NECOM.EQ.4) K s 1
    IF(NECOM.EQ.4) GO TO 8355
    CALL DETAZ(DIN'AZI'N'CVAR'VIN'XTEMP'INC)
    FLX s AZI
    IF(EAZI. EQ.0.0) GO TO 8355
    CALL DETAZ(DIN'EAZI'N'CVAR'VIN'XTEMP'0)
    EBX s EAZI
    DIRE s FLX - EBX
    ATZ s  .0
    PIRE s ABS(DIRE)
    IF(PIRE.GT.180.0) ATZ s PIRE - 180.0
    IF(PIRE.LT.180.0) ATZ s 180.0 - PIRE
    ARZ s ATZ/2.0
    ZAR s AINT(ARZ)
    IF(DIRE.LT.0.0) AZI s FLX + ZAR
    IF(DIRE.GT.0.0) AZI s FLX - ZAR
    PRINT 7359' AZI'DIRE'ARZ'ZAR
8355 CALL AZIM(DIN'VIN'AZI'VN'K'N'CVAR'NECOM)
    IF(LSORT - 1)107'106'106
106 CALL SORT(VN'XTEMP'N'JJ)
    NsNN
    GO TO 108
107 CALL TEMP(VN'XTEMP' N)


    FOURIER ANALYSIS PERFORMED FOR FIVE MAJOR TIDAL FREQUENCIES


108 XM2 s TFAC*SXM2/FLOAT(NSPH)
    XS2 s TFAC*SXS2/FLOAT(NSPH)
    XN2 s TFAC*SXN2/FLOAT(NSPH)
    XO s TFAC*SXO1/FLOAT(NSPH)
    XK s TFAC*SXK1/FLOAT(NSPH)
    GO TO 8357
8356 PRINT 7358
    CALL EXIT
8357 CALL FORAN(XTEMP'XM2'RES'ZEP'N'4)
    CHSIP(1) s ZEP(1)
    CHSIP(6) s ZEP(2)
    CHSIP(7) s ZEP(3)
    CHSIP(8) s ZEP(4)
    CRP(1) s RES(1)
    CRP(6) s RES(2)
    CRP(7) s RES(3)
    CRP(8) s RES(4)
110 CALL FORAN(XTEMP'XN2' RES'ZEP' N' 1)
    CHSIP(2)s ZEP(1)
    CRP(2) s RES(1)
111 CALL FORAN(XTEMP'XS2' RES'ZEP' N' 3)
    CHSIP(3) s ZEP(1)
    CHSIP(9) s ZEP(2)
    CHSIP(10) sZEP(3)
    CRP(3) s RES(1)
    CRP(9) s RES(2)
    CRP(1 ) s RES(3)
    CALL FORAN( XTEMP'XO' RES' ZEP' N' 1)
    CHSIP(4) s ZEP(1)
    CRP(4) s RES(1)
    CALL  FORAN(XTEMP'XK' RES' ZEP' N' 1)
    CHSIP(5) s ZEP(1)
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      CRP(5) s  RES(1)
      CALL TWOPI(CHSIP'10)
      IF(NECOM.EQ.3.OR.NECOM.EQ.4) GO TO 8058
      GO TO 8057
 8058 IF(K.EQ.2) GO TO 8059

      DETERMINATION OF VO+ U FOLLOWS WITH LOGF AND ARGUMENTS

 8057 CALL DAYXX(MONTH'DAY'STT'TM'DAYB'DAYM'GRBS'GRMS'CP)
      DO 7135 JAN s 1'19
      LXN s JAN + 18
      TAB1(LXN) s TAB1(JAN)
      TAB2(LXN) s TAB2(JAN)
      TAB3(LXN) s TAB3(JAN)
 7135 TAB4(LXN) s TAB4(JAN)
      CALL ASTRO(XYER'DAYB'DAYM'GRBS'GRMS'29)
      PM s CXX(1)
      PL s CXX(2)
      SL s CXX(3)
      PS s CXX(4)
      PLM s CXX(5)
      SKYN s CXX(6)
      VI s CXX(9)
      V s CXX(10)
      XI s CXX(11)
      VP s CXX(12)
      VPP s CXX(13)
      P s CXX(14)
      AUL s CXX(15)
      AUM s CXX(16)
      PAPA s 0.0
      DO 3073 NAP s 1'37
      DEG(NAP) s PAPA
 3073 PAPA s PAPA + 10.0

      DETERMINATION  OF EQUILIBRIUM  ARGUMENTS (VO + U)

 7777 TML s CP - GONL
      CON s SL + TML
      COVU(1) s2.0*(CON - PM +XI -V)
      COVU(2) s COVU(1) -(PM - PL)
      COVU(3) s 2.0*(TML)
      COVU(4) s CON - V - 2.0*(PM - XI) - 90.0
      COVU(5) s CON - VP + 90.0
      COVU(6) s 2.0*CON - VPP
      COVU(7) s 2.0* CON - PM -PL + AUL
      COVU(8) s COVU(2) -(PM - PL)
      COVU(9) s SL - PS + 180.0 + 2.0*(TML)
      COVU(10) s COVU(3) - (SL - PS)
      COVU(11) s COVU(1) -(2.0*(SL - PM)) - (PM - PL) + 180.0
      COVU(12) s COVU(1) + 2.0*(SL - PM)
      COVU(13) s COVU(12) + (PM - PL)
      COVU(14) s CON + PM - PL - V + 90.0
      COVU(15) s CON - PM + AUM
      COVU(16) s CON - V + 2.0*(PM - XI) + 90.0
      COVU(17) s TML + 270.0 - SL
      COVU(18) s COVU(4) - (PM - PL)
      COVU(19) s COVU(18) - (PM - PL)
      COVU(20) s COVU(18) + 2.0*(SL - PL)
      COVU(21) s 2.0*(COVU(1))
      COVU(22) s 3.0*(COVU(1))
      COVU(23) s 4.0*(COVU(1))
      COVU(24) s 2.0*(COVU(3))
      COVU(25) s 3.0*(COVU(3))
      CALL TWOPI(COVU'25)
```

```
      DETERMINATION  OF NODE FACTOR RECIPROCALS (F)
      V s V*.0174533
      P s P*.0174533
      VI sVI*.0174533
      CRA s 1.0/SQRT(1.0 - 12.0*(SIN(.5*VI)**2/COS(.5*VI)**2)*COS(2.0*P)
     1+ 36. *(SIN(.5*VI)**4/COS(.5*VI)**4))
      COA s 1.0/SQRT(2.310 + 1.435*COS(2.0*P))
      CF(1) s 1.0/(COS(.5*VI)**4/.91544)
      CF(2) s CF(1)
      CF(3) s 1.0
      CF(4) s 1.0/(SIN(VI)*COS(.5*VI)**2/.37988)
      CF(5) s 1.0/SQRT(0.8965*SIN(2.0*VI)**2 + 0.6001*SIN(2.0*VI)*COS(V)
     1+ 0.1  6)
      CF(6) s 1.0/SQRT(19.0444*SIN(VI)**4 + 2.7702*SIN(VI)**2*COS(2.0*V)
     1+ 0.0981) - 0.000999
      CF(7) s CF(1)*CRA
      CF(8) s CF(1)
      CF(9) s1.0
      CF(10)s 1.0
      CF(11)s CF(1)
      CF(12) s CF(1)
      CF(13) s CF(1)
      CF(14) s 1.0/(SIN(2.0*VI)/0.72137)
      CF(15) s CF(4)*COA
      CF(16) s 1.0/(SIN(VI)*SIN(.5*VI)**2/0.016358)
      CF(17) s 1.0
      CF(18) s CF(4)
      CF(19) s CF(18)
      CF(20) s CF(19)
      CF(21) s CF(1)**2
      CF(22) s CF(1)**3
      CF(23) s CF(1)**4
      CF(24) s 1.0
      CF(25) s 1.0
      CKKF s 1.0/CF(6)
      AHNAT s CF(4)*CRP(4)
      C5F s CF(5)


      ENTER  SECONDARY EFFECTS AND  DETERMINE KAPPA


      CALL SASTR(DEG'C5F'CKKF'SMAC'PROD'ACCP'RESAM'37'TAB1'TAB2'TAB3'TAB
     14'TAB5'TAB6'SL'VPP'PS'VP'CF'25)
 8059 DO 21 I s 1'5
   21 CKAPAP(I) s CHSIP(I) + COVU(I)
      CALL TWOPI(CKAPAP' 5)
      CKAP(1) s CKAPAP(1)
      CKAP(2) s CKAPAP(2)
      CKAP(3) s CKAPAP(3) + SMAC
      CKAP(4) s CKAPAP(4)
      CKAP(5) s CKAPAP(5) + ACCP
      CKAP(6) s CKAP(3)
      DMN s CKAP(1)- CKAP(2)
      CALL ONEPI( DMN)
      CKAP(7) s CKAP(1)+ DMN
      CKAP(8) s CKAP(2)- DMN
      CKAP(9) s CKAP(3)
      CKAP(10) s CKAP(3)
      SMD s CKAP(3)- CKAP(1)
      CALL ONEPI(SMD)
      CKAP(11) s CKAP(1) + 0.464*SMD
      CKAP(12) s CKAP(1) - SMD
      CKAP(13) s CKAP(1) - 0.866*DMN
      OKD s CKAP(5) - CKAP(4)
      CALL ONEPI(OKD)
      CKAP(14) s CKAP(5) + 0.5*OKD
      CKAP(15) s CKAP(5) - 0.5*OKD
      CKAP(16) s CKAP(5) + OKD
      CKAP(17)s CKAP(5)
      CKAP(18) s CKAP(5) - 1.5*OKD
      CKAP(19) s CKAP(5) - 2.0*OKD
      CKAP(20) s CKAP(5) - 1.43*OKD
      CALL TWOPI(CKAP'20)
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      DETERMINATION OF ZETA(A) AND R(A) FOLLOWS

      DO 22 I s 1'20
   22 CHSI(I) s CKAP(I) - COVU(I)
      CALL TWOPI(CHSI' 20)
      CR(1) s CRP(1)
      CR(2) s CRP(2)
      CR(3) s CRP(3)/PROD
      CR(4) s CRP(4)
      CR(5) s CRP(5)/RESAM
      CR(6) s 0.272*CR(3)/CF(6)
      CR(7) s 0.145*CR(2)/CRA
      CR(8) s 0.133*CR(2)
      CR(9) s 0.008*CR(3)
      CR(10)s 0.059*CR(3)
      CR(11) s 0.007*CR(1)
      CR(12) s 0.024*CR(1)
      CR(13) s 0.194*CR(2)
      CR(14) s 0.079*AHNAT/CF(14)
      CR(15) s 0.071*CR(4)/CQA
      CR(16) s 0.043*AHNAT/CF(16)
      CR(17) s 0.331*CR(5)*CF(5)
      CR(18) s 0.194*CR(4)
      CR(19) s 0.026*CR(4)
      CR(20) s 0.038*CR(4)

      ELIMINATION OF COMPONENT EFFECTS AND DETERMINE KAPPA AND H(A)

      DO 35 I s 1'5
      SUM s  .0
      SOQ s  .0
      DO 20 J s 1'20
  331 BELL(J) s CR(J)*TXXIX1(I'J)
      IF(BELL(J)-.0005)23'24'24
   23 BELL(J) s 0.0
   24 BINGO(J)s TXXIX2(I'J) - CHSI(J) + CHSIP(I)
      IF(BINGO(J))25'28'26
   25 BINGO(J) s ( BINGO(J) + 360.)*0.0174533
      GO TO 29
   26 IF(BINGO(J) - 360.0) 28'28'27
   27 BINGO(J) s (BINGO(J) + 360.0)*0.0174533
      GO TO 29
   28 BINGO(J) s BINGO(J)*0.0174533
   29 SUM s SUM + BELL(J)*SIN(BINGO(J))
   20 SOQ s SOQ + BELL(J)*COS(BINGO(J))
      QOS s CRP(I) - SOQ
      CALL FITAN(SUM'QOS'DCCH'2)
      CDCH s DCCH*0.0174533
      CRC(I) s 0.0
      IF(DCCH.EQ.90.0.OR.DCCH.EQ.270.0) GO TO 34
      CRC(I) s(CRP(I) - SOQ)/COS(CDCH)
   34 G(I) s CRC(I)*CF(I)
      ZETA(I) s CHSIP(I) +  CDCH*57.29578
   35 PAK(I) s CHSIP(I) + CDCH*57.29578 + COVU(I)
      CALL TWOPI(PAK' 5)

      INFERENCE  OF     H(A)    FROM MAJOR CONSTITUENTS

      D(1) s 0.079*G(4)
      D(2) s G(5)
      D(3) s 0.272*G(3)
      D(4) s 0.028*G(1)
      D(5) s 0.071*G(4)
      D(6) s G(1)
      D(7) s CRP(6)*CF(21)
      D(8) s CRP(7)*CF(22)
      D(9) s CRP(8)*CF(23)
      D(10) s G(2)
      D(11) s 0.133*G(2)
      D(12) s G(4)
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```
      D(13) s 0.043*G(4)
      D(14) s 0.331*G(5)
      D(15) s 0.194*G(4)
      D(16) s 0.026*G(4)
      D(17) s 0.008*G(3)
      D(18) s G(3)
      D(19) s CRP(9)*CF(24)
      D(20) s CRP(10)*CF(25)
      D(21) s 0.059*G(3)
      D(22) s 0.007*G(1)
      D(23) s 0.194*G(2)
      D(24) s 0.038*G(4)


      INFERENCE  OF   KAPPA(A)  FROM MAJOR CONSTITUENTS


      PAFX s PAK(5) - PAK(4)
      GAFX s PAK(5) - PAK(4)
      PAOT s PAK(1) - PAK(2)
      FPAX s PAK(5) + PAK(4)
      PATO s PAK(2) - PAK(1)
      PATTO s PAK(3) - PAK(1)
      CALL ONEPI(PAFX)
      CALL ONEPI(PAOT)
      IF(ABS(GAFX).LT.180.0) GO TO 6781
      IF(GAFX)6779'6781'6780
6779  FPAX s FPAX + 360.0
      GO TO 6781
6780  FPAX s FPAX - 360.0
6781  CALL ONEPI(PATO)
      CALL ONEPI(PATTO)
      W(1)  s PAK(5) + 0.5*PAFX
      W(2) s PAK(5)
      W(3) s PAK(3)
      W(4) s 2.0*PAK(1) - PAK(2)
      W(5) s 0.5*FPAX
      W(6) s PAK(1)
      W(7) s CHSIP(6) + COVU(21)
      W(8) s CHSIP(7) + COVU(22)
      W(9) s CHSIP(8) + COVU(23)
      W(10) s PAK(2)
      W(11) s 2.0*PAK(2) - PAK(1)
      W(12) s PAK(4)
      W(13) s 2.0*PAK(5) - PAK(4)
      W(14) s PAK(5)
      W(15) s PAK(5) -1.5*PAFX
      W(16) s PAK(5) - 2.0*PAFX
      W(17) s PAK(3)
      W(18) s PAK(3)
      W(19) s CHSIP(9)  + COVU(24)
      W(20) s CHSIP(10) + COVU(25)
      W(21) s PAK(3)
      W(22) s PAK(3) - 0.536*PATTO
      W(23) s PAK(1) - 0.866*PAOT
      W(24) s PAK(5) - 1.43*PAFX
      CALL TWOPI(W'24)


      STATION IDENTIFICATION PRINTED


      PRINT 13
      PRINT 810' (IDENS(KJ)'KJ s 1'18)


      ZETA PRIME AND R PRIME OUTPUT FOR FIVE MAJOR TIDAL CONSTITUENTS
      AND SECOND'THIRD' AND FOURTH HARMONICS


      PRINT 811
      PRINT 73' (CHSIP(I)'I s 1' 5)
      PRINT 812'(CRP(I)'I s 1' 5)
      PRINT 813
      PRINT 73' (CHSIP(I)'I s 6'10)
      PRINT 812'(CRP(I)'I s 6'10)
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```
PRINT 5
PRINT 6' CKKF'CRA'CQA'AHNAT

EQUILIBRIUM ARGUMENTS AND NODE FACTORS PRINTED

PRINT 7
PRINT 811
PRINT 814'(COVU(I)'I s 1' 5)
PRINT 815'(CF(I)'I s 1' 5)
PRINT 816
PRINT 814'(COVU(I)'I s 6'10)
PRINT 815'(CF(I)'I s 6'10)
PRINT 817
PRINT 814'(COVU(I)'I s11'15)
PRINT 815'(CF(I)'I s11'15)
PRINT 818
PRINT 814'(COVU(I)'I s16'20)
PRINT 815'(CF(I)'I s16'20)
PRINT 813
PRINT 814'(COVU(I)'I s21'25)
PRINT 815'(CF(I)'I s21'25)

KAPPA' ZETA' AND R PRINTED FOR TIDAL CONSTITUENTS AND HARMONICS
PRIOR TO ELIMINAT)ON PROCESS

PRINT 9
PRINT 811
PRINT 819'(CKAP(I)'I s 1' 5)
PRINT 820'(CHSI(I)'I s 1' 5)
PRINT 821'(CR(I)'I s 1' 5)
PRINT 816
PRINT 819'(CKAP(I)'I s 6'10)
PRINT 820'(CHSI(I)'I s 6'10)
PRINT 821'(CR(I)'I s 6'10)
PRINT 817
PRINT 819'(CKAP(I)'I s11'15)
PRINT 820'(CHSI(I)'I s11'15)
PRINT 821'(CR(I)'I s11'15)
PRINT 818
PRINT 819'(CKAP(I)'I s16'20)
PRINT 820'(CHSI(I)'I s16'20)
PRINT 821'(CR(I)'I s16'20)

R' ZETA' KAPPA' AND H PRINTED FOR FIVE MAJOR TIDAL CONSTITUENTS
AFTER ELIMINATION PROCESS

PRINT 11
PRINT 822' CRC(1)'ZETA(1)'PAK(1)'G(1)
PRINT 823' CRC(2)'ZETA(2)'PAK(2)'G(2)
PRINT 824' CRC(3)'ZETA(3)'PAK(3)'G(3)
PRINT 825' CRC(4)'ZETA(4)'PAK(4)'G(4)
PRINT 826' CRC(5)'ZETA(5)'PAK(5)'G(5)

COMPUTED VALUES OF H(A) AND KAPPA(A) PRINTED FOR THE CONSTITUENTS
         M2   S2   N2   O1   K1
         M4   M6   M8   S4   S6

INFERRED VALUES OF H(A) AND KAPPA(A) PRINTED FOR THE CONSTITUENTS
         K2   L2   2N   R2   T2   LAMBDA   MU2   NU2
         J1   M1   OO1  P1   Q1   2Q1    RHO1

PRINT 15
PRINT 16
PRINT 71'(W(I)'I s 1'5)
PRINT 72'(D(I)'I s 1'5)
PRINT 17
PRINT 71'(W(I)'I s 6'10)
PRINT 72'(D(I)'I s 6'10)
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      PRINT 18
      PRINT 71'(W(I)'I s 11'15)
      PRINT 72'(D(I)'I s 11'15)
      PRINT 19
      PRINT 71'(W(I)'I s 16'20)
      PRINT 72'(D(I)'I s 16'20)
      PRINT 220
      PRINT 71'(W(I)'I s 21'24)
      PRINT 7360
      PRINT 72'(D(I)'I s 21'24)
      CALL XMEAN(XTEMP'SUTZ'N)
      IF(NECOM.EQ.3.AND.K.EQ.1) GO TO 5998
      IF(NECOM.EQ.4.AND.K.EQ.1) GO TO 5998
      GO TO 5899
 5998 K s 2
      GO TO (5899'5899'8355'8355)'NECOM
 5999 AZI s 90.0
      GO TO 8355
 5899 GO TO (1111'1112'1111'1112'1111)'MAP
 1112 REWIND 9
 1111 CONTINUE
      STOP

    5 FORMAT(// 28X'7H1/F(K2)' 6X'2HRA' 8X' 2HQA' 6X' 6HHbO(1))
    6 FORMAT(1H '25X' F9.4' 2F10.5' F10.4//)
    7 FORMAT(21X'49HEQUILIBRIUM (V + U) AND ELIMINATION (F) ARGUMENTS /)
    9 FORMAT(/ 42X'22HANALYSIS AND INFERENCE //)
   11 FORMAT(1H0'3X'33H ELIMINATION OF COMPONENT EFFECTS //15X'4HR(A)'5X
     14HZETA'5X' 5HKAPPA' 5X' 4HH(A) )
   13 FORMAT(1H1'48X'27HHARMONIC ANALYSIS'  29-DAYS )
   14 FORMAT(1H1'40X'27HHARMONIC ANALYSIS' 15-DAYS' 2X'13HN(2) INFERRED)
   15 FORMAT(/// 14X'19HHARMONIC CONSTANTS'1X'13H(H) AND KAPPA //)
   16 FORMAT(16X'4HJ(1)'6X'4HK(1)'6X'4HK(2)'6X'4HL(2)'6X'4HM(1))
   17 FORMAT(16X'4HM(2)'6X'4HM(4)'6X'4HM(6)'6X'4HM(8)'6X'4HN(2))
   18 FORMAT(16X'4H(2N)'6X'4HO(1)'6X'4H(OO)'6X'4HP(1)'6X'4HQ(1))
   19 FORMAT(16X'4H(2Q)'6X'4HR(2)'6X'4HS(2)'6X'4HS(4)'6X'4HS(6))
  220 FORMAT(16X'4HT(2)'4X'6HLAMBDA'5X'5HNU(2)'4X'6HRHO(1))
   71 FORMAT( 5X' 5HKAPPA' 5F10.2 /)
   72 FORMAT( 6X' 4HH(A)' 5F10.4 //)
   73 FORMAT( 9X'11HZETA(PRIME)' 5F12.3)
   74 FORMAT(24F3.1)
   76 FORMAT(F5.0'5I5'F5.0'2I5'F10.8'F5.0)
   77 FORMAT(60X'F3.0'24X'F4.2)
   78 FORMAT(24F3.2)
   79 FORMAT(24F3.0)
  221 FORMAT(I5)
  222 FORMAT(3I5)
  555 FORMAT(I5'F10.0'F10.2)
  808 FORMAT(9A8/9A8)
  810 FORMAT(/24X'9A8//24X'9A8///)
  811 FORMAT(27X'4HM(2)'8X'4HN(2)'8X'4HS(2)'8X'4HO(1)'8X'4HK(1))
  812 FORMAT(1H0'10X'8HR(PRIME)' 5F12.3//)
  813 FORMAT(27X'4HM(4)'8X'4HM(6)'8X'4HM(8)'8X'4HS(4)'8X'4HS(6))
  814 FORMAT( 12X'7H(V + U)'1X' 5F12.3)
  815 FORMAT(1H0'13X' 4HF(A)'2X' 5F12.5 //)
  816 FORMAT(27X'4HK(2)'8X'4HL(2)'8X'4H(2N)'8X'4HR(2)'8X'4HT(2))
  817 FORMAT(26X'6HLAMBDA'6X'5HMU(2)'7X'5HNU(2)'8X'4HJ(1)'8X'4HM(1))
  818 FORMAT(26X'5HOO(1)'8X'4HP(1)'8X'4HQ(1)'8X'4H(2Q)'7X'6HRHO(1))
  819 FORMAT(15X'5HKAPPA' 5F12.3)
  820 FORMAT(1H0'15X' 4HZETA' 5F12.1)
  821 FORMAT(1H0'15X' 4HR(A)' 5F12.4 //)
  822 FORMAT( 5X' 4HM(2)' F10.5' 2F10.2' F10.5)
  823 FORMAT( 5X' 4HN(2)' F10.5' 2F10.2' F10.5)
  824 FORMAT( 5X' 4HS(2)' F10.5' 2F10.2' F10.5)
  825 FORMAT( 5X' 4HO(1)' F10.5' 2F10.2' F10.5)
  826 FORMAT( 5X' 4HK(1)' F10.5' 2F10.2' F10.5)
 2037 FORMAT(5F7.3'F5.0)
 2038 FORMAT( F5.0'I5'F5.0'F5.2'2F6.2)
 2039 FORMAT(4A8' 3A8)
 4040 FORMAT(1H0'10X' F6.0' 6F10.2)
 4041 FORMAT(1H0' 4F10.5)
 4440 FORMAT(1H0' 10F12.4 /// 1X' 10F12.4)
 7358 FORMAT(1H0'23HJOB TERMINATED........'24H NSPH OR TFAC s 0 (ZERO))
 7359 FORMAT(5X' F10.1'4X' F10.1'4X' 2F10.1)
 7360 FORMAT(1H0)
      END
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      SUBROUTINE FORAN(SER' SP' RES' ZEP' N' M )


      FOURIER ANALYSIS -  DETERMINE ZETA(PRIME)AND R(PRIME)

      DIMENSION  SER(N)' RES(M)' ZEP(M)
      DO 55 JR s 1' M
      RES(JR) s 0.0
      ZEP(JR) s 0.0
      C s 0.0
      S s 0.0
      DO 10  L s 1'N
      C s C   COS(FLOAT(L-1)*(3.141593*(FLOAT(JR) *SP)))*SER(L)
  100 S s S   SIN(FLOAT(L-1)*(3.141593*(FLOAT(JR) *SP)))*SER(L)
      C s 2.0/ FLOAT(N)* C
      S s 2.0/ FLOAT(N)* S
      X s S/C
      IF DIVIDE CHECK 14'15
   14 IF(S)16'55'17
   16 ZEP(JR)s 270.0
      GO TO 18
   17 ZEP(JR) s 90.0
      GO TO 18
   15 ZEP(JR) s ATAN(X)*57.29578
      IF(S) 32'32'34
   32 IF(C) 33'55'37
   33 ZEP(JR) s 180.0 + ZEP(JR)
      GO TO 18
   34 IF(C) 35'17'36
   35 ZEP(JR) s ZEP(JR) + 180.0
      GO TO 18
   37 ZEP(JR) s ZEP(JR) + 360.0
      GO TO 18
   36 ZEP(JR) s ZEP(JP)*1.0
   18 RES(JR) s SQRT( C**2 + S**2)
   55 CONTINUE
      RETURN
      END


      SUBROUTINE SASTR(DEG C5F'CKKF'ACS'APS'ACK'APK'IOT'TAB1'TAB2' TAB3'
     1TAB4'TAB5'TAB6'SL'VPP'PS'VP'CF'JOP)


      DETERMINE SECONDARY CONSTITUENT EFFECTS

      DIMENSION DEG(IOT)'TAB1(IOT)'TAB2(IOT)'TAB3(IOT)'TAB4(IOT)'TAB5(IO
     1T)'TAB6(IOT)'CF(JOP)
 2043 FORMAT( 1H0'4F10.5 ///)
 2044 FORMAT(//// 6X'4HSMAC'6X'4HPROD'6X'4HACCP'4X'5HRESAM)
 2045 FORMAT(///// 2X' 6F10.4)
      AMT s SL - 0.5*VPP
      CALL TWOPI(AMT' 1)
      CALL TERPO(DEG'TAB3'37'RAK'AMT)
      TAZ s RAK
      AMP s SL - PS
      CALL TWOPI(AMR'1)
      CALL TERPO(DEG'TAB5'37'RAL'AMR)
      TAZ1 s RAL
      ACS s RAK*CKKF + RAL
      CALL TERPO(DEG'TAB4'37'SKO'AMT )
      TAZ2 s SKO
      CALL TERPO(DEG'TAB6'37'STOX'AMR)
      TAZ3 s STOX
      APS s STOX*(1.0 + (SKO*CKKF))
      FALT s SL - 0.5*VP
      CALL TWOPI(EALT'1)
      CALL TERPO(DEG'TAB1'37'PKX'EALT)
      TAZ4 s PKX
      ACK s PKX*C5F
      CALL TERPO(DEG'TAB2'37'PKXA'EALT)
      TAZ5 s PKXA
      APK s 1.0 + (C5F*PKXA)
      PRINT 2044
      PRINT 2043' ACS'APS'ACK'APK
      PRINT 2045'TAZ' TAZ1' TAZ2' TAZ3' TAZ4' TAZ5
      RETURN
      END
```

```
      SUBROUTINE DAYXX(MONTH'DAY'STT'TM'DAYB'DAYM'GRBS'GRMS'CP)


 8800 FORMAT( //// 5X' 8H DAYB s 'F5.0'10X' 8H DAYM s 'F5.0 /// 5X' 8H G
     1HBS s 'F7.2'10X' 8H GHMS s 'F7.2 /// 5X'17H ORIGINAL T.M. s 'F7.2'
     210X'18H CORRECTED T.M. s 'F7.2)
      GO TO (207'209'211'213'215'217'219'251'223'225'227'229)'MONTH
  207 DAYB s DAY
      GO TO 230
  209 DAYB s DAY + 31.
      GO TO 230
  211 DAYB s DAY + 59.
      GO TO 230
  213 DAYB s DAY + 90.
      GO TO 230
  215 DAYB s DAY + 120.
      GO TO 230
  217 DAYB s DAY + 151.
      GO TO 230
  219 DAYB s DAY + 181.
      GO TO 230
  251 DAYB s DAY + 212.
      GO TO 230
  223 DAYB s DAY + 243.
      GO TO 230
  225 DAYB s DAY + 273.
      GO TO 230
  227 DAYB s DAY + 304.
      GO TO 230
  229 DAYB s DAY + 334.
  230 IF(STT.GT.12.0) GO TO 233
      CP s TM + (STT*15.0)
      IF(CP.LE.180.0) GO TO 235
  233 CP s TM - (24.00 - STT)*15.0
      DAYB s DAYB + 1.
  235 GRBS s CP/15.0
      GRMS s GRBS + 12.00
      IF(GRMS.GT.24.0) GO TO 240
      DAYM s DAYB + 14.0
      GO TO 242
  240 GRMS s GRMS - 24.00
      DAYM s DAYB + 16.0
  242 PRINT 8800'DAYB'DAYM'GRBS'GRMS'TM'CP
      RETURN
      END


      SUBROUTINE AZIM(DX'VR'A'VN'K'J'COMPV'NEC)


      COMPUTE MAJOR OR MINOR AXIS OR COMPUTE NORTH AND EAST COMPONENTS

      DIMENSION DX(J)' VR(J)' VN(J)
      DO 10  I s 1'J
  100 VN(I) s (DX(I) + COMPV - A )*0.0174533
      GO TO (1'2)'K
    1 DO 66 I s 1'J
   66 VN(I) s VR(I)*COS(VN(I))
      GO TO 88
    2 IF(NEC.EQ.4.OR.NEC.EQ.3) GO TO 109
      DO 77 Is1'J
   77 VN(I) s VR(I)*SIN(VN(I))
      RETURN
   88 DO 99 LM s 1'J
      TB s VN(LM)
      TA s VR(LM)
   99 VN(LM) s SIGN(TA'TB)
  109 RETURN
      END
```

```
      SUBROUTINE ASTRO(XYER'DAYB'DAYM'GRBS'GRMS'JOBX)

  DETERMINATION OF ORBITAL ELEMENTS FOR OBSERVED SERIES

      COMMON/COSTX/CXX(30)'OEX(5)
      COMMON / LEAPYR / DAY'MONTH
 2110 FORMAT(1H0' 38HERROR.....PARAMETER (I) EXCEEDS LIMITS )
 2111 FORMAT(1H0'15X'1HR'10X'1HQ'15X'9HU OF M(2))
 2112 FORMAT( 8X' F10.3' 3X' F10.3' 9X' F10.4)
 2040 FORMAT(1H1'10F10.3//// 1X'10F10.3//// 1X'10F10.3)
      CALL ORBIT(XCEN'XSX'XPX'XHX'XP1X'XNX'OEX'T'XYER'5)
      DO 30 NOE s 1'30
   30 CXX(NOE) s 0.0
      XCET s XCEN + 1.0
      DOBY s 0.25*(XYER - XCET)
      AMI s XYER - XCEN
      AMIT s AINT(DOBY)
      FARM s 0.25*(AMI)
      FARX s FARM - AINT(FARM)
      IF(FARX.EQ.0.0.AND.MONTH.EQ.3) GO TO 35
   31 IF(FARX.EQ.0.0.AND.DAYB.LE.60.0) DAYB s DAYB - 1.0
      IF(FARX.GT.0.0) DAYB s DAYB - 1.0
      IF(FARX.EQ.0.0.AND.DAYM.LE.60.0) DAYM s DAYM - 1.0
      IF(FARX.GT.0.0) DAYM s DAYM - 1.0
   32 CXX(1) s XSX + 129.38482032*AMI + 13.176396768*(DAYB + AMIT) + 0.5
     149016532*GRBS
      CXX(2) s XPX + 40.66246584*AMI + 0.111404016*(DAYB + AMIT) + 0.004
     1641834*GRBS
      CXX(3) s XHX - 0.238724988*AMI + 0.9856473288*(DAYB + AMIT) + 0.04
     110686387*GRBS
      CXX(4) s XP1X + 0.01717836*AMI + 0.000047064*(DAYB + AMIT) + 0.000
     1001961*GRBS
      CXX(5) s XPX + 40.66246584*AMI + 0.111404016*(DAYM + AMIT) + 0.004
     1641834*GRMS
      CXX(6) s XNX - 19.328185764*AMI - 0.0529539336*(DAYM + AMIT) - 0.0
     1022064139*GRMS
      IF(JOBX.LE.15.AND.JOBX.GT. 0 ) GO TO 40
      CALL TWOPI(CXX'6)
      GO TO 41
   35 IF(DAY.EQ.1.) GO TO 32
      GO TO 31
   40 CXX(7) s XPX + 40.66246584*AMI + 0.111404016*(DAYM + AMIT) + 0.004
     1641834*GRBS
      CXX(8) s XNX - 19.328185764*AMI - 0.0529539336*(DAYM + AMIT) - 0.0
     1022064139*GRBS
      CALL TWOPI(CXX' 8)
   41 AN s  CXX(6)*0.0174533
      AX s  CXX(6)
      EYE s  .9136949 - 0.0356926*COS(AN)
      CXX(9) s ACOS(EYE)*57.2957795
      IF(CXX(9).LT.17.0.OR.CXX(9).GT.30.0) PRINT 2110
      CIG s  CXX(9)*0.0174533
      IF(CIG.EQ.0.0) GO TO 230
      IF(AX.EQ.0.0.OR.AX.EQ.180.0) GO TO 230
      VXX s  .0896831*SIN(AN)/SIN(CIG)
      CXX(1 ) s ASIN(VXX)*57.2957795
      IF(AX.GT.180.0.AND. CXX(10).GT.0.0) CXX(10) s -1.0*CXX(10)
      CVX s CXX(10)*0.0174533
      EXX s  .2067274*SIN(AN)*(1.0 - 0.0194926*COS(AN))
      IF(EXX.EQ.0.0) GO TO 202
      EZZ s  .9979852 + 0.2067274*COS(AN) - 0.0020148*COS(2.0*AN)
      IF(EZZ.EQ.0.0) GO TO 202
      EXEZ  s EXX/EZZ
      IF(EXEZ.GT.3450.0) GO TO 202
      CXX(11) s ATAN(EXEZ)*57.2957795
      IF(AX.GT.180.0.AND.CXX(11).GT.0.0) CXX(11) s -1.0*CXX(11)
      CEX s CXX(11)*0.0174533
  202 VPX s SIN(CVX)/(COS(CVX) + 0.334766/SIN(2.0*CIG))
      CXX(12) s ATAN(VPX)*57.2957795
      IF(AX.GT.180.0.AND.CXX(12).GT.0.0) CXX(12) s -1.0*CXX(12)
      PVC s CXX(12)*0.0174533
      VPY s SIN(2.0*CVX)/(COS(2.0*CVX) + 0.0726184/SIN(CIG)**2)
      CXX(13) s ATAN(VPY)*57.2957795
      IF(AX.GT.180.0.AND.CXX(13).GT.0.0) CXX(13) s -1.0*CXX(13)
      PVCP s CXX(13)*0.0174533
```

```
230 PGX s CXX(5) - CXX(11)
    CALL TWOPI(PGX' 1)
    XPG s PGX*0.0174533
    CXX(14) s PGX
    RAX s SIN(2.0*XPG)/(COS(0.5*CIG)**2/(6.0*SIN(0.5*CIG)**2) - COS(2.
   10*XPG))
    RXX s ATAN(RAX)*57.2957795
    UM2 s 2.0*(CXX(11) - CXX(10))
    UL2 s  UM2 - RXX
    IF(UL2.GT.180.0) UL2 s UL2 - 180.0
    IF(UL2.LT.180.0) UL2 s UL2 + 180.0
    CXX(15) s UL2
    ZFS s ( 5.0*COS(CIG) - 1.0)*SIN(XPG)
    ZFC s (7.0*COS(CIG) + 1.0)*COS(XPG)
    CALL FITAN(ZFS'ZFC'QXX'2)
    CRAV   s  0.5*( UM2)  + QXX  + 90.0
    CALL TWOPI(CRAV'1)
    CXX(16) s CRAV
    IF(JOBX.GT.15.AND.JOBX.GT.0 ) GO TO 88
    PGXX s  CXX(7) - CXX(11)
    CALL TWOPI(PGXX'1)
    XXPG s PGXX*0.0174533
    CXX(17) s PGXX
    BATX s CXX(8)*0.0174533
    EYEX s 0.9136949 - 0.0356926*COS(BATX)
    CXX(2 ) s ACOS(EYEX)*57.2957795
    UM2X s 2.0*(CXX(11) - CXX(10))
    EYIT s CXX(20)*0.0174533
    ZFXS s (5.0*COS(EYIT) - 1.0)*SIN(XXPG)
    ZFXC s ( 7.0*COS(EYIT) + 1.0)*COS(XXPG)
    CALL FITAN( ZFXS'ZFXC'QXXX'2)
    CXX(19) s  0.5*(UM2X) + QXXX + 90.0
    CRAVX s CXX(19)
    CALL TWOPI(CRAVX'1)
    CXX(19) s CRAVX
 88 DO 33 NT s 1'30
    DROP s CXX(NT)*10000. + 5.0
 33 CXX(NT) s AINT(DROP)*0.0001
    PRINT 2040'(CXX(IAX)'IAX s 1'30)
    PRINT 2111
    PRINT 2112' RXX'QXX'UM2
    RETURN
    END
```

```
      SUBROUTINE ORBIT(XCEN'XSX'XPX'XHX'XP1X'XNX'OEX'T'XYER'NNN)

    DETERMINATION OF ORBITAL ELEMENTS FOR BEGINNING OF CENTURY

      DIMENSION OEX(NNN)
    8 FORMAT(1H0' 5F12.4' 5X' F5.0' 2F6.1)
      S s 13.1763968
      P s 0.1114040
      XH s  .9856473
      P1 s  .0000471
      XN s   .0529539
      XCAN s XYER*0.01 + 0.001
      XCEN s AINT(XCAN)*100.0
      T s -3.0
      YR s 2.5
      GAT s 1600.0
      DO 10 JK s 1'30
      GP s (GAT)*0.01/4.0 + 0.00001
      FPX s ABS(GP)
      FP s AINT(FPX)
      COL s FPX - FP
      IF(COL.LT.0.010) GO TO 11
      IF(GAT.EQ.XCEN) GO TO 12
      YR s YR - 1.0
      GO TO 9
   11 IF( GAT.EQ.XCEN) GO TO 12
    9 GAT s GAT + 100.0
   10 CONTINUE
   12 T s (GAT - 1900.0)*0.01
      OEX(1) s 270.43742222 + 307.892*T + 0.002525*T**2 + 0.00000189*T**
     13 + YR*S
      OEX(2) s 334.32801944 + 109.0322055*T - 0.01034444*T**2 - 0.000012
     15*T**3 + YR*P
      OEX(3) s 279.69667778 + 0.768925*T + 0.0003025*T**2 + YR*XH
      OEX(4) s 281.22083333 + 1.719175*T + 0.00045278*T**2 + 0.00000333*
     1T**3   YR*P1
      OEX(5) s 259.18253333 - 134.1423972*T + 0.00210556*T**2 + 0.000002
     122*T**3 + YR*XN
      CALL TWOPI(OEX'5)
      XSX s OEX(1)
      XPX s OEX(2)
      XHX s OEX(3)
      XP1X s OEX(4)
      XNX s OEX(5)
      PRINT 8' (OEX(JX)'JX s 1'5) ' GAT' T' YR
      RETURN
      END
```

```
      SUBROUTINE TWOPI( AUG' IO)
C
C
C     ELIMINATE NEGATIVE OR ANGLES GREATER THAN 360 DEGREES
C
      DIMENSION  AUG(IO)
      DO 114 MO s 1'IO
  120 IF(AUG(MO))112'114'113
  112 AUG(MO) s AUG(MO)+ 360.0
      GO TO 120
  113 IF(AUG(MO) - 360.0)114'114'115
  115 AUG(MO) s AUG(MO) - 360.0
      GO TO 120
  114 CONTINUE
      RETURN
      END
      SUBROUTINE FITAN( AUS'AUC'RTA'JMAP)
C
C
C     DETERMINE ARCTANGENT AND PLACE IN CORRECT QUADRANT
C
      BXG s  AUS/AUC
      IF DIVIDE CHECK 14'15
   14 IF(AUS)16'55'17
   16 RTA s 270.0
      GO TO 88
   17 RTA s 90.0
      GO  TO 88
   15 RTA s ATAN(BXG)*57.2957795
      GO TO (88'38)'JMAP
   38 IF(AUS)32'32'34
   32 IF(AUC)33'55'37
   33 RTA s 180.0 + RTA
      GO TO 88
   34 IF(AUC)35'17'88
   35 RTA s RTA + 180.0
      GO TO 88
   37 RTA s RTA + 360.0
      GO TO 88
   55 RTA s  .0
   88 CONTINUE
      RETURN
      END
      SUBROUTINE XMEAN(VIN'EH'N)
C
C
C     MEAN SERIES FOR NON-TIDAL CURRENT OR MEAN SEA LEVEL
C
      DIMENSION VIN(N)
   15 FORMAT(//// 1X'14H SUM OF SERIES'3X'F12.3 // 1X' 7HDIVISOR'12X'I10
     1 // 1X'14HMEAN OF SERIES'5X'F10.5 // 1X'10HTOTAL DATA'9X'I10 )
      MA s N
      EH s  .0
      DO 10 NA s 1'N
      IF(VIN(NA).EQ.0.0) MA s MA - 1
   10 EH s EH + VIN(NA)
      BH s EH/FLOAT(MA)
      PRINT 15' EH' MA' BH' N
      RETURN
      END
h
h
```

```
      SUBROUTINE TERPO(ANG'TXX'LID'ANSWER'AUGM)


      INTERPOLATE TABLES 21'22'23'24'25'AND 26

      DIMENSION ANG(LID)' TXX(LID)
    1 FORMAT(///23H JOB TERMINATED........26HFAILED TO INTERPOLATE ANG.)
      LIN s LID - 1
      DO 20   ION s 1'LIN
      IF(AUGM.GT.ANG(ION).AND.AUGM.LT.ANG(ION+1)) GO TO 28
      IF(AUGM.EQ.ANG(ION)) GO TO 26
      IF(AUGM.EQ.ANG(ION+1)) GO TO 27
      GO TO 200
   26 ANSWER s TXX(ION)
      GO TO 201
   27 ANSWER s TXX(ION+1)
      GO TO 201
   28 REW s AUGM*0.1
      WER s REW - AINT(REW)
      FRA s WER*10.0
      RET s ABS(TXX(ION))
      TEX s ABS(TXX(ION+1))
      IF(RET.GT.TEX) GO TO 29
      IF(RET.LT.TEX) GO TO 30
      IF(RET.EQ.TEX) GO TO 31
   29 DIFR s (RET - TEX)*0.1
      IF(TXX(ION).GE.0.0.AND.TXX(ION+1).LT.0.0) DIFR s (RET + TEX)*0.1
      IF(TXX(ION).LT.0.0.AND.TXX(ION+1).GE.0.0) DIFR s (RET + TEX)*0.1
      DIFX s DIFR*FRA
      CHS s SIGN(DIFX'TXX(ION))
      ANSWER s TXX(ION) - CHS
      GO TO 201
   30 DIFR s (TEX - RET)*0.1
      IF(TXX(ION).GE.0.0.AND.TXX(ION+1).LT.0.0) DIFR s (RET + TEX)*0.1
      IF(TXX(ION).LT.0.0.AND.TXX(ION+1).GE.0.0) DIFR s (RET + TEX)*0.1
      DIFX s DIFR*FRA
      CHS s SIGN(DIFX'TXX(ION+1))
      ANSWER s TXX(ION) + CHS
      GO TO 201
   31 IF(TXX(ION).GE.0.0.AND.TXX(ION+1).GE.0.0) GO TO 26
      IF(TXX(ION).LT.0.0.AND.TXX(ION+1).LT.0.0) GO TO 26
      IF(TXX(ION).GE.0.0.AND.TXX(ION+1).LT.0.0) GO TO 32
      IF(TXX(ION).LT.0.0.AND.TXX(ION+1).GE.0.0) GO TO 32
      PRINT 1
      CALL EXIT
   32 DIFR s (TXX(ION+1) - TXX(ION))*0.1
      DIFX s DIFR*FRA
      ANSWER s TXX(ION) + DIFX
      GO TO 201
  200 CONTINUE
  201 RETURN
      END
```

```
      SUBROUTINE DETAZ(FIN'AZO'NR'COMPV'VIN'XTEMP'INC)


      DETERMINATION OF TRUE AZIMUTH
    THIS ROUTINE IS A SPECIAL PURPOSE PROGRAM FOR USE WITH TIDAL CURRENT
    ANALYSES IN THE COAST AND GEODETIC SURVEY

      DIMENSION FIN(NR)'VIN(NR)'XTEMP(NR)
    2 FORMAT(1H1'30H AZIMUTH OR MEAN FLOOD DIR. s 'F7.2'5X'I5'5X'F10.2)
    3 FORMAT(1H0'14HERROR IN DETAZ)
    6 FORMAT(1H1'28HOPERATOR.......STOP THIS JOB)
      LMN s
      SUMD s 0.0
      AIZ s AZO
      IF(AZO.EQ.360.0) AIZ s 0.0
      DO 10  KAZ s 1'NR
      TDIR s FIN(KAZ) + COMPV
      IF(TDIR.LE.20.0) TDIR s TDIR + 360.0
      IF(ABS(TDIR - AIZ - 360.0).LE. 20.0) GO TO 90
      IF(ABS(TDIR - AZO).LE. 20.0) GO TO 90
      IF(ABS(TDIR - AZO + 360.0).LE. 20.0) GO TO 90
      GO TO 100
   90 LMN s LMN + 1
      SUMD s SUMD + TDIR
  100 CONTINUE
      AZO s SUMD / FLOAT(LMN)
      IF DIVIDE CHECK 8'5
    8 PRINT 6
    4 PRINT 3
      RETURN
    5 AZO s AINT(AZO)
      CALL TWOPI(AZO'1)
      PRINT 2' AZO'LMN'SUMD
      IF(INC.EQ.00) GO TO 7
      CALL TILT(VIN'XTEMP'NR)
    7 RETURN
      END
```

```
      SUBROUTINE EDAT(MX'VIN'DIN'MA'LX'ICOR'CD'CV'LRD'XTEMP'INC)


      INFER DATA CORRECTIONS TO SERIES FROM MAGNETIC TAPE

      DIMENSION ICOR(LX)' DIN(MA)'VIN(MA)'CD(LX)'CV(LX)'XTEMP(MA)
      COMMON/FORT/AQ(4)'BQ(3)
    5 FORMAT(19X'A5)
    6 FORMAT(60X'F3.0'24X'F4.2)
    7 FORMAT(5X'I5'5X'F5.0'5X'F5.2'5X'I5'5X'A5)
    9 FORMAT(24F3.2)
   10 FORMAT(24F3.0)
   12 FORMAT(110X'F3.0)
   51 FORMAT(19X'F5.0)
      REWIND 9
      IF(INC.EQ.00) GO TO 14
      IF(LRD.EQ.00) GO TO 13
      READ(9'51)(XTEMP(IM)'IM s 1'LRD)
   13 READ(9'BQ) (XTEMP(IP)'IP s 1'MA)
      REWIND 9
   14 IE s 1
      LAG s
      LEN s 1
      DO 98 I s 1'MX'LEN
      IF(LRD)99'1'2
    2 IF(I    LRD)3'3'1
    3 READ(9'5) ITRASH
      GO TO 98
    1 LAG s LAG + 1
      IF(IE.GT.LX) GO TO 11
      LD s ICOR(IE)
      IF(LD.EQ.I)GO TO 4
      LDX s ICOR(IE) - 1
   11 IF(IE.GT.LX) LDX s MX
      DO 40  IX s I'LDX
      READ(9'AQ) DIN(LAG)' VIN(LAG)
      IF(IX.EQ.LDX) GO TO 400
      LAG s LAG + 1
  400 CONTINUE
      IF(LDX.EQ.MX) GO TO 97
      LEN s LD - I
      GO TO 98
    4 READ(9'5) ITRASH
      DIN(LAG) s CD(IE)
      VIN(LAG)s CV(IE)
      XTEMP(LAG) s 0.0
      PRINT 7' I' DIN(LAG)' VIN(LAG)' ICOR(IE)'ITRASH
      LEN s 1
      IE s IE + 1
   98 CONTINUE
   97 IF(LAG.LT.MA) GO TO 8
      GO TO 99
    8 LAG s LAG + 1
      READ 9' (VIN(IN) 'IN s LAG'MA)
      READ 10' (DIN(ID)' ID s LAG'MA)
      DO 30  MAG s LAG'MA
  300 XTEMP(MAG) s 0.0
   99 IF(INC.EQ.1) CALL TILT(VIN'XTEMP'MA)
      IF(INC.EQ.1) INC s 0
      RETURN
      END
```

```
      SUBROUTINE TILT(GIN'TEM'LIT)


      CORRECT DATA FOR INSTRUMENTAL TILT

      DIMENSION GIN(LIT)'TEM(LIT)
    2 FORMAT(1H0'I6'5X'28HTILT EXCEEDS 35 DEGREE LIMIT'3X'I3)
      DO 10  IB s 1'LIT
      IF(TEM(IB).EQ.0.0) GO TO 100
      MIX s IFIX(TEM(IB))
      NIX s MIX/5 + 1
      GO TO (100'101'102'103'104'105'106'107'110'110'110'110'110)'NIX
  101 GIN(IB) s .03*GIN(IB) + GIN(IB)
      GO TO 100
  102 GIN(IB) s .06*GIN(IB) + GIN(IB)
      GO TO 100
  103 GIN(IB) s .09*GIN(IB) + GIN(IB)
      GO TO 100
  104 GIN(IB) s .12*GIN(IB) + GIN(IB)
      GO TO 100
  105 GIN(IB) s .16*GIN(IB) + GIN(IB)
      GO TO 100
  106 GIN(IB) s .20*GIN(IB) + GIN(IB)
      GO TO 100
  107 GIN(IB) s .25*GIN(IB) + GIN(IB)
      GO TO 100
  108 GIN(IB) s .51*GIN(IB) + GIN(IB)
      GO TO 100
  109 GIN(IB) s .65*GIN(IB) + GIN(IB)
      GO TO 100
  110 PRINT 2' IB'MIX
  100 CONTINUE
      RETURN
      END
      SUBROUTINE  TEMP(XSER'XTEMP'I )


      STORE SERIES FOR FOURIER ANALYSIS

      DIMENSION   XSER(I) ' XTEMP(I)
      DO 10  J s 1' I
  100 XTEMP(J) s XSER(J)
      RETURN
      END
      SUBROUTINE SORT(SORX'VX'KK'JJ)


      SORT DATA AND FORM NEW SERIES
      DIMENSION  SORX( KK )' VX( KK)
      COMMON/CONTT/NN
    1 DO 10  I s 1'KK'JJ
      NN s I/JJ + 1
  100 VX(NN) s SORX(I)
      RETURN
      END
      SUBROUTINE ONEPI( AUX)


      TEST FOR 180 DEGREE DIFFERENCE BETWEEN TWO ANGLES

      IF(ABS(AUX) -180.0)170'170'163
  163 IF(AUX)164'164'165
  164 AUX s AUX + 360.0
      GO TO 170
  165 AUX s AUX - 360.0
  170 RETURN
      END
```



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(*Continued from inside front cover*)

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