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GODDARD BROUWER ORBIT BULLETIN

D. B. MORGAN
R. A. GORDON

JULY 1971

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

The Goddard Brouwer Orbit Bulletin provides operational support for earth space research and technological missions by producing a tape containing pertinent spacecraft orbital information which is provided to a number of cities around the world in support of individual missions. This document presents a program description of the main and associated subroutines, and a complete description of the input, output and requirements of the Bulletin program.

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GODDARD BROUWER ORBIT BULLETIN

I. INTRODUCTION

Goddard Brouwer Orbit Bulletin is an economical means of providing operational support for earth space research and technological missions. The Bulletin routine accepts as input a set of orbital elements generated by the Definitive Orbit Determination System (DODS) and produces an output tape containing pertinent spacecraft orbital information. This information is provided to a number of cities around the world in support of missions such as International Satellite for Ionospheric Studies (ISIS). The Bulletin information includes the following:

1. The mean characteristics of the orbit of the satellite at epoch
2. Prediction space elements for use when approximate satellite positions are needed
3. Osculating space elements
4. Ascending nodal crossings during a requested time period
5. An ephemeris which furnishes the positions of the satellite at regular intervals
6. Brouwer data acquisition facility parameters to be used by each data acquisition facility to generate its topocentric predictions for satellite acquisition

Section II is a program description of the main and associated subroutines. A complete description of the input, output and requirements is given in Section III, Operating Instructions.

II. PROGRAM DESCRIPTION

A. PURPOSE

This program provides an economical means of disseminating pertinent spacecraft orbital information to observing stations and other interested parties.

B. FLOW CHARTS AND FUNCTIONAL DESCRIPTIONS

The following pages contain flow charts and functional descriptions of the main routine and associated subroutines. Flow charts and corresponding descriptions are grouped alphabetically, with the main routine presented first and the block data last.

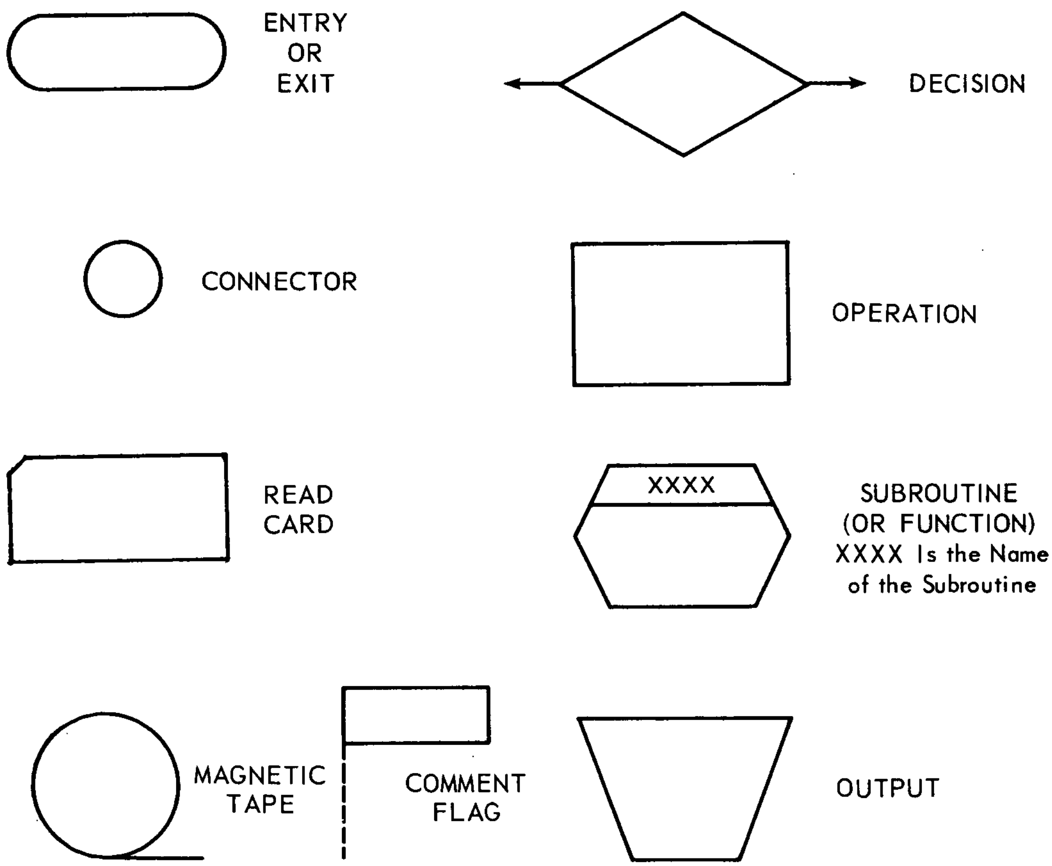
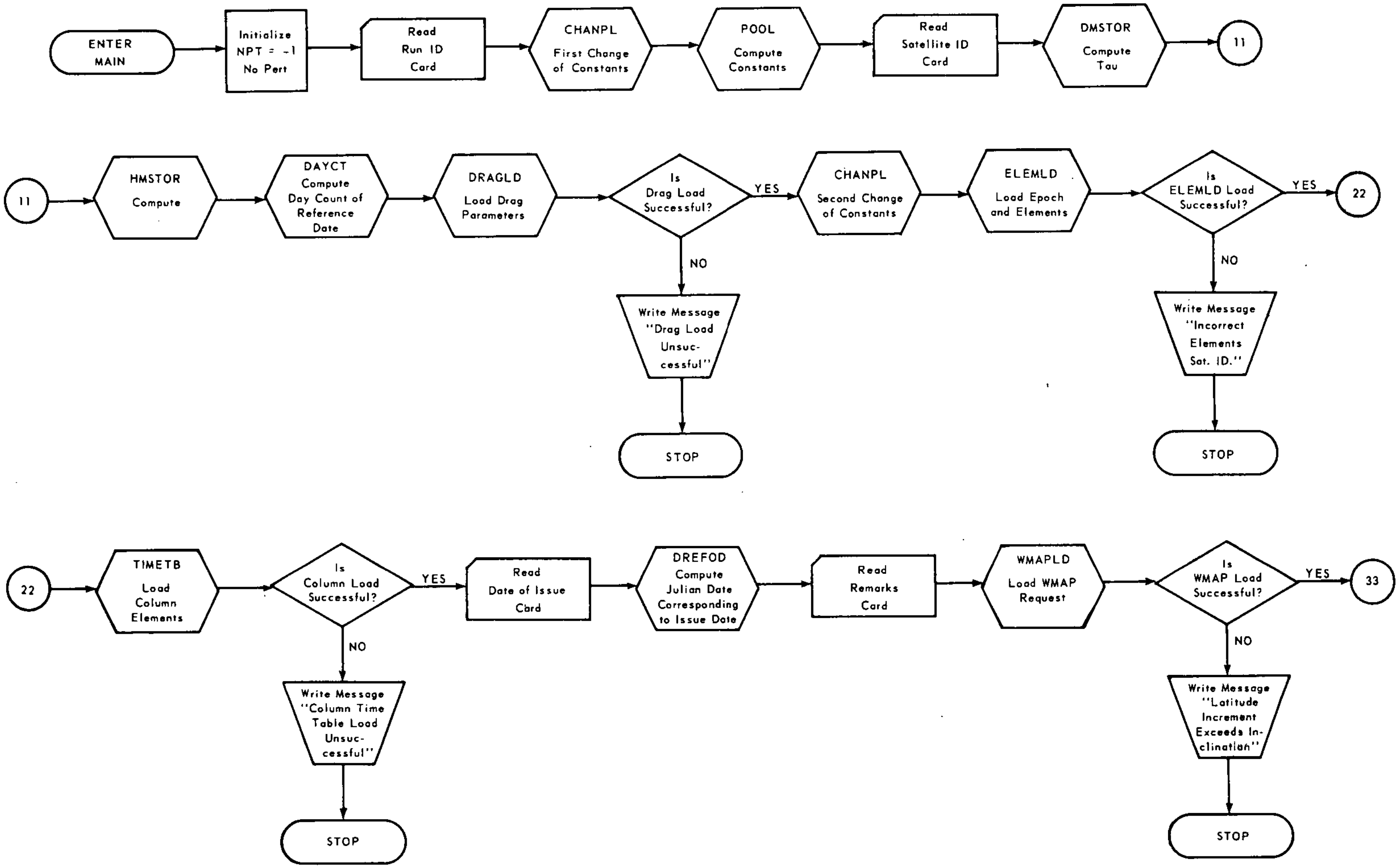
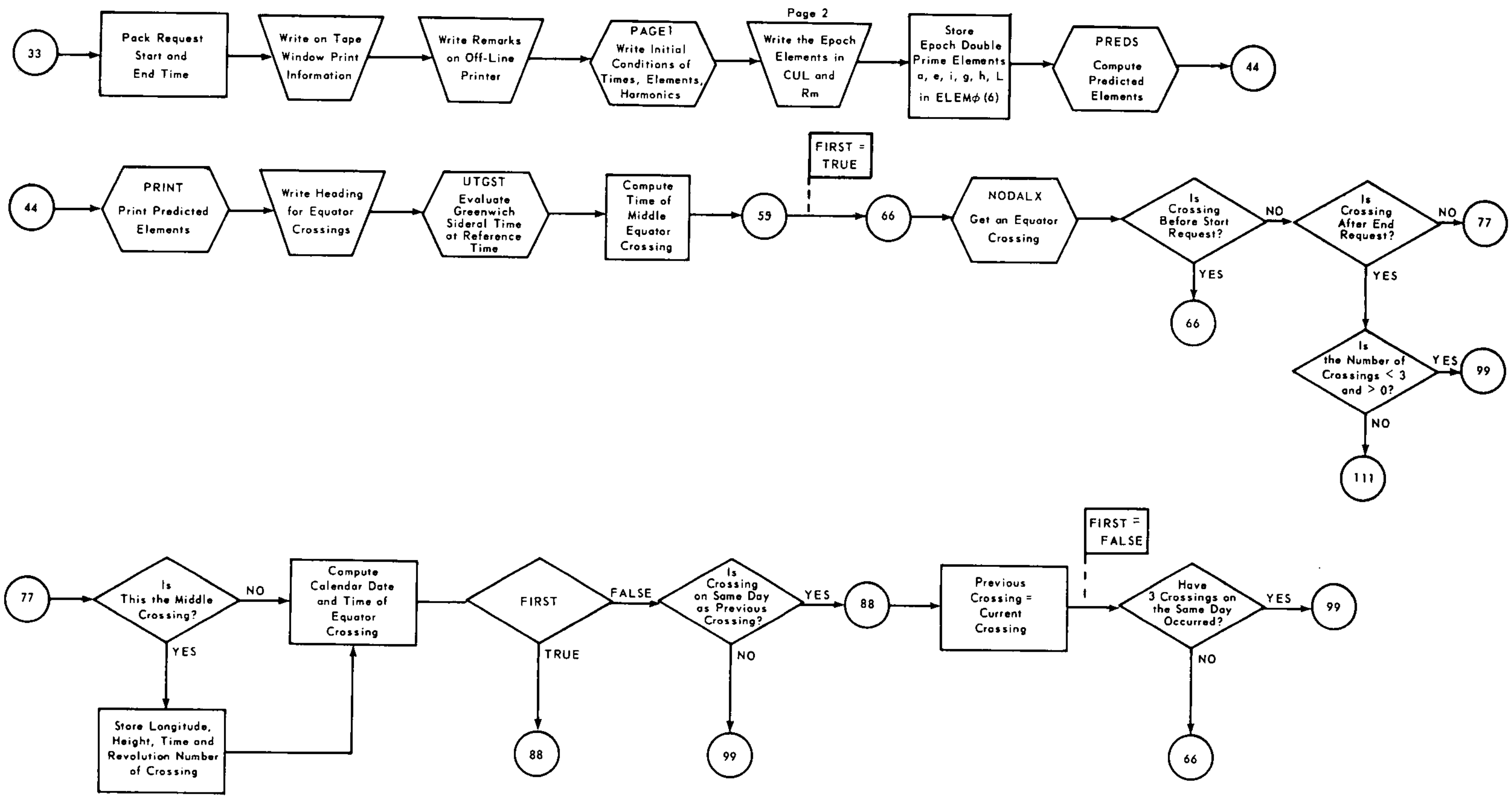


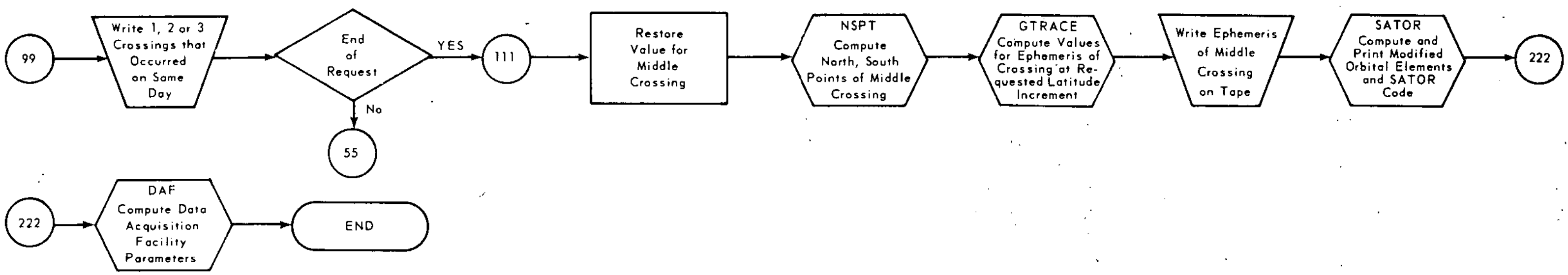
Figure 1. Flow Chart Symbols



MAIN Flowchart



MAIN Flowchart (continued)



MAIN Flowchart (continued)

BRWORB

Brouwer Orbit Generator

PURPOSE

Given a time t, referenced to some epoch, the subroutine determines a set of osculating elements corresponding to this time with the Brouwer Orbit Theory.

METHOD

Brouwer (59) made use of Von Zeipel's procedure to modify Delaunay's method in the development of an artificial satellite theory. The subroutine "BRWORB" is a faithful coding of Brouwer's formulas as they appear in Sec. 9 "Formulas for Computation", Brouwer, D., "Solution of the Problem of Artificial Satellite Theory Without Drag," Astronomical Journal, 64 (November 1959), 378-397., except for modifications made to include the perturbation (pert) tape option.

FORMULATION

I. Compute Brouwer epoch elements corrections:

1. Without Pert tape

$$\left.\begin{aligned} a_0 &= a'' \\ e_0 &= e'' \\ i &= i'' \\ \ell_0 &= \ell'' \\ g_0 &= g'' \\ h_0 &= h'' \end{aligned}\right\} \text{at } t = t_0 \qquad n_0' = \sqrt{\frac{\mu}{(a'')^3}}$$

2. With Pert tape

a. For $\dot{\ell}''$ calculation

$$a'' = a_0 + \Delta a$$

$$e'' = e_0 + \Delta e$$

$$i'' = i_0 + \Delta i$$

$$n_0 = \sqrt{\frac{\mu}{(a'')^3}}$$

b. For $\dot{g}''$ and $\dot{h}''$ calculation

$$a'' = a_0 + \frac{\Delta a}{2}, \qquad n_0 = \sqrt{\frac{\mu}{(a'')^3}}$$

$$e'' = e_0 + \frac{\Delta e}{2}$$

$$i_0'' = i_0 + \frac{\Delta i}{2}$$

c. Correction to ℓ_0, g_0, and h_0 (epoch angular elements)

$$\ell_0 \, \mathrm{dl} = \ell_0 + \Delta \ell$$

$$g_0 = g_0 + \Delta g$$

$$h_0 = h_0 + \Delta h$$

$$\ell_0 = \ell'' \qquad \text{at } (t = t_0)$$

II. Calculation of abbreviated notation to simplify formulas:

$$\eta \equiv \sqrt{1 - e''^2} \qquad \theta \equiv \cos i''$$

$$\gamma_2 = \frac{k_2}{a''^2} \qquad \gamma_4 = \frac{k_4}{a''^4}$$

$$\gamma_2' = \frac{\gamma_2}{\eta^4} \qquad \gamma_4' = \frac{\gamma_4}{\eta^8}$$

III. Compute the first time derivative of the secular terms:

1. ~~Mean~~ Mean anomaly derivative, Anomalistic Mean Motion and period;

$$\dot{\ell} = \frac{dl''}{dt} - n_0 t = n_0 \eta \left\{ \gamma_2' \left[\frac{3}{2}(3\theta^2 - 1) + \frac{3}{32}\gamma_2' \left[25\eta^2 + 16\eta - 15 \right.\right.\right.$$

$$\left.\left. + (30 - 96\eta - 90\eta^2)\theta^2 + (105 + 144\eta + 25\eta^2)\theta^4 \right]\right]$$

$$\left. + \frac{15}{16}\gamma_4' e''^2 (3 - 30\theta^2 + 35^4) \right\}$$

$$l_0 D = n_0' + \dot{l}, \quad n = k l_0 D, \quad P = \frac{2\pi}{n}, \quad \dot{l}_0 = n_0' + \dot{l} \quad \text{at } (t = t_0)$$

2. Mean Argument of Perigee derivative;

$$\dot{g} = \frac{dg''}{dt} = n_0 \left\{ \gamma_2' \left[\frac{3}{2}(5\theta^2 - 1) + \frac{3}{32}\gamma_2' \left[25\eta^2 + 24\eta - 35 \right.\right.\right.$$

$$\left.\left. + (90 - 192\eta - 126\eta^2)\theta^2 + (385 + 360\eta + 45\eta^2)\theta^4 \right]\right]$$

$$\left. + \frac{15}{16}\gamma_4' \left[21 - 9\eta^2 + (126\eta^2 - 270)\theta^2 + (385 - 189\eta^2)\theta^4 \right] \right\}$$

3. Mean longitude of ascending node derivative;

$$\dot{h} = \frac{dh''}{dt} = n_0 \left\{ \gamma_2' \left[\frac{3}{8}\gamma_2' \left[(9\eta^2 + 12\eta - 5)\theta + (-35 - 36\eta - 5\eta^2)\theta^3 \right] - 3\theta \right] \right.$$

$$\left. + \frac{5}{4}\gamma_4' (5 - 3\eta^2)\theta(3 - 7\theta^2) \right\}$$

IV. Compute constants for long-period terms;

$$\gamma_3 = \frac{k}{a''^3} \qquad \gamma_5 = \frac{k_5}{a''^5}$$

$$\gamma_3' = \frac{\gamma_3}{\eta^6} \qquad \gamma_5' = \frac{\gamma_5}{\eta^{10}}$$

$$(1 - 5\theta^2)^{-1}$$

Compute $\ell P_1 - \ell P_{15}$

$$\ell P_1' \equiv 40\theta^4 (1 - 5\theta^2)^{-1}$$

$$\ell P_1 \equiv \frac{1}{8} \gamma_2' \eta^2 (1 - 11\theta^2 - \ell P_2')$$

$$\ell P_2 \equiv \frac{5}{12} \frac{\gamma_4'}{\gamma_2'} \eta^2 [1 - 3\theta^2 - 8\theta^4 (1 - 5\theta^2)^{-1}]$$

$$\ell P_3 \equiv \frac{1}{4} \frac{\gamma_3'}{\gamma_2'} \eta^2 \sin i''$$

$$\ell P_4' \equiv [1 - 9\theta^2 - 24\theta^4 (1 - 5\theta^2)^{-1}]$$

$$\ell P_4 \equiv \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} \eta^2 \ell P_4' \sin i''$$

$$\ell P_5' \equiv 1 - 5\theta^2 - 16\theta^4 (1 - 5\theta^2)^{-1}$$

$$\ell P_5 \equiv \frac{35}{384} \frac{\gamma_5'}{\gamma_2'} e''^2 \eta^2 \sin i'' \ell P_5$$

$$\ell P_6' \equiv \ell P_1 (1 - 5\theta^2)^{-1}$$

$$\ell P_6 \equiv 3 + 16\theta^2 (1 - 5\theta^2)^{-1} + \ell P_6'$$

$$\ell P_7 \equiv 4 + 3e''^2$$

$$\ell P_8 \equiv \frac{35}{576} \frac{\gamma_5'}{\gamma_2'} e''^3 \theta \sin i'' \left(5 + 32\theta^2 (1 - 5\theta^2)^{-1} + 2\ell P_6'\right)$$

$$\ell P_9 \equiv \frac{e'' \theta}{\sin i''}$$

$$\ell P_{10} \equiv \frac{35}{1152} \frac{\gamma_5'}{\gamma_2'} e''^2 \ell P_9 \ell P_5'$$

$$\ell P_{11} \equiv \frac{\sin i''}{e''}$$

$$\ell P_{12} \equiv 2 + e''^2$$

$$\ell P_{13} \equiv (2 + 3e''^2)\theta^2$$

$$\ell P_{14} \equiv 8(2 + 5e''^2)\theta^4 (1 - 5\theta^2)^{-1}$$

$$\ell P_{15} \equiv \frac{e''}{\eta^2 \tan i''}$$

Compute $A_1 - A_{11}$

$$A_1 = e''(\ell P_1 - \ell P_2)$$

$$A_2 = \ell P_3 + (4 + 3e''^2)\ell P_4$$

$$A_3 = \eta(\ell P_1 - \ell P_2)$$

$$A_4 = \frac{\eta}{e''}[\ell P_5 + (4 + 9e''^2)\ell P_4]$$

$$A_5 = \frac{\eta}{e''} \ell P_5$$

$$A_6 = \frac{1}{16} \gamma_2' (\ell P_{12} - 11 \ell P_{13} - 5 \ell P_{14} - 10 e''^2 \theta^2 \ell P_6')$$

$$+ \frac{5}{24} \frac{\gamma_4'}{\gamma_2'} (\ell P_{12} - 3 \ell P_{13} - \ell P_{14} - 2 e''^2 \theta^2 \ell P_6')$$

$$A_7 = \frac{1}{4} \frac{\gamma_3'}{\gamma_2'} (\ell P_{11} - \theta \ell P_9) + \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} [(\eta^2 \ell P_{11} - \theta \ell P_9) \ell P_7$$

$$+ e'' \sin i'' (26 + 9 e''^2)] \ell P_4' - \frac{15}{32} \frac{\gamma_3'}{\gamma_2'} e'' \theta^2 \sin i \ell P_7 \ell P_6$$

$$A_8 = - \frac{35}{1152} \frac{\gamma_5'}{\gamma_2'} [e'' \sin i'' (3 + 2e''^2) - e''^2 \theta \ell P_9] \ell P_5' + \theta \ell P_8$$

$$A_9 = - \frac{1}{8} \gamma_2' e''^2 \theta [11 + 80\theta^2 (1 - 5\theta^2)^{-1} + 5 \ell P_6'] + \frac{5}{12} \frac{\gamma_4'}{\gamma_2'} e''^2 \theta \ell P_6$$

$$A_{10} = \ell P_9 \left[\frac{1}{4} \frac{\gamma_3'}{\gamma_2'} + \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} \ell P_7 \ell P_4' \right]$$

$$A_{11} = \ell P_{10} + \ell P_8$$

V. Compute constants for short-period terms included:

Compute SP_1 - SP_6

$$SP_1 \equiv \frac{\eta^2}{2e''} \qquad SP_3 \equiv \frac{1}{2} \gamma_2'$$

$$SP_2 \equiv \gamma_2' (1 - \theta^2) \qquad SP_4 \equiv 2(-1 + 3\theta^2)$$

$$SP_5 \equiv 6(-1 + 5\theta^2) \qquad SP_6 \equiv \theta\, SP_3 (1 - \theta^2)^{1/2}$$

VI. Call DRAG Subroutine to compute Δl_{drag} at Observation time t.

$$\Delta \ell_{drag} = \sum_{q=0}^{m} \sum_{P=2}^{3} N_{P,q} (t - t_q)^P$$

where

$$m = 0, 1, 2, \ldots, 19$$

VII. Compute Secular Terms:

1. ℓ'' = <u>mean</u> mean anomaly;

$$\ell_0 dgL = (\ell_0 + \Delta\ell_{drag}) \qquad \ell_0 dgPt = \mathrm{mod}(\ell_0 d\ell + \Delta\ell_{drag}, 2\pi)$$

$$\ell'' = \mathrm{mod}(n_0' t, 2\pi) + \mathrm{mod}(\dot{\ell} t, 2\pi) + \mathrm{mod}(\ell_0 d\ell + \Delta\ell_{drag}, 2\pi)$$

2. g'' = mean argument of Perigee;

$$g'' = \mathrm{mod}(\dot{g} t + g_0, 2\pi)$$

3. h'' = mean longitude of Ascending node;

$$h'' = \mathrm{mod}(\dot{h} t + h_0, 2\pi)$$

VIII. Test for Critical Inclination:

$$\Delta i = |i'' - i_c|$$

where

$$i_c = 63.43°$$

if

$$\Delta i < 1.5$$

then

$$\delta_1 e = \delta_1 I = l' = g' = h'$$

IX. Compute Long-Period terms:

1. ℓ' = mean anomaly;

$$\ell' = \ell'' + A_3 \sin 2g'' - A_4 \cos g'' + A_5 \cos 3g'' \quad , \quad \mathrm{mod}\,(\ell', 2\pi)$$

$$\ell_1 = \ell' - \dot{\ell}_0 t + \ell_0 + \Delta\ell_{drag} \quad , \quad \mathrm{mod}\,(\ell_1, 2\pi)$$

2. g' = Argument of Perigee;

$$g' = g'' + A_6 \sin 2g'' + A_7 \cos g'' + A_8 \cos 3g'' \quad , \quad \mathrm{mod}\,(g', 2\pi)$$

3. h' = longitude of Ascending node;

$$h' = h'' + A_9 \sin 2g'' + A_{10} \cos g'' - A_{11} \cos 3g'', \quad \mathrm{mod}\,(h', 2\pi)$$

4. Call KEPLR1 Subroutine to determine E' and compute f' from

$$f' = \tan^{-1}\left(\frac{\sqrt{1 - e''^2}\ \sin(E')}{\cos E' - e''}\right)$$

$$\frac{a_0''}{r'} = \frac{1}{1 - e'' \cos E'}$$

X. Compute Short-Period terms included:

Compute $B_1 - B_6$

$$B_1 \equiv \gamma_2 \left[(-1 + 3\theta^2)\left(\frac{a''^3}{r'^3} - \eta^{-3}\right) + 3(1 - \theta^2)\frac{a''^3}{r'^3} \cos(2g' + 2f')\right]$$

$$B_2 \equiv 3e'' \cos(2g' + f') + e'' \cos(2g' + 3f')$$

$$B_3 \equiv \frac{a''^2}{r'^2}\eta^2 + \frac{a''}{r'}$$

$$B_4 \equiv SP_4 (B_3 + 1) \sin f'$$

$$+ 3(1-\theta^2)\left[(-B_3 + 1)\sin(2g' + f') + \left(B_3 + \frac{1}{3}\right)\sin(2g' + 3f')\right]$$

$$B_5 \equiv f' - l' + e'' \sin f'$$

$$B_6 \equiv 3\sin(2g' + 2f') + 3e'' \sin(2g' + 2f')$$

$$+ 3e'' \sin(2g' + f') + e'' \sin(2g' + 3f')$$

XI. Compute Osculating Elements:

1. Compute a (semi-major axis)

$$a = a''(1 + B_1)$$

2. Compute e (eccentricity)

$$e = e'' + \delta_1 e + SP_1\left(B_1 - \gamma_2 \eta^{-4} \cos(2g' + 2f')\, 3(1-\theta^2) - SP_2 B_2\right)$$

3. Compute i (inclination)

$$i = i'' + \delta_1 i + SP_6 [3\cos(2g' + 2f') + B_2] \qquad , \quad \mathrm{mod}(i, 2\pi)$$

4. Compute g (argument of Perigee)

$$g = g' + SP_1 SP_3 B_4 + \frac{SP_3}{2}[SP_5 B_5 + (3 - 5\theta^2) B_6] \qquad , \quad \mathrm{mod}(g, 2\pi)$$

5. Compute h (longitude of ascending node)

$$h = h' - \theta\, SP_3 (6B_5 - B_6) \qquad , \quad \mathrm{mod}(h, 2\pi)$$

6. Compute l (mean anomaly)

$$\ell = \ell' - \eta SP_1 SP_3 B_4 \qquad , \bmod (\ell, 2\pi)$$

7. Call KEPLR1, to compute E (eccentric anomaly)

8. Compute f (true anomaly)

$$f = \tan^{-1}\left(\frac{\sqrt{1 - e^2}\ \text{Sin } E}{\cos E - e}\right)$$

XII. Compute Position and Velocity Vectors:

Call the UVIJK Routine to perform the mapping, (osculating keplerian elements to rectangular cartesian)

$$a,\ e,\ i,\ g,\ h,\ \ell \rightarrow x,\ y,\ z,\ \dot{x},\ \dot{y},\ \dot{z}$$

CALLING SEQUENCE

CALL BRWORB (T0, T, DRG, NQ, F, EA, R, DR, RMAG, DRMAG, N, PD, PASS, K, SATID)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	T0	Epoch time and date
I	T	Observation time
I	DRG(60)	DRG(1) ↓ DRG(20) $\}$ $t_0, t_1, \ldots, t_{19}$ DRG(21) ↓ DRG(40) $\}$ $N_{2,0}, N_{2,1}, \ldots, N_{2,19}$

Arguments (continued)

I/O	Variable	Description
		DRG(41) ↓ DRG(60) } $N_{3,0}, N_{3,1}, \ldots, N_{3,19}$
I	NQ	Number of drag inputs
O	F	True Anomaly
O	EA	Eccentric Anomaly
O	R(3)	x, y, z Satellite Position Vector
O	DR(3)	$\dot{x}, \dot{y}, \dot{z}$ Satellite Velocity Vector
O	RMAG	r — magnitude of Position Vector
O	DRMAG	v — magnitude of Velocity Vector
O	N	Anomalistic mean motion
O	PD	Anomalistic Period
I	PASS	PASS = 1 Compute constants (at t_0) needed in computation of osculating elements PASS = 2 Update osculating elements to observation time t
I	$K = \sqrt{GM}$	Gravitational Constant $(\text{length})^{3/2}/\text{time}$
I	SATID(11)	SATID(1) = Satellite identification number SATID(2) = reference year SATID(11) = day count of reference date

Common

I/O	Block	Variable
I	BPOOL	TABLE(12) - TABLE(15) = J_2, J_3, J_4, J_5 TABLE(16) = Deg./rad. TABLE(22) = r_e TABLE(31) = TOL TABLE(41) = μ TABLE(61) - TABLE(64) = K_2, K_3, K_4, K_5
O	SECPRM	DPELE(6) = $a'', e'', i'', g'', h'', l''$
O	DOTELE	L0DOT = $\dot{\ell}_0$ LDOT = $\dot{\ell}$ GDOT = $\dot{g}$ HDOT = $\dot{h}$

Common

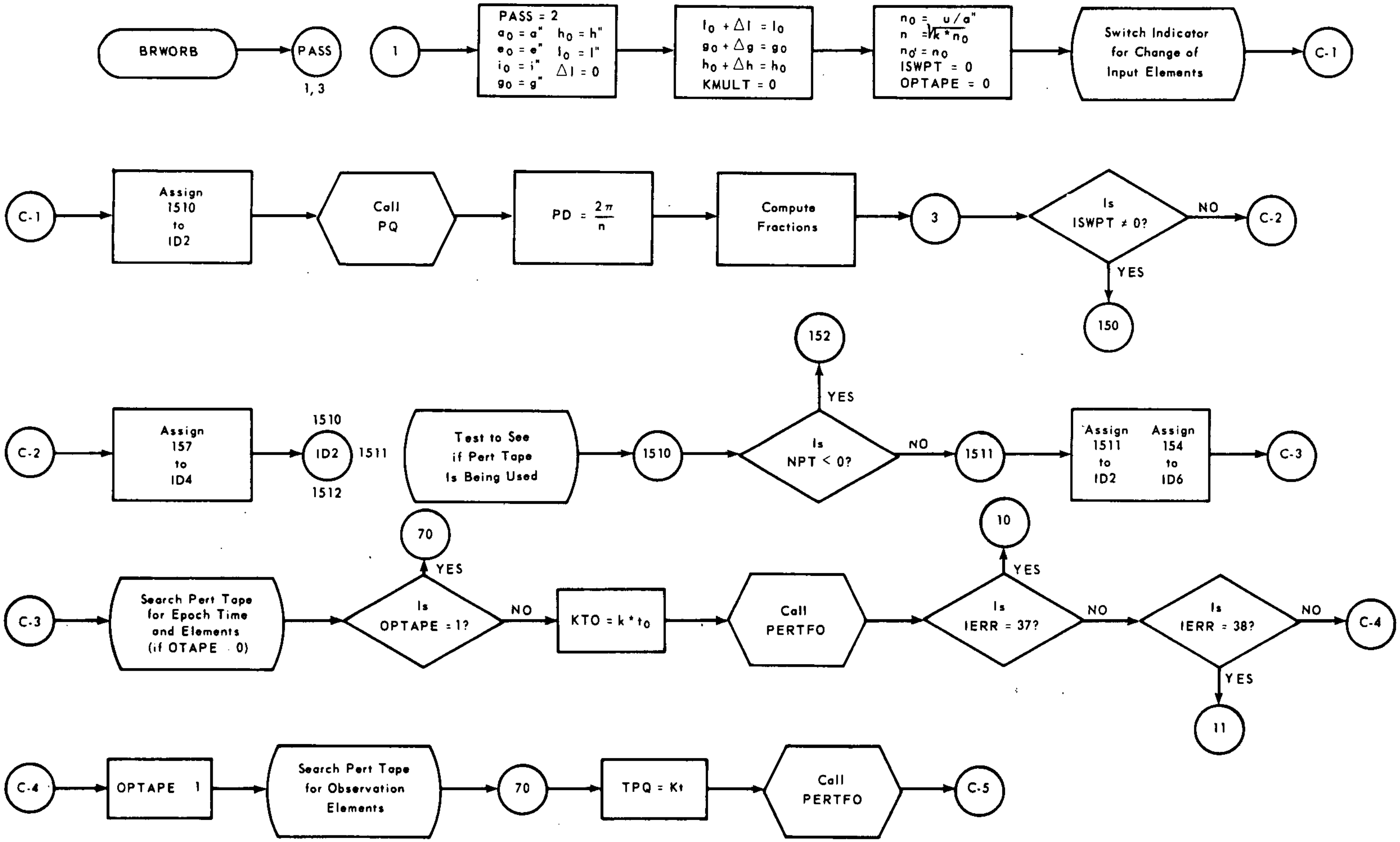
I/O	Block	Variable
O	LPPRM	DEL1E = $\delta_1 e$
		DEL1I = $\delta_1 i$
		L1 = ℓ_1
		LP = ℓ'
		GP = g'
		HP = h'
O	OSCELE	ORBPRM(6) = a, e, i, g, h, ℓ
O	ETAP	η^3, η^6, η^4
O	THETA	M1P3T2 = $3\theta^2 - 1$, THETA = $\theta = \cos i$
O	GMPR	γ_2
O	UVPQ	U, V, P, Q
O	DGPRM	L0DGL = $\ell_0 + \Delta\ell_{drag}$
O	DAFPRM	LDAF(1) = A_1
		LDAF(2) = A_2
		LDAF(3) = $-\ell P_5$
		LDAF(4) = A_3
		LDAF(5) = $-A_4$
		LDAF(6) = A_5
		LDAF(7) = A_6
		LDAF(8) = A_7
		LDAF(9) = A_8
		LDAF(10) = A_9
		LDAF(11) = A_{10}
		LDAF(12) = $-A_{11}$
		LDAF(13) = ℓP_{15}
I	PIND	NPT
O	PERTL	L0DGPT = $\ell_0 + \Delta\ell + \Delta\ell_{drag}$
		E_0
O	DELKEP	DKEP(6) = Δa, Δe, Δi, Δg, Δh, $\Delta\ell$
O	PRTKEP	PKEP(3) = $g_0 + \Delta g$, $h_0 + \Delta h$, $\ell_0 + \Delta\ell$
O	NOD	L0D = $\ell_0 D$

CALLED BY

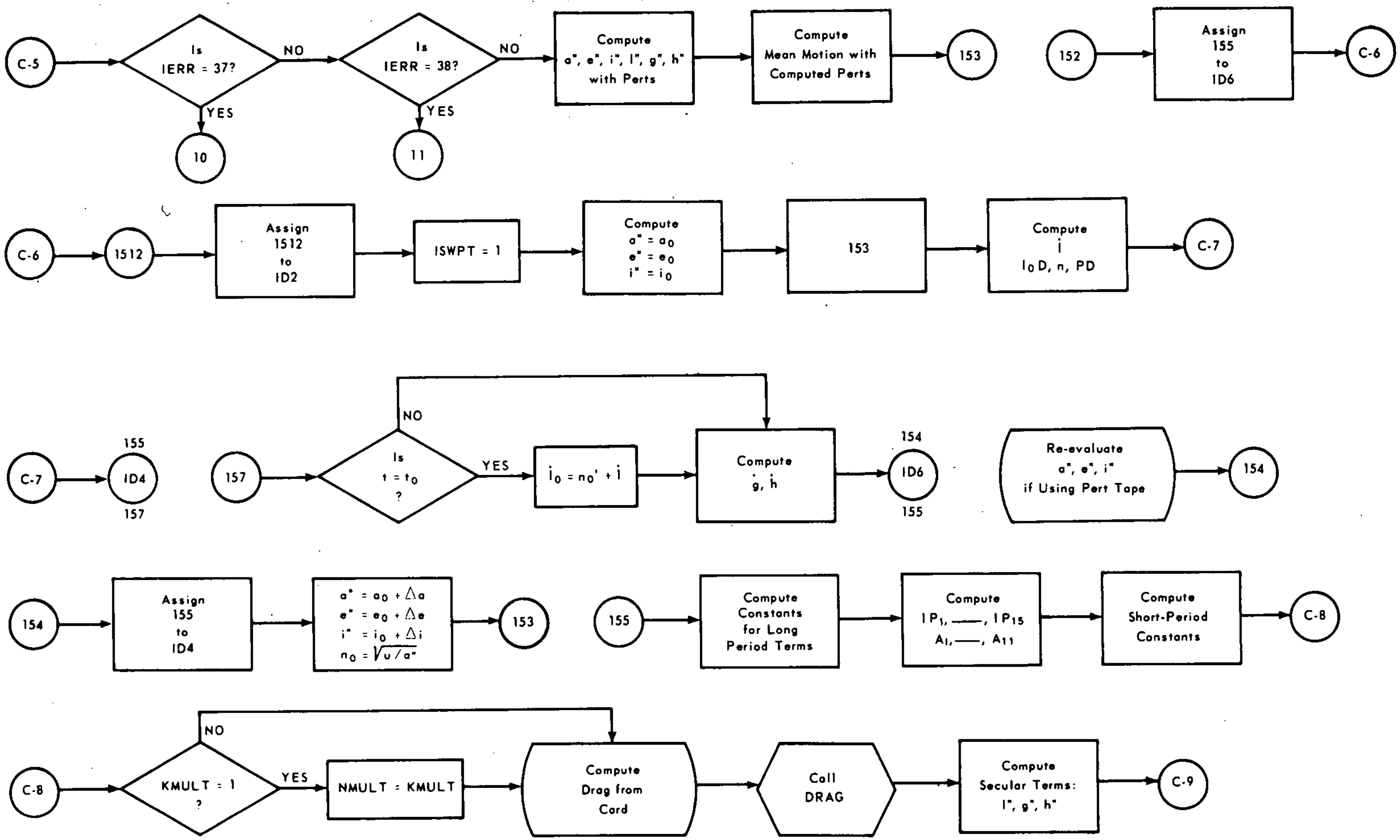
DAF
ELEMLD
PREDS
SPACEL
GTRACE
NODALX
NSPT

CALLS

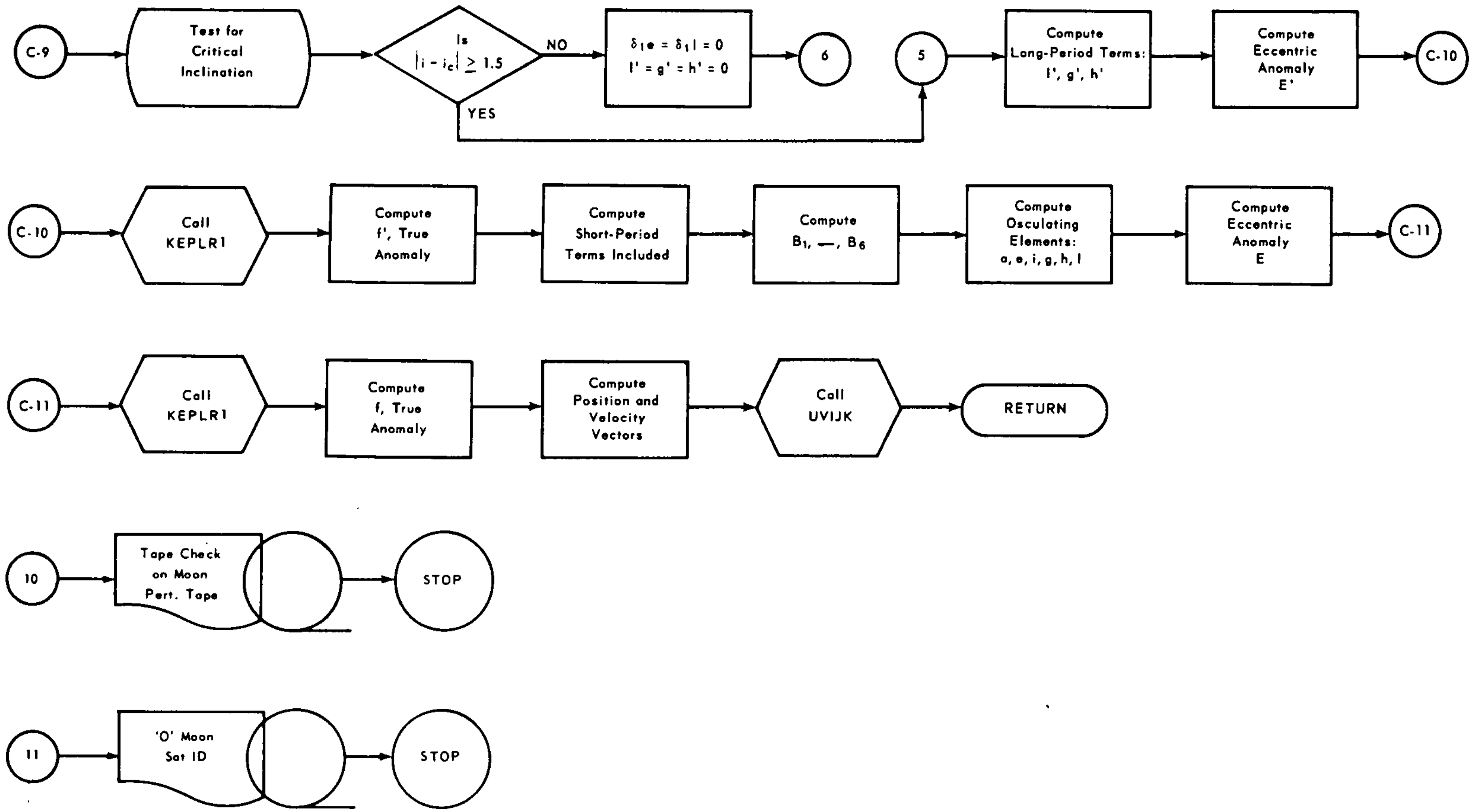
PQ
PERTF0
DRAG
KEPLR1
REDUCE
UVIJK



BRWORB Flowchart



BRWORB Flowchart (continued)



BRWORB Flowchart (continued)

CHANPL

Change of Constants

PURPOSE

To change any constant that is in the BLOCK DATA or POOL Subroutine.

METHOD

Constants from the BLOCK DATA or POOL subroutine are changed according to the values on the change of constants cards. Each card permits change of one to three constants. The first forty constants, which are in the BLOCK DATA, can be changed by the first change of constants card(s). The remaining forty constants, which are defined in the POOL subroutine, can be changed by the second change of constants card(s). All eighty constants are stored in COMMON BPOOL.

CALLING SEQUENCE

CALL CHANPL

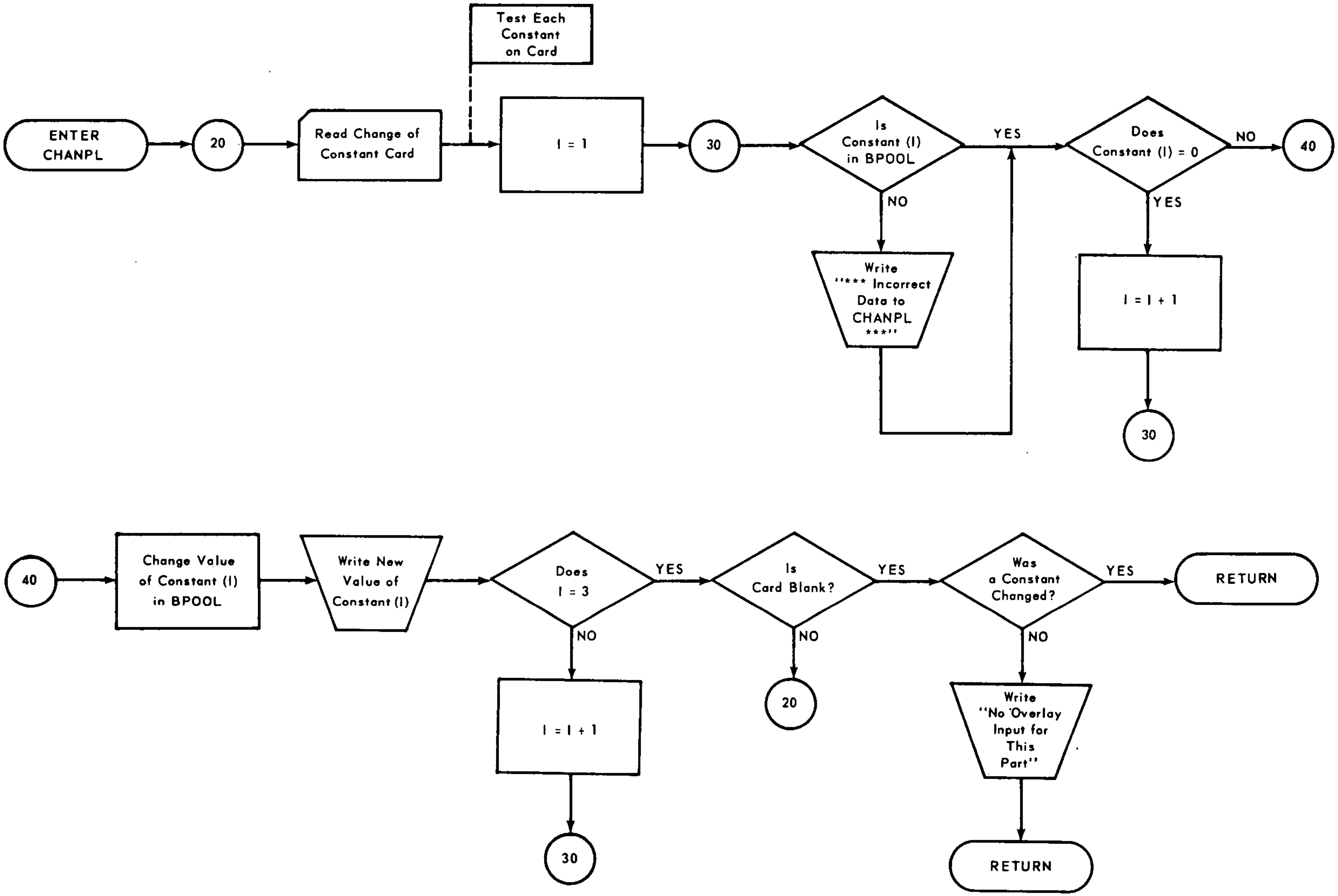
INPUT/OUTPUT

Common

I/O	Block	Variable	Description
I/O	BPOOL	TABLE(80)	Frequently used constants that are previously set in the program but may be changed by the change of constants cards.

CALLED BY

MAIN



CHANPL Flowchart

CKSUM

Check Sum

PURPOSE

To sum the digits of a line of data to modulo ten.

METHOD

A data line in SPACEL contains ten numbers which will be summed modulo ten in CKSUM.

CALLING SEQUENCE

CALL CKSUM (NCK, NX)

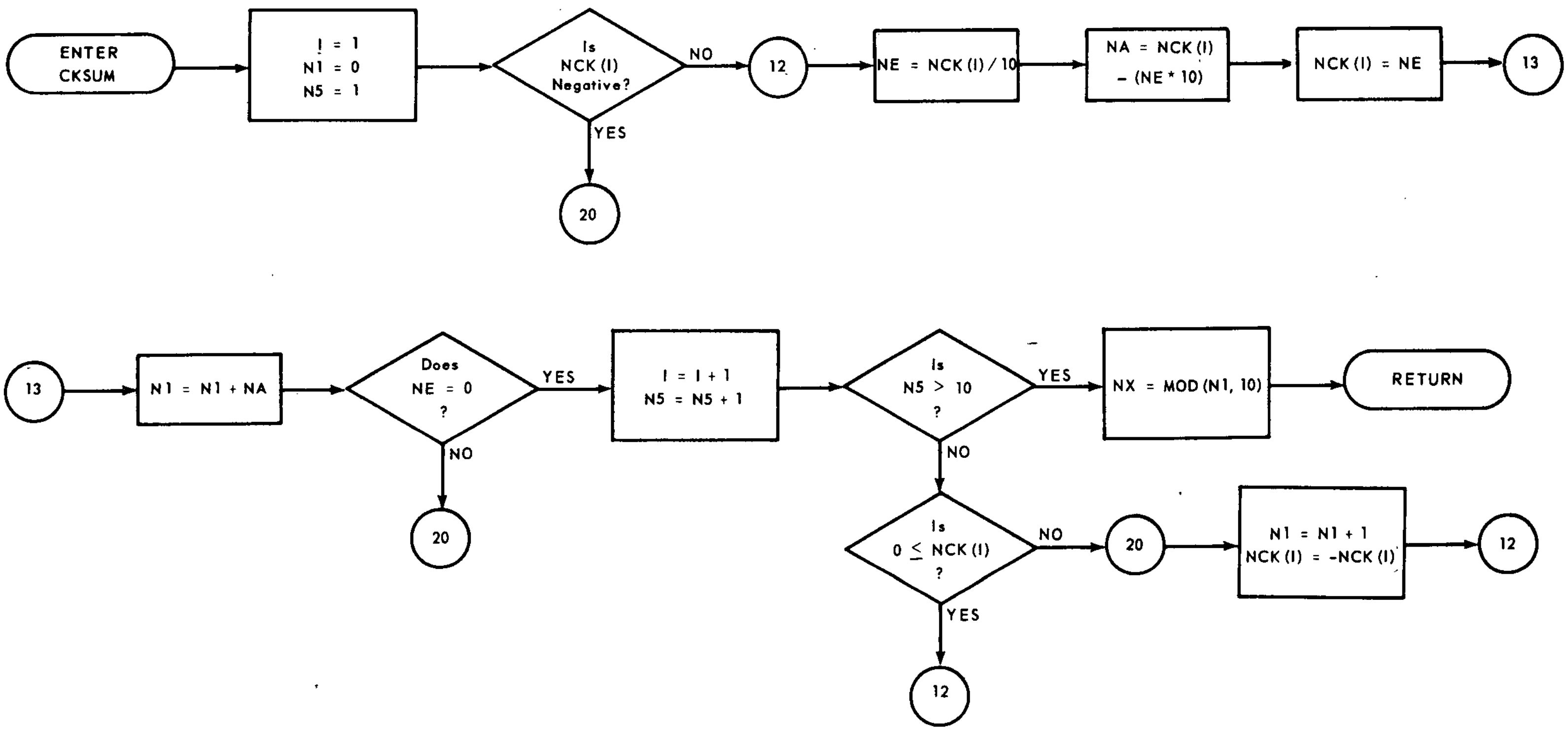
INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	NCK(10)	Array of ten numbers from a line of data
O	NX	Sum of all digits from NCK modulo ten

CALLED BY

SPACEL



CKSUM Flowchart

DAF

Data Acquisition Facility Parameters

PURPOSE

To compute Brouwer parameters to be used by each data acquisition facility to generate its topocentric predictions for satellite acquisition.

METHOD

The following quantities are computed by Brouwer Satellite Theory Orbit Generator (BRWORB). They are defined here using Brouwer's Terminology.

$$\text{LDOT} = \Big\{ 1 + \frac{3}{2}\gamma_2' \eta (-1 + 3\theta^2) + \frac{3}{32}\gamma_2'^2 \eta [-15 + 16\eta + 25\eta^2$$

$$+ (30 - 96\eta - 90\eta^2)\theta^2 + (105 + 144\eta + 25\eta^2)\theta^4]$$

$$+ \frac{15}{16}\gamma_4' \eta e''^2 [3 - 30\theta^2 + 35\theta^4] \Big\}$$

$$\text{GDOT} = \Big\{ \frac{3}{2}\gamma_2' (-1 + 50\theta^2) + \frac{3}{32}\gamma_2'^2 [-35 + 24\eta + 25\eta^2$$

$$+ (90 - 192\eta - 126\eta^2)\theta^2 + (385 + 360\eta + 45\eta^2)\theta^4]$$

$$+ \frac{5}{16}\gamma_4' [21 - 9\eta^2 + (-270 + 126\eta^2)\theta^2 + (385 - 189\eta^2)\theta^4] \Big\}$$

$$\mathrm{HDOT} = \Big\{ -3\gamma_2'\theta + \frac{3}{8}\gamma_2'^2 \left[(-5 + 12\eta + 9\eta^2)\theta + (-35 - 36\eta - 5\eta^2)\theta^3\right]$$

$$+ \frac{5}{4}\gamma_4' (5 - 3\eta^2)\theta(3 - 7\theta^2) \Big\}$$

$$\mathrm{LDAF}_1 = \Big\{ \frac{1}{8}\gamma_2' e'' \eta^2 \left[1 - 11\theta^2 - 40\theta^4 (1 - 5\theta^2)^{-1}\right]$$

$$- \frac{5}{12}\frac{\gamma_4'}{\gamma_2'} e'' \eta^2 \left[1 - 3\theta^2 - 8\theta^4 (1 - 5\theta^2)^{-1}\right] \Big\}$$

$$\mathrm{LDAF}_2 = \Big\{ \frac{1}{4}\frac{\gamma_3'}{\gamma_2'} \eta^2 \sin I''$$

$$+ \frac{5}{64}\frac{\gamma_5'}{\gamma_2' \eta^2} \sin I'' (4 + 3e''^2) \left[1 - 9\theta^2 - 24\theta^4 (1 - 5\theta^2)^{-1}\right] \Big\}$$

$$\mathrm{LDAF}_3 = -\frac{35}{384}\frac{\gamma_5'}{\gamma_2'} e''^2 \eta^2 \sin I'' \left[1 - 5\theta^2 - 16\theta^4 (1 - 5\theta^2)^{-1}\right]$$

$$\mathrm{LDAF}_4 = \Big\{ \frac{1}{8}\gamma_2' \eta^3 \left[1 - 11\theta^2 - 40\theta^4 (1 - 5\theta^2)^{-1}\right]$$

$$- \frac{5}{12}\frac{\gamma_4'}{\gamma_2'} \eta^3 \left[1 - 3\theta^2 - 8\theta^4 (1 - 5\theta^2)^{-1}\right] \Big\}$$

$$\mathrm{LDAF}_5 = \left\{ -\frac{1}{4} \frac{\gamma_3'}{\gamma_2'} \frac{\eta^3}{e''} \sin I'' \right.$$

$$\left. - \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} \frac{\eta^3}{e''} \sin I'' \; (4 + 9e''^2) \; [1 - 9\theta^2 - 24\theta^4 (1 - 5\theta^2)^{-1}] \right\}$$

$$\mathrm{LDAF}_6 = \frac{35}{384} \frac{\gamma_5'}{\gamma_2'} \eta^3 e'' \sin I'' \; [1 - 5\theta^2 - 16\theta^4 (1 - 5\theta^2)^{-1}]$$

$$\mathrm{LDAF}_7 = \left\{ -\frac{1}{16} \gamma_2' \; [+ (2 + e''^2) - 11 (2 + 3e''^2) \theta^2 - 40 (2 + 5e''^2) \theta^4 (1 - 5\theta^2)^{-1} \right.$$

$$- 400 e''^2 \theta^6 (1 - 5\theta^2)^{-2}] + \frac{5}{24} \frac{\gamma_4'}{\gamma_2'} \; [2 + e''^2 - 3 (2 + 3e''^2) \theta^2$$

$$\left. - 8 (1 + 5e''^2) \theta^4 (1 - 5\theta^2)^{-1} - 80 e''^2 \theta^6 (1 - 5\theta^2)^{-2}] \right\}$$

$$\mathrm{LDAF}_8 = \left\{ \frac{1}{4} \frac{\gamma_3'}{\gamma_2'} \left(\frac{\sin I''}{e''} - \frac{e'' \theta^2}{\sin I''} \right) + \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} \right.$$

$$\times \left[\left(\frac{\eta^2 \sin I''}{e''} - \frac{e'' \theta^2}{\sin I''} \right) (4 + 3e''^2) + e'' \sin I'' \; (26 + 9e''^2) \right] \; [1 - 9\theta^2$$

$$- 24\theta^4 (1 - 5\theta^2)^{-1}] - \frac{15}{32} \frac{\gamma_5'}{\gamma_2'} \; e'' \theta^2 \sin I'' \; (4 + 3e''^2)$$

$$\left. [3 + 16\theta^2 (1 - 5\theta^2)^{-1} + 40\theta^4 (1 - 5\theta^2)^{-2}] \right\}$$

$$\mathrm{LDAF}_9 = \left\{ -\frac{35}{1152} \frac{\gamma_5'}{\gamma_2'} \left[e'' \sin I'' (3 + 2e''^2) - \frac{e''^3 \theta^2}{\sin I''} \right] [1 - 5\theta^2 \right.$$

$$- 16\theta^4 (1 - 5\theta^2)^{-1}] + \frac{35}{576} \frac{\gamma_5'}{\gamma_2'} e''^3 \theta^2 \sin I'' [5 + 32\theta^2 (1 - 5\theta^2)^{-1}$$

$$\left. + 80\theta^4 (1 - 5\theta^2)^{-2}] \right\}$$

$$\mathrm{LDAF}_{10} = \left\{ -\frac{1}{8} \gamma_2' e''^2 \theta \; [11 + 80\theta^2 (1 - 5\theta^2)^{-1} + 200\theta^4 (1 - 5\theta^2)^{-2}] \right.$$

$$\left. + \frac{5}{12} \frac{\gamma_4'}{\gamma_2'} e''^2 \theta \; [3 + 16\theta^2 (1 - 5\theta^2)^{-1} + 40\theta^4 (1 - 5\theta^2)^{-2}] \right\}$$

$$\mathrm{LDAF}_{11} = + \left\{ \frac{1}{4} \frac{\gamma_3'}{\gamma_2'} \frac{e'' \theta}{\sin I''} + \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} \frac{e'' \theta}{\sin I''} (4 + 3e''^2) [1 - 9\theta^2 \right.$$

$$- 24\theta^4 (1 - 5\theta^2)^{-1}] + \frac{15}{32} \frac{\gamma_5'}{\gamma_2'} e'' \theta \sin I'' (4 + 3e''^2)$$

$$\left. [3 + 16\theta^2 (1 - 5\theta^2)^{-1} + 40\theta^4 (1 - 5\theta^2)^{-2}] \right\}$$

$$\mathrm{LDAF}_{12} = \left\{ - \frac{35}{1152} \frac{\gamma_5'}{\gamma_2'} \frac{e''^3 \theta}{\sin I''} \left[1 - 5\theta^2 - 16\theta^4 (1 - 5\theta^2)^{-1}\right] \right.$$

$$\left. - \frac{35}{576} \frac{\gamma_5'}{\gamma_2'} e''^3 \theta \sin I'' \left[5 + 32\theta^2 (1 - 5\theta^2)^{-1} + 80\theta^4 (1 - 5\theta^2)^{-2}\right] \right\}$$

$$\mathrm{LDAF}_{13} = \frac{e''}{\eta^2 \tan I''}$$

where

e'' = eccentricity

I'' = inclination

θ = $\cos i_0$

i_0 = inclination at epoch

η = $\sqrt{1 - e''^2}$

γ_n' = γ_n / η^{2n}

γ_n = K_n / a^n

a = semimajor axis

K_n = Brouwer's representation of the harmonics of the earth's potential

CALLING SEQUENCE

CALL DAF (T0, DRG, JDT0, ETIME, SATID, ELEM0, NQ)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	T0	Epoch date and time in CUT
I	DRG(60)	DRG(1) ↓ DRG(20) } $t_0, t_1, \ldots, t_{19}$
		DRG(21) ↓ DRG(40) } $N_{2,0}, N_{2,1}, \ldots, N_{2,19}$
		DRG(41) ↓ DRG(60) } $N_{3,0}, N_{3,1}, \ldots, N_{3,19}$
I	JDT0	No. of days from reference to epoch
I	ETIME	Epoch hours, minutes, and seconds converted to seconds
I	SATID(11)	SATID(1) = satellite identification number SATID(2) = reference year SATID(11) = day count of reference date
I	ELEM0(6)	Orbital elements (a, e, i, ω, Ω, M)
I	NQ	Number of drag inputs

Common

I/O	Block	Variable
I	BPOOL	TABLE(2) = KMCUL TABLE(24) = BK TABLE(35) = MINDAY TABLE(41) = MU TABLE(49) = ω_e TABLE(59) = MINCUT TABLE(61) = K2
I	DAFPRM	LDAF(13)
I	DOTELE	LDOT GDOT HDOT
I	THETAP	THETA
I	RADIAN	AMBDA

TAPE OUTPUT

The output from the Brouwer DAF parameters function is written on tape. Two lines of identifying information precede the six lines of output parameters.

Line 1 — Title

Col. 1	Blank
Col. 2-24	'Brouwer DAF Parameters'
Col. 25-80	Blank

Line 2 — DAF Parameters Request Card Printout

Col. No.	Format	Description	
1		Blank	
2-8	XXXXX	Satellite number	
9		Blank	
10-11	XX	Year	Date predictions begin
12		Blank	Date predictions begin
13-14	XX	Month	Date predictions begin
15		Blank	Date predictions begin
16-17	XX	Day	Date predictions begin
18		Blank	
19-20	XX	Hour	Time predictions begin
21		Blank	Time predictions begin
22-23	XX	Minutes	Time predictions begin

If the satellite number of the Brouwer DAF request card agrees with the input satellite number then Col. 24-80 are blank. If not — Col. 30-52 of line 2 contain **ERROR IN DAF SAT ID**.

Lines 3-8 contain the requested output parameters in the following floating point decimal form:

Col. No.	Format
1-15	SXXXXXXXXXXDSXX
16	Blank
17-31	SXXXXXXXXXXDSXX
32	Blank
33-47	SXXXXXXXXXXDSXX
48	Blank

Col. No.	Format
49-63	SXXXXXXXXXXDSXX
64	Blank
65-79	SXXXXXXXXXXDSXX
80	Blank
81-95	SXXXXXXXXXXDSXX
96	Blank
97-111	SXXXXXXXXXXDSXX

The order of the parameters is as follows:

Line 3 — $LDAF_4/2\pi$

$LDAF_5/2\pi$

$LDAF_6/2\pi$

$LDAF_7$

$LDAF_8$

$LDAF_9$

$LDAF_{10}$

Line 4 — $LDAF_{11}$

$LDAF_{12}$

$LDAF_1$

$LDAF_2$

$LDAF_3$

$\cos I''$

e''

Line 5 — GDOT/13.4472

HDOT/13.4472

$\bar{g}_0''$

$\bar{h}_0''$

$\bar{l}_0''/2\pi$

$I''/2\pi$

$\lambda_g(t_{pi})/2\pi$

Line 6 — $-\mathrm{LDAF}_{13}/2\pi$

d

h

m

a

$N_2/2\pi\ (13.4472)^2$

$n_0 + S_1/2\pi\,(13.4472)$

Line 7 — K_2

K_3

$-K_8$

$1/4\ \gamma_2'$

$K_9/2\pi$

K_1

K_4

Line 8 — $-K_5$

$-K_6$

$\eta/4e''\ \gamma_2'$

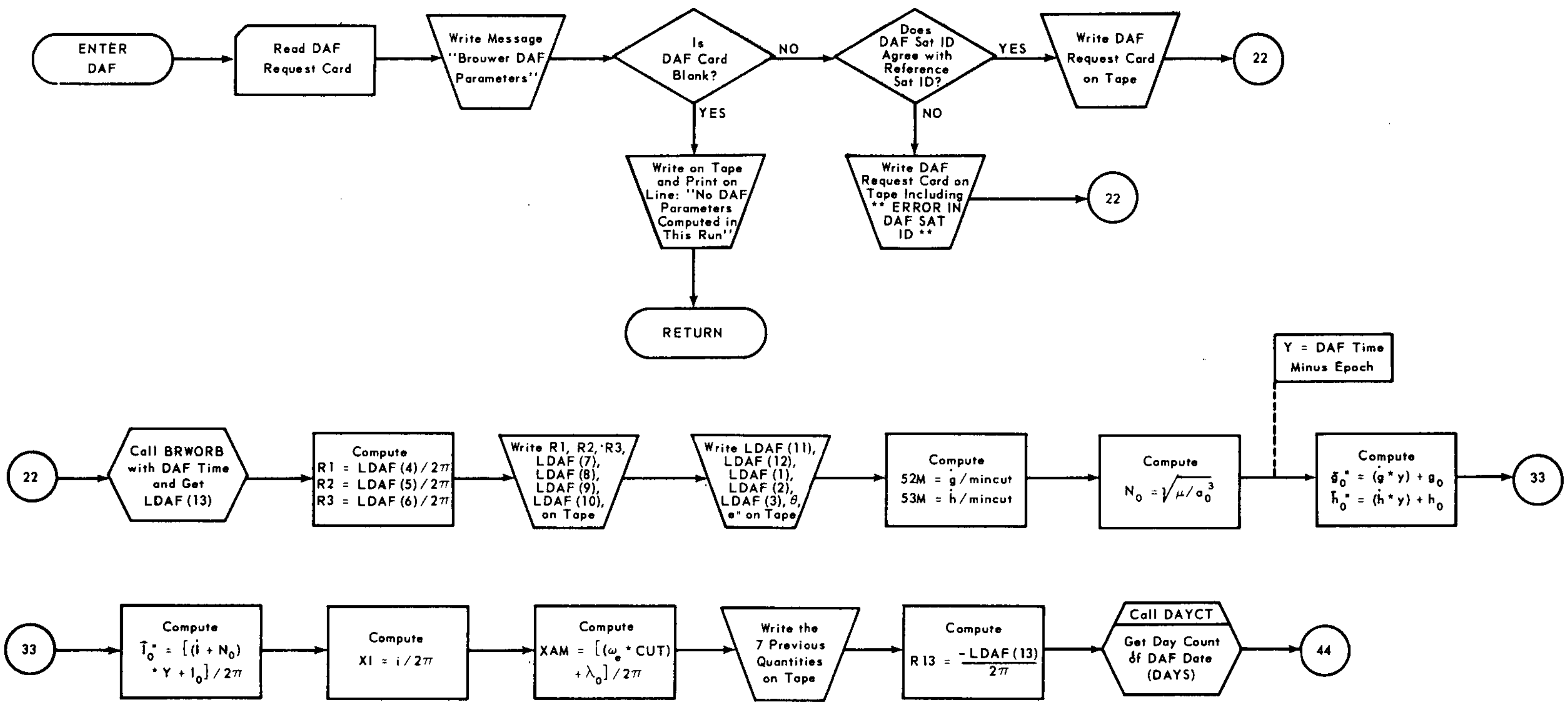
$t_{pi} - t_0$

CALLED BY

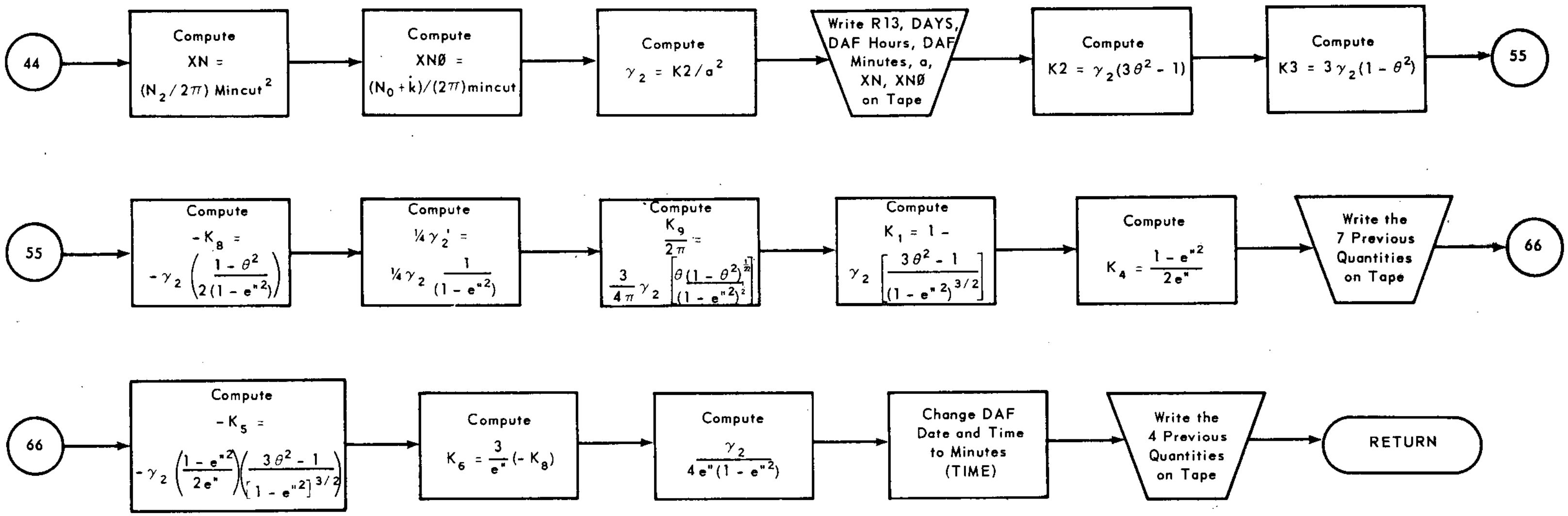
MAIN

CALLS

DREFOD
JDSCUT
BRWORB
REDUCE
DAYCT



DAF Flowchart



DAF Flowchart (continued)

DATAN0

Double Precision Arctangent (Y/X)

PURPOSE

To compute a value for the arctangent between 0 and 2PI where the tangent is defined by the two input arguments as ARG1/ARG2.

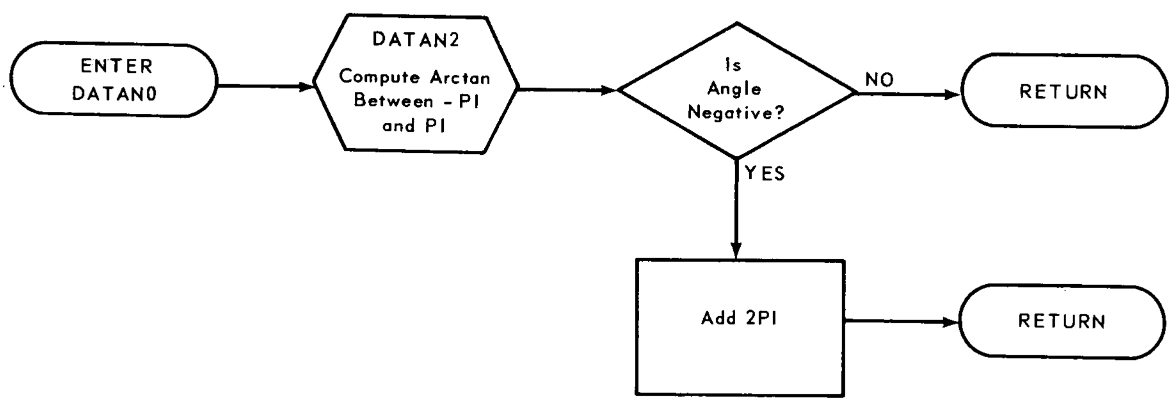
CALLING SEQUENCE

DATAN0 (ARG1, ARG2)

Note that DATAN0 is a function.

CALLED BY

PRINT



DATAN0 Flowchart

DATE

Calendar Date

PURPOSE

To convert year and day count (number of days from January 0 of given year to a given date) to year, month and day.

CALLING SEQUENCE

```
CALL DATE (IYR, IDY, IY, IM, ID)
```

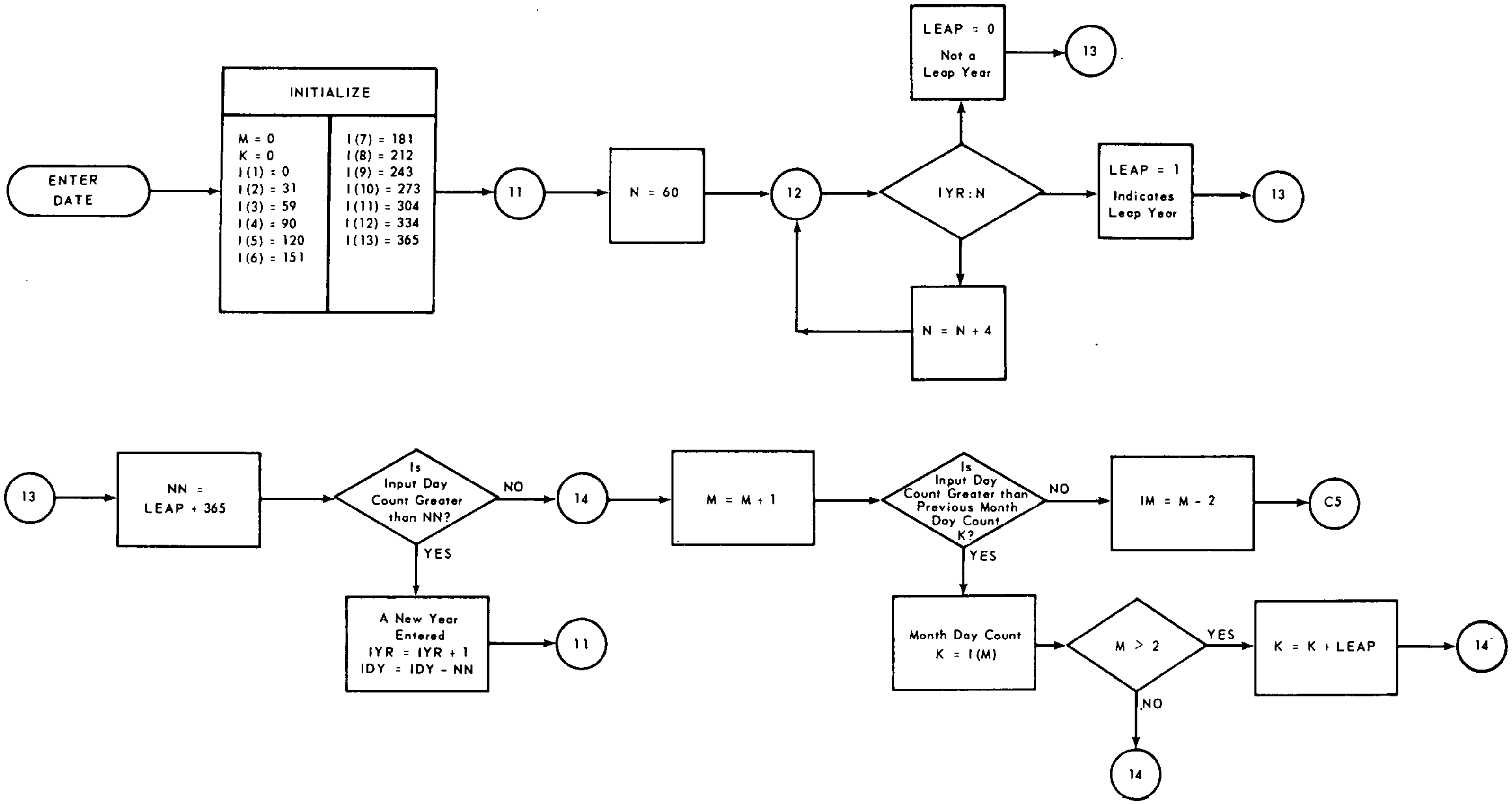
INPUT/OUTPUT

Arguments

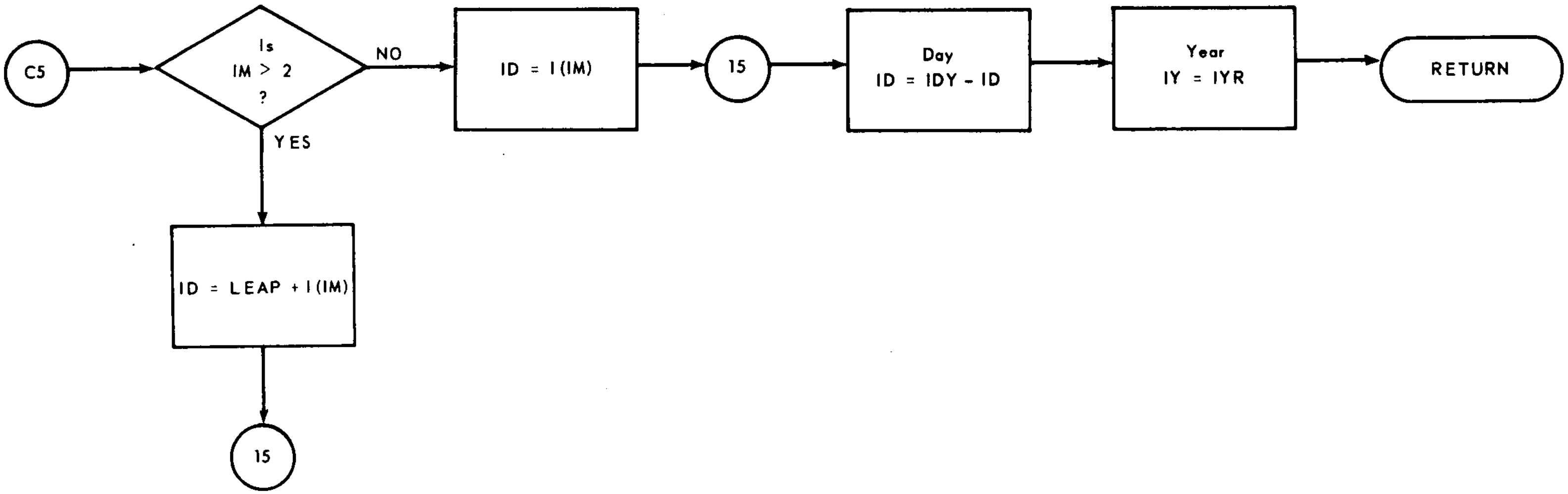
I/O	Variable	Description
I	IYR	Year
I	IDY	Number of days from January 0 of year IYR
O	IY	Year
O	IM	Month
O	ID	Day

CALLED BY

MAIN
SATOR
TIMETB



DATE Flowchart



DATE Flowchart (continued)

DAYCT

Day Count

PURPOSE

To convert year, month and day to the number of days from January 0 of a given year to the given date.

CALLING SEQUENCE

```
CALL DAYCT (IY, IM, ID, IDAYS)
```

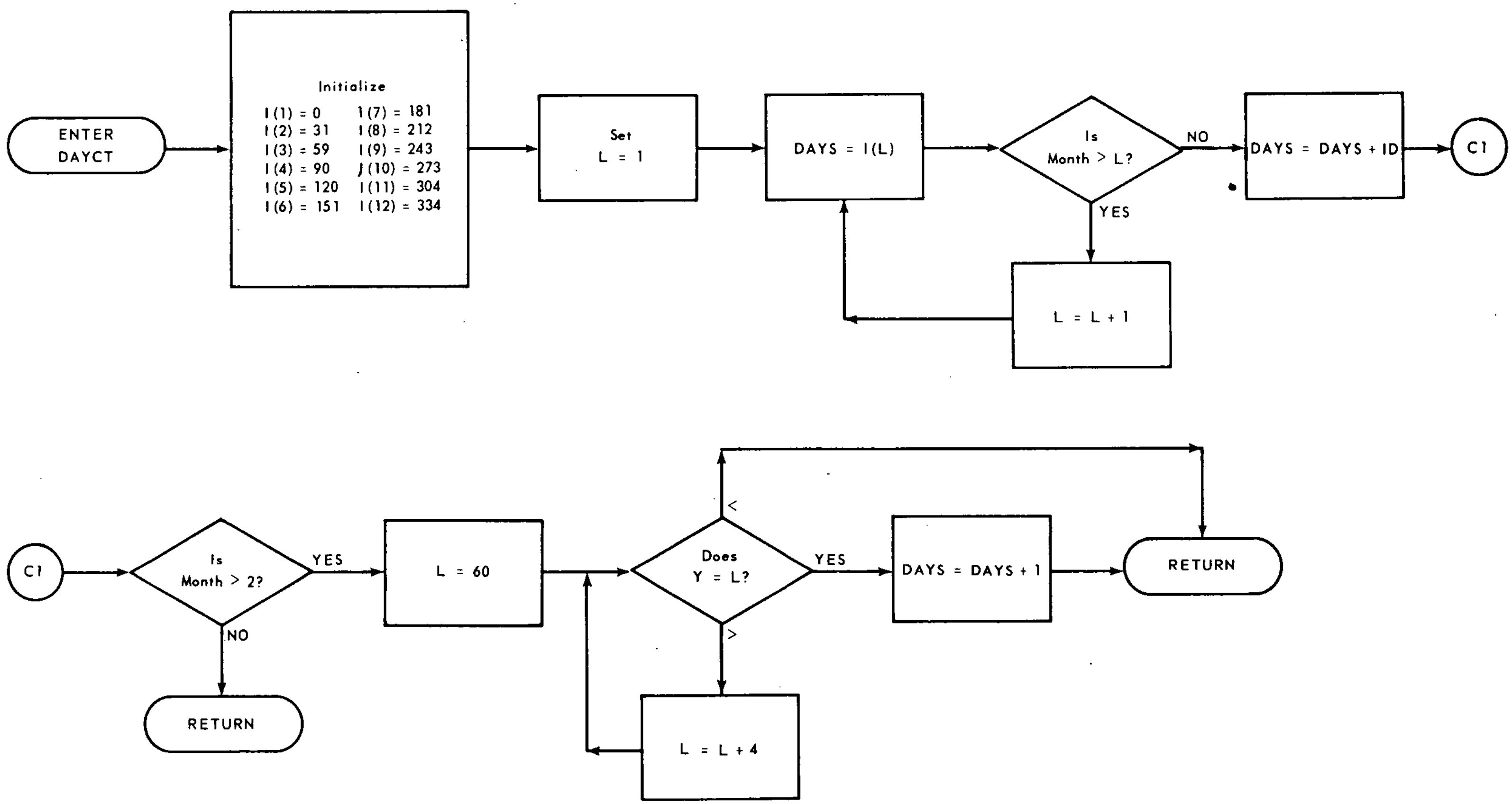
INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	IY	Year
I	IM	Month
I	ID	Day
O	IDAYS	Number of days from January 0 of given year to given date

CALLED BY

MAIN
DAF
DREFOD



DAYCT Flowchart

DMSTOR

Degrees, Minutes, Seconds to Radians

PURPOSE

To convert degrees, minutes and seconds to radians.

METHOD

Radians = ((sec/60 + minutes)/60 + deg)/degrees per rad.

CALLING SEQUENCE

CALL DMSTOR (DEG, FM, SS, RAD)

INPUT/OUTPUT

Arguments

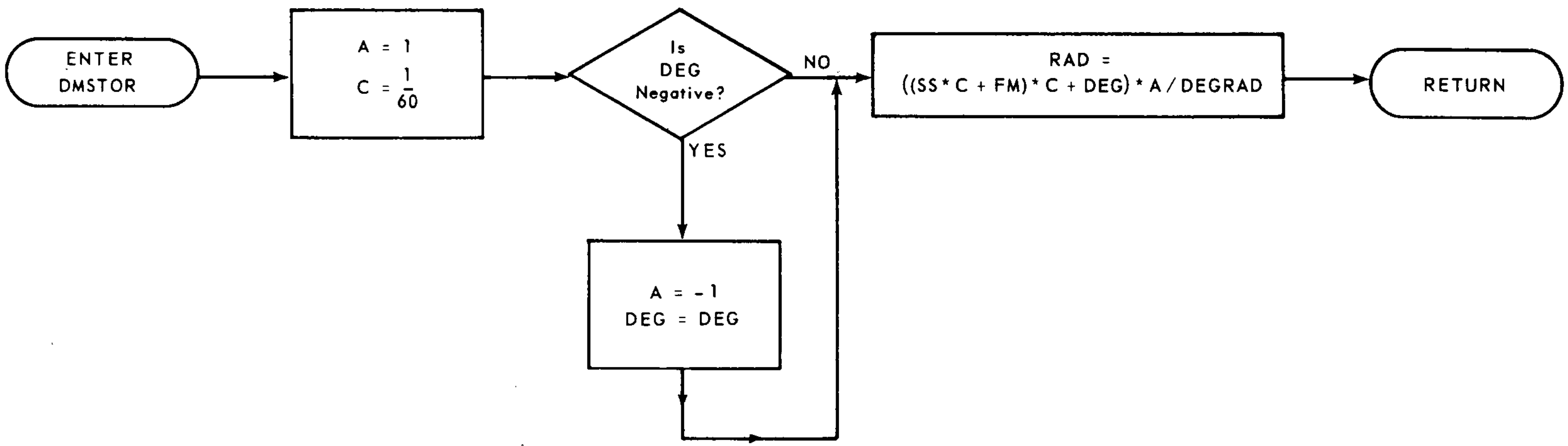
I/O	Variable	Description
I	DEG	Degrees
I	FM	Minutes
I	SS	Seconds
O	RAD	Radians

Common

I/O	Block	Variable
I	BPOOL	TABLE(16) = DEGRAD (deg/rad)

CALLED BY

MAIN
POOL



DMSTOR Flowchart

DRAG

Compute Drag

PURPOSE

To compute $\Delta \ell_{drag}$ which provide corrections for the Brouwer Orbit Generator.

METHOD

$$\Delta \ell_{drag} = \sum_{q=0}^{m} \sum_{p=2}^{3} N_{P,q} (t - t_q)^P$$

where

m = 0, 1, 2, 3, . . ., 19

t = observation time

t_q = drag time

$N_{P,q}$ = drag parameters

CALLING SEQUENCE

CALL DRAG (DRG, PI2, DRAGL, T0, T, KMULT, N0)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	DRG(60)	DRG(1) → DRG(20) $\}$ $t_0, t_1, \ldots, t_{19}$

Arguments (continued)

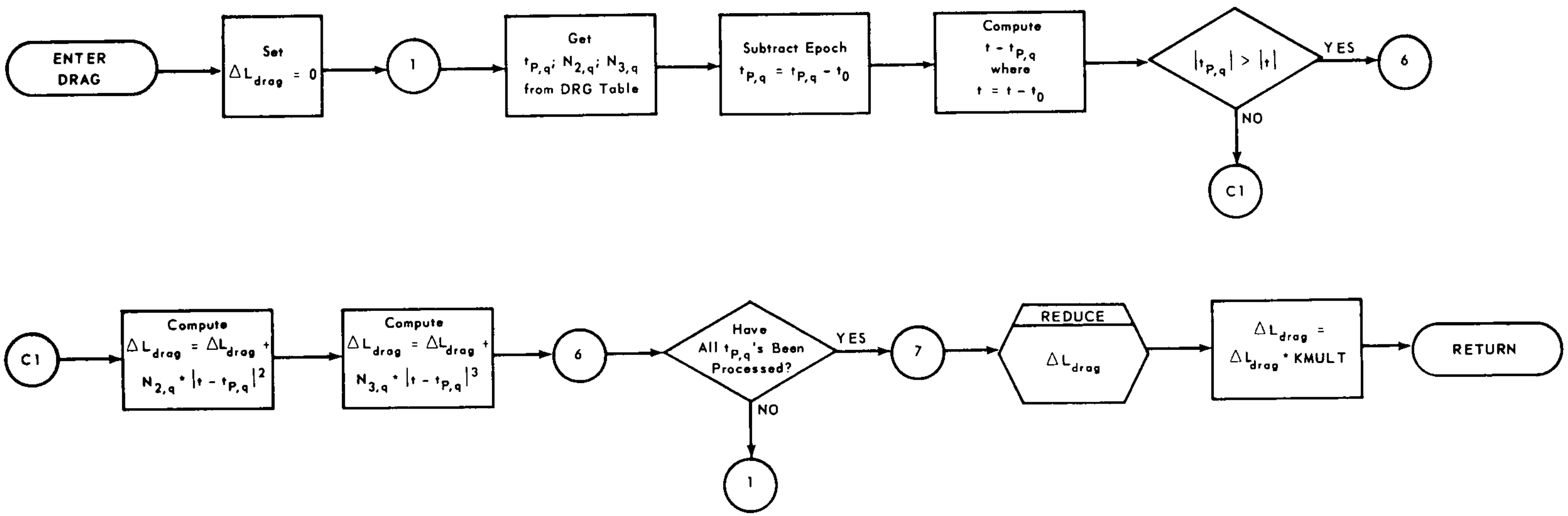
I/O	Variable	Description
I	DRG(60)	DRG(21) ↓ DRG(40): $N_{2,0}, N_{2,1}, \ldots, N_{2,19}$ DRG(41) ↓ DRG(60): $N_{3,0}, N_{3,1}, \ldots, N_{3,19}$
I	PI2	2π radians
O	DRAGL	ΔL
I	T0	Epoch time
I	T	Observation time - T0
I	KMULT	K multiplier
I	NQ	Number of drag inputs

CALLED BY

BRWORB

CALLS

REDUCE



DRAG Flowchart

DRAGLD

Drag Load

PURPOSE

To load $N_{(P,q)}$ data for the computation of ΔL drag.

CALLING SEQUENCE

CALL DRAGLD (SATID, DRAGDT, DRG, NQ, NERROR)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	SATID(11)	SATID(1) = reference satellite ID number SATID(2) = reference year SATID(11) = day count of reference date
O	DRAGDT(40)	DRAGDT(1), DRAGDT(3) ↓ DRAGDT(30): packed drag date DRAGDT(2), DRAGDT(4) ↓ DRAGDT(40): packed drag time
O	DRG(60)	DRG(1) ↓ DRG(20): $t_0, t_1, \ldots, t_{19}$ DRG(21) ↓ DRG(40): $N_{2,0}, N_{2,1}, \ldots, N_{2,19}$ DRG(41) ↓ DRG(60): $N_{3,0}, N_{3,1}, \ldots, N_{3,19}$
O	NQ	Number of drag inputs

Arguments (continued)

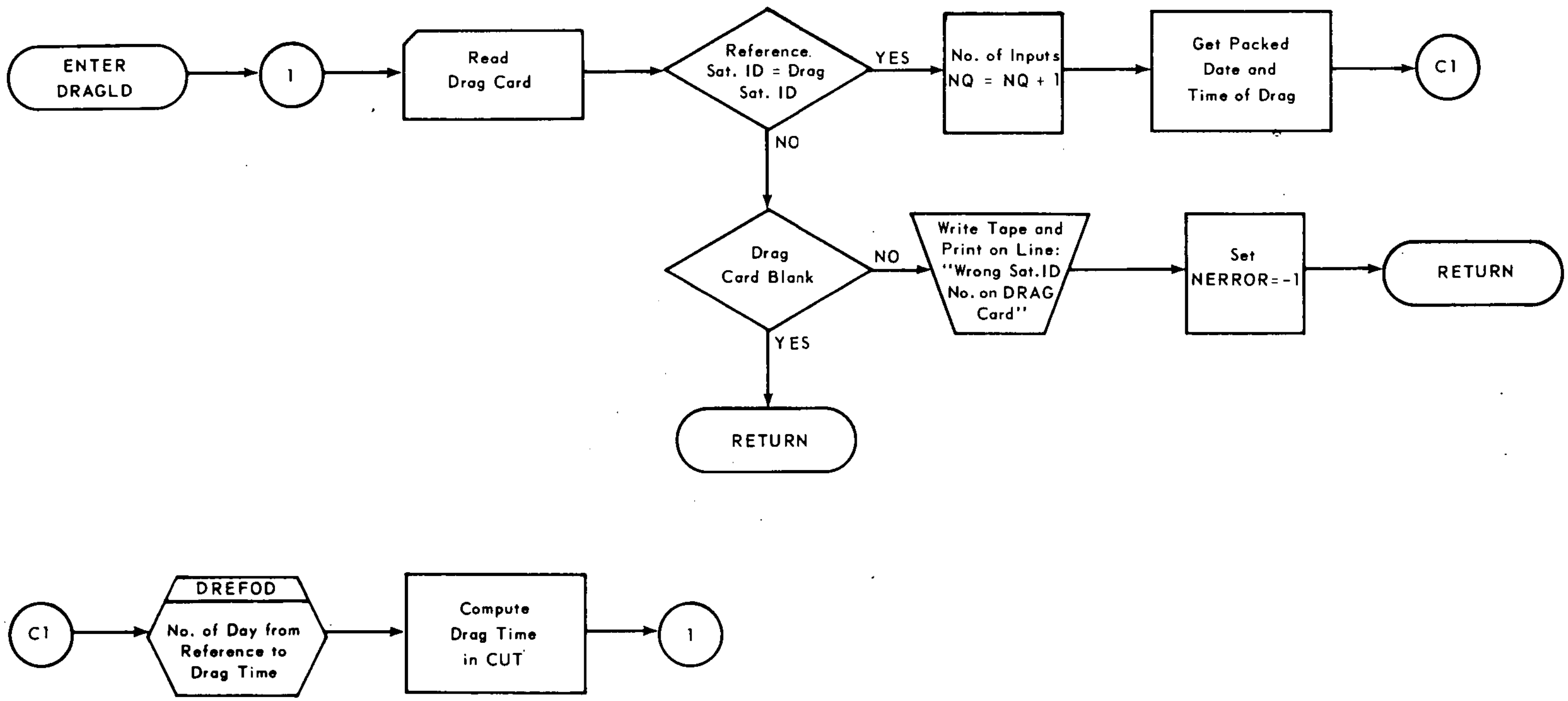
I/O	Variable	Description
O	NERROR	Error indicator = 0 no error = -1 wrong Sat. ID number on drag card

CALLED BY

MAIN

CALLS

DREFOD
JDSCUT



DRAGLD Flowchart

DREFOD

Day Count from Reference Date to Observation

PURPOSE

To compute the number of days from the reference date to the observation date.

CALLING SEQUENCE

CALL DREFOD (IYREF, IDC, IOY, IOM, IOD, IDAYS)

INPUT/OUTPUT

Arguments

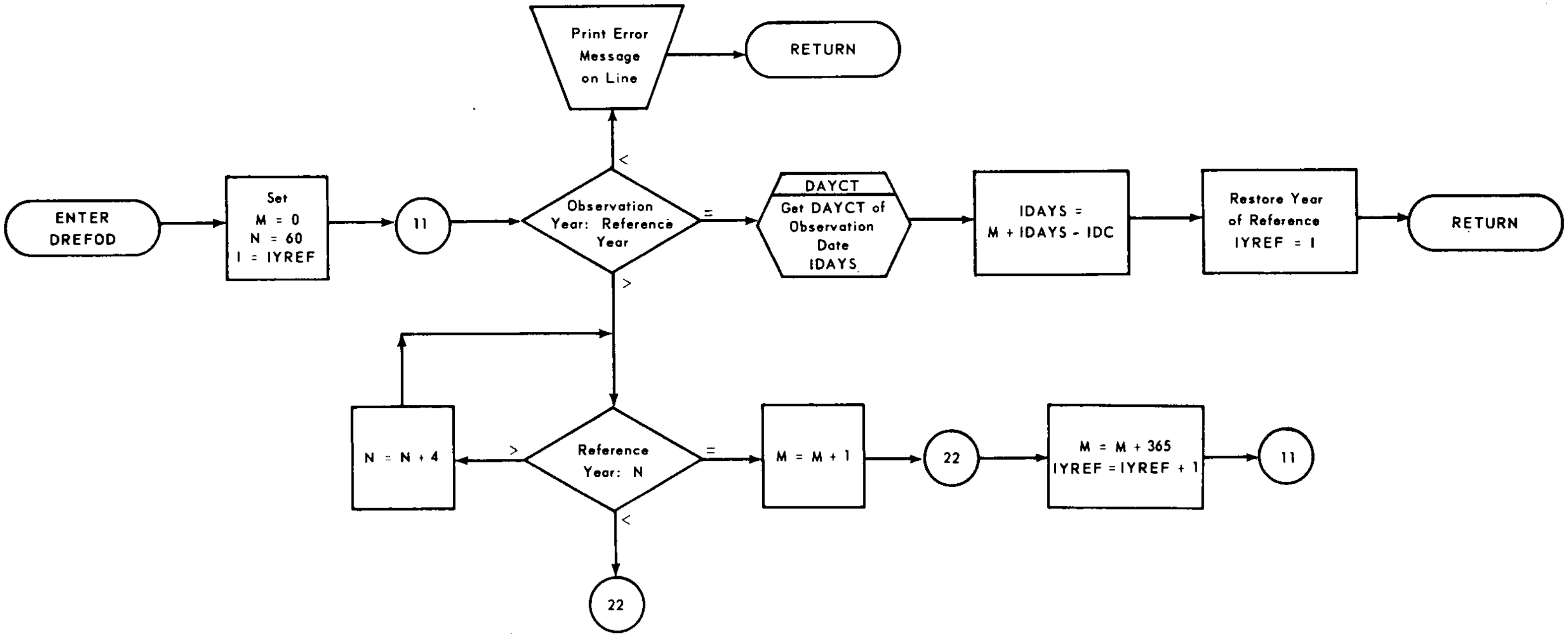
I/O	Variable	Description
I	IYREF	Year of reference date
I	IDC	Number of days from January 0 of the year to the day of reference
I	IOY	Year of observation date
I	IOM	Month of observation date
I	IOD	Day of observation date
O	IDAYS	Number of days from the reference date to the observation date

CALLED BY

MAIN
DAF
DRAGLD
ELEMLD
PERTFO
PRINT
TIMETB
WMAPLD

CALLS

DAYCT



DREFOD Flowchart

ELCON0

Elements Conversion

PURPOSE

- To convert position and velocity vectors to Keplerian elements.
- To convert Keplerian elements to position and velocity vectors.

METHOD

ELOSC — Convert position and velocity vectors to osculating elements.

Let r be the magnitude of the position vector $\underline{r} = (x, y, z)$ and v be the magnitude of the velocity vector $\dot{\underline{r}} = (\dot{x}, \dot{y}, \dot{z})$.

Compute

$$\underline{h} = (h_x, h_y, h_z) = \underline{r} \times \dot{\underline{r}}.$$

Compute the semi-major axis of the orbit:

$$a = \frac{\mu r}{2\mu - r v^2}.$$

Compute the inclination angle:

$$i = \tan^{-1}\left[\frac{(h_x^2 + h_y^2)^{1/2}}{h_z}\right],$$

where

$$0 \leq i < \pi.$$

Compute the eccentricity:

$$e = \left[\frac{\mu a - h^2}{\mu a}\right]^{1/2},$$

where

$$h^2 = h_x^2 + h_y^2 + h_z^2.$$

Compute longitude of ascending node:

$$\Omega = \tan^{-1}\left[\frac{h_x}{-h_y}\right] \text{for } i \neq 0.$$

where

$$0 \leq \Omega < 2\pi$$

and

$$\Omega = 0 \text{ for } i = 0.$$

Compute argument of perigee:

$$\omega = u - \nu, \quad \text{for } e \neq 0,$$

where:

$$\nu = \tan^{-1}\left[\frac{h\,(\underline{r} \cdot \dot{\underline{r}})}{h^2 - \mu r}\right],$$

$$u = \tan^{-1}\left[\frac{z}{\sin i\,(x \cos \Omega + y \sin \Omega)}\right] \text{ for } i \neq 0,$$

$$u = \tan^{-1}\left[\frac{y}{x}\right] \text{ for } i = 0,$$

and

$$0 \leq \omega < 2\pi.$$

$$\omega = 0, \text{ for } e = 0.$$

Compute mean anomaly:

$$M = E - e \sin E, \text{ for } e \neq 0,$$

where

$$E = 2 \tan^{-1}\left[\left(\frac{1 - e}{1 + e}\right)^{1/2} \frac{\sin \nu}{(1 + \cos \nu)}\right].$$

and

$$0 \leq M < 2\pi.$$

$$M = u, \text{ for } e = 0.$$

ELIRV — Convert osculating elements to position and velocity vectors.

Call subroutine KEPLR1 to compute the eccentric anomaly, E, given the mean anomaly, M, and the eccentricity, e.

Compute the true anomaly, ν:

$$\nu = 2 \tan^{-1}\left[\left(\frac{1 + e}{1 - e}\right)^{1/2} \cdot \frac{\sin E}{(1 + \cos E)}\right].$$

Compute the position magnitude, r:

$$r = a(1 - e \cos E).$$

Compute the radial and horizontal components of $\dot{\underline{r}}$, V_r and V_p, respectively:

$$V_r = \frac{\sqrt{\mu a}}{r} (e \sin E)$$

$$V_p = \frac{\sqrt{\mu a}}{r} \cdot \sqrt{1 - e^2}$$

Compute the position and velocity vectors, $\underline{r} = (x, y, z)$ and $\dot{\underline{r}} = (\dot{x}, \dot{y}, \dot{z})$, respectively:

$$x = r [\cos \Omega \cos (\omega + \nu) - \sin \Omega \cos i \sin (\omega + \nu)]$$

$$y = r [\sin \Omega \cos (\omega + \nu) + \cos \Omega \cos i \sin (\omega+\nu)]$$

$$z = r \sin i \sin (\omega + \nu)$$

$$\dot{x} = \frac{V_r}{r} \cdot x - V_p [\cos \Omega \sin (\omega + \nu) + \sin \Omega \cos i \cos (\omega + \nu)]$$

$$\dot{y} = \frac{V_r}{r} \cdot y + V_p [-\sin \Omega \sin (\omega + \nu) + \cos \Omega \cos i \cos (\omega + \nu)]$$

$$\dot{z} = \frac{V_r}{r} \cdot z + V_p \sin i \cos (\omega + \nu).$$

CALLING SEQUENCE

Subroutine ELCON0 is accessed through one of its entry points, ELOSC or ELIRV.

CALL ELOSC (INPUT, OUTPUT); convert position and velocity vectors $(x, y, z, \dot{x}, \dot{y}, \dot{z})$ to osculating elements $(a, e, i, \omega, \Omega, M)$.

CALL ELIRV (INPUT, OUTPUT, IERR); convert osculating elements $(a, e, i, \omega, \Omega, M)$ to position and velocity vectors $(x, y, z, \dot{x}, \dot{y}, \dot{z})$.

INPUT/OUTPUT

Arguments

I/O	Variable	Description
From entry point ELOSC		
I	INPUT(6)	Position and velocity vectors ($x, y, z, \dot{x}, \dot{y}, \dot{z}$)
O	OUTPUT(6)	Osculating elements ($a, e, i, \omega, \Omega, M$)
From entry point ELIRV		
I	INPUT(6)	Osculating elements
O	OUTPUT(6)	Position and velocity vectors
O	IERR	Error return from KEPLR1 = 0, convergence of eccentric anomaly > 0, no convergence

Common

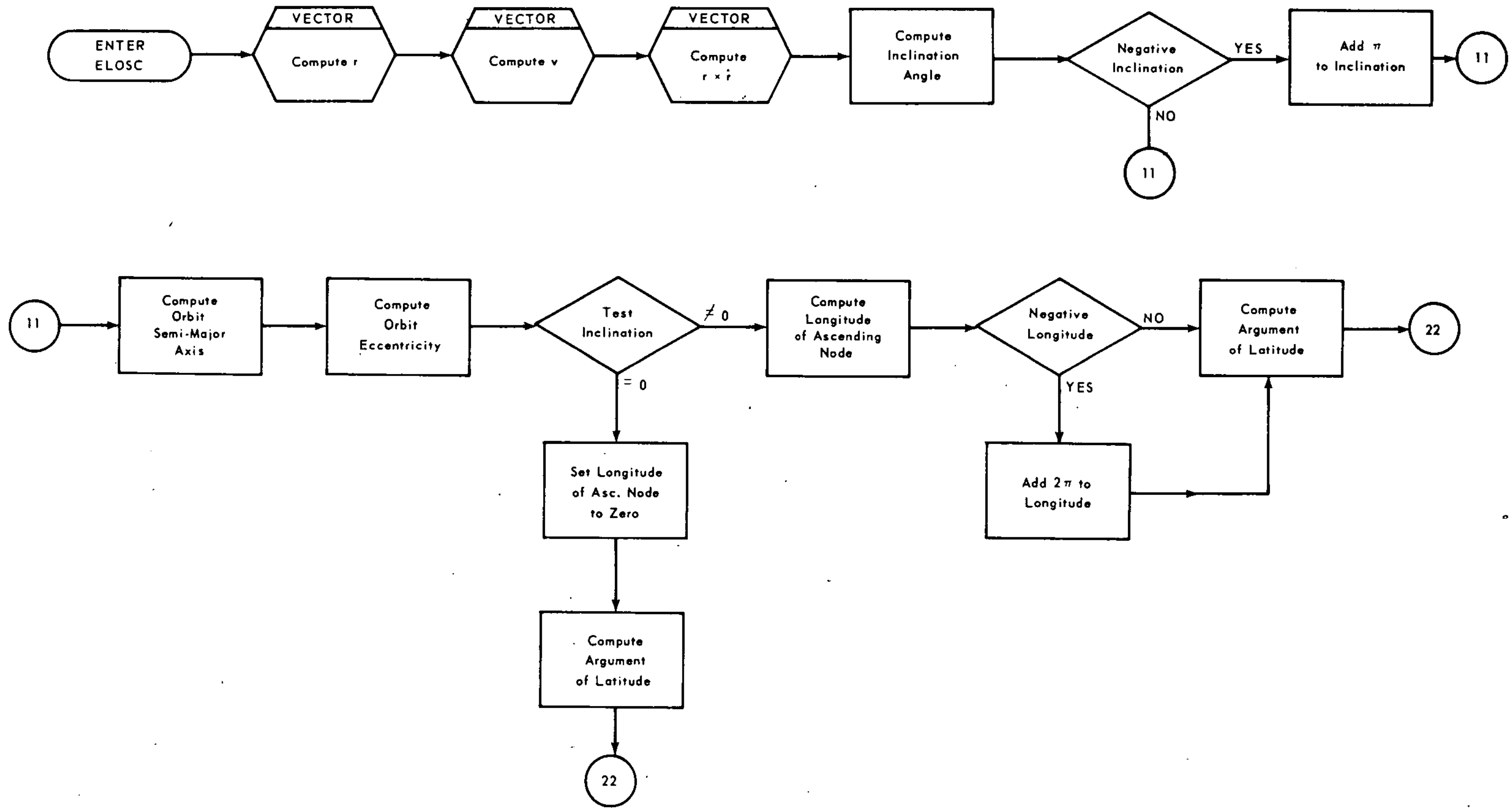
I/O	Block	Variable
I	BPOOL	TABLE(34) = PI TABLE(4) = MU

CALLED BY

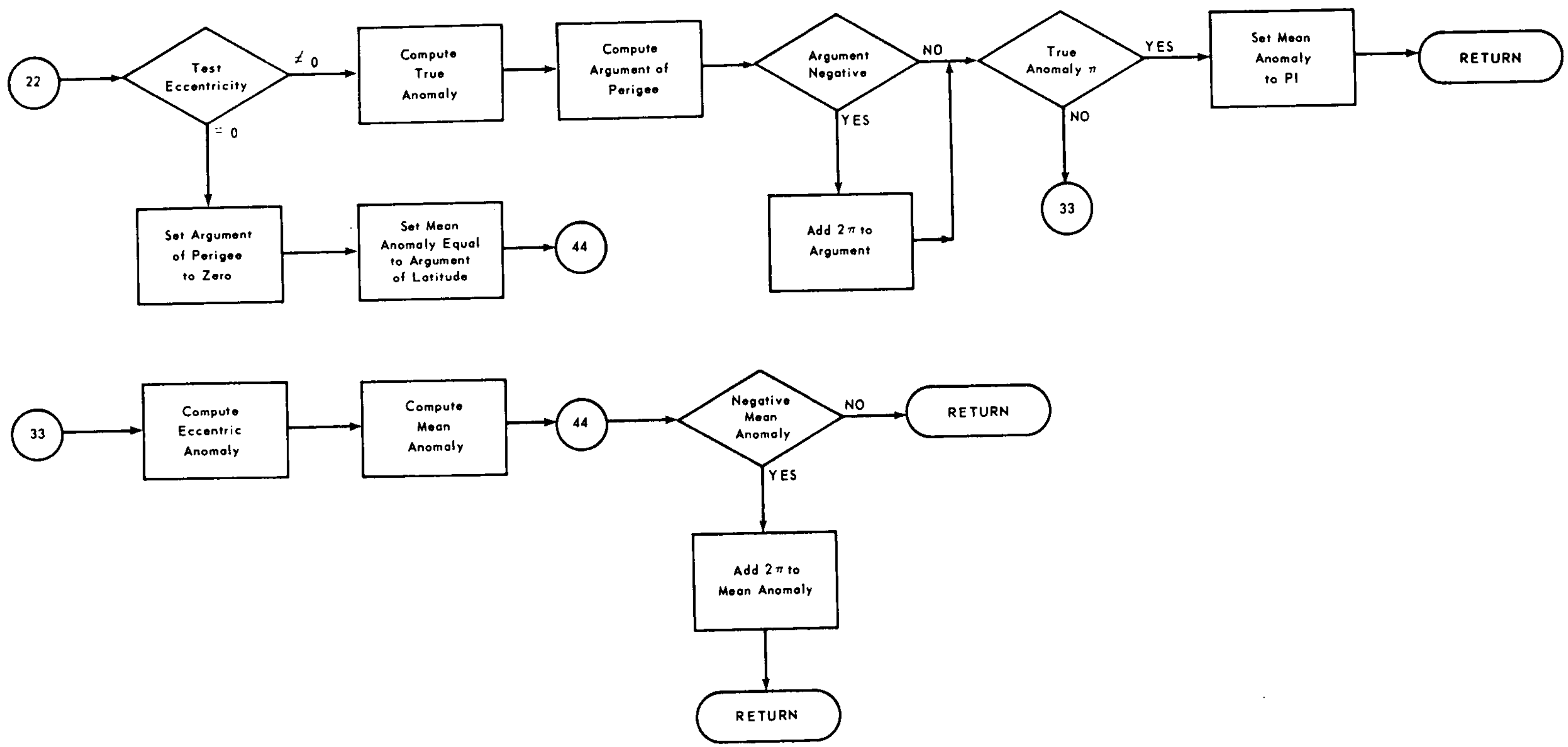
ELEMLD

CALLS

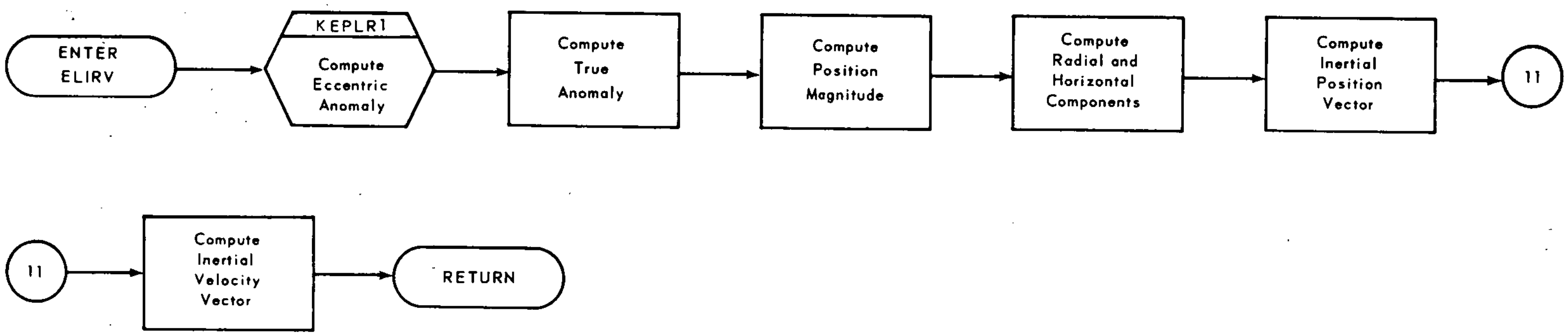
VECTOR
VMAG
VCROSS
VDOT
KEPLR1



ELOSC Flowchart



ELOSC Flowchart (continued)



ELOSC Flowchart (continued)

ELEMLD

Elements Load

PURPOSE

To load the epoch and element data.

CALLING SEQUENCE

CALL ELEMLD (SATID, EPOCH, T0, ETIME, JDT0, ELEM0, JDT0, ELEM0, OSC0, PV, OUTPUT, NERROR, XINPUT, IFLAG, DRG, NQ)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	SATID(11)	SATID(1) = reference satellite identification number SATID(2) = reference year SATID(11) = day count of reference date
O	EPOCH(10)	EPOCH(1) = epoch satellite identification number EPOCH(2) = year of epoch EPOCH(3) = month of epoch EPOCH(4) = day of epoch EPOCH(5) = hours of epoch EPOCH(6) = minutes of epoch EPOCH(7) = seconds of epoch EPOCH(8) = type of input epoch elements code = 1, position and velocity vectors = 2, osculating elements EPOCH(9) = pass number EPOCH(10) = perturbation indicator = 0, no perturbation = 1, use perturbation tape
O	T0	Epoch date and time in Canonical Unit of Time
O	ETIME	Epoch time (hr, min, sec) in seconds

Arguments (continued)

I/O	Variable	Description
O	JDT0	Number of days from the date of reference to the date of epoch
O	ELEM0(6)	Epoch elements in CUL
O	XINPUT(6)	Epoch elements in KM
		(ELEM0(6) and XINPUT(6) may be Keplerian elements — a, e, i, ω, Ω, M, or position and velocity vectors, x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$, according to the elements input type)
O	OSC0(6)	Brouwer osculating elements at epoch
O	PV(6)	Position and velocity vectors at epoch
O	OUTPUT(6)	Converted ELEMØ elements
O	NERROR	Error indicator
		= 0 no error
		> 0 elements sat. ID does not agree with reference sat. ID
O	IFLAG	Elements unit indicator
		= 0 input elements in CUL
		= 1 input elements in Km
I	DRG(60)	Drag parameters table
I	NQ	Number of drag inputs

Common

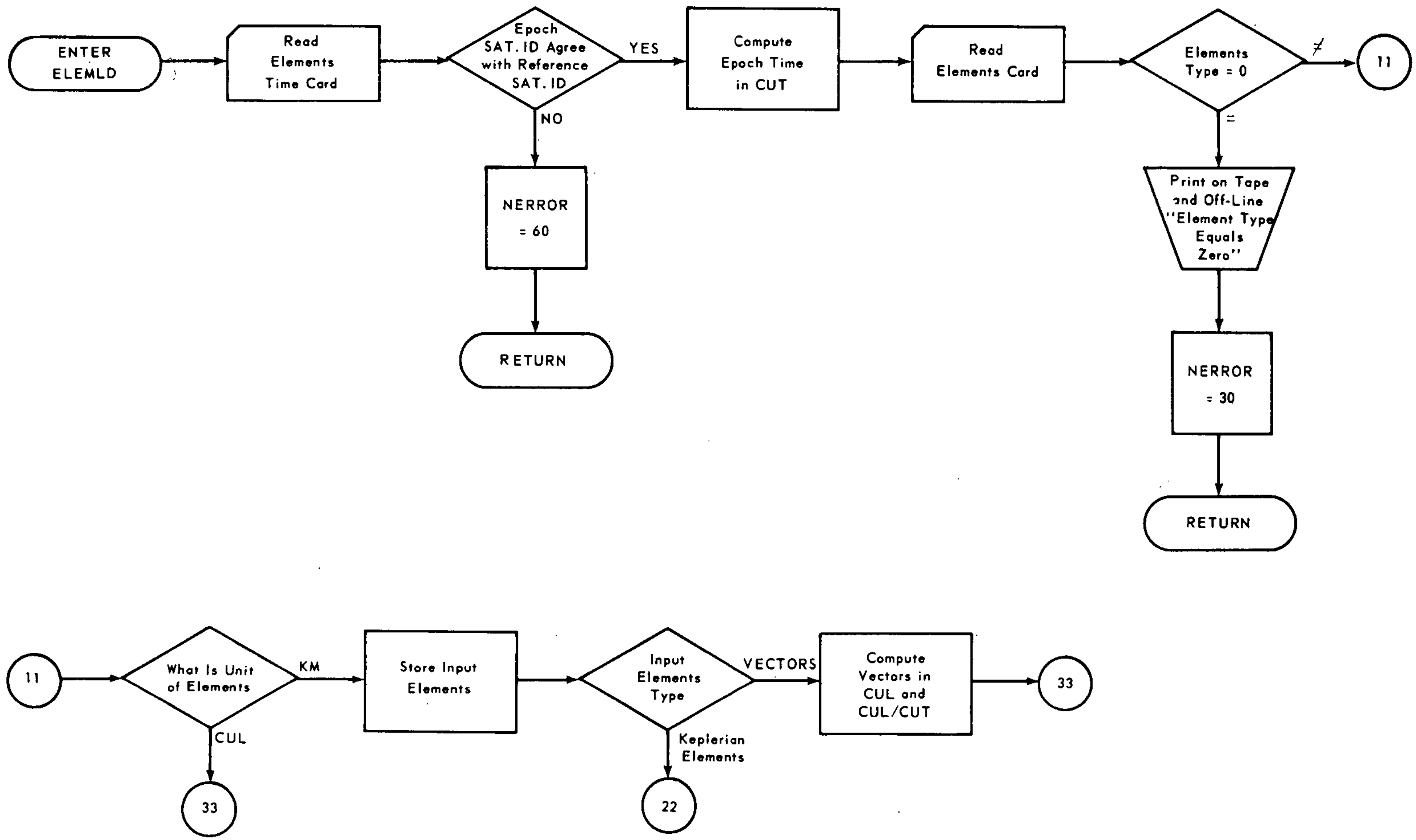
I/O	Block	Variable
O	SECPRM	DPELE(6) = Brouwer input mean elements
I	OSCELE	ORBPRM(6) = Brouwer osculating elements
I	BPOOL	TABLE(24) = BK
		TABLE(34) = PI
		TABLE(41) = MU
O	PERTL	EA0 = eccentric anomaly at epoch
O	PIND	NPT = pertape logical number

CALLED BY

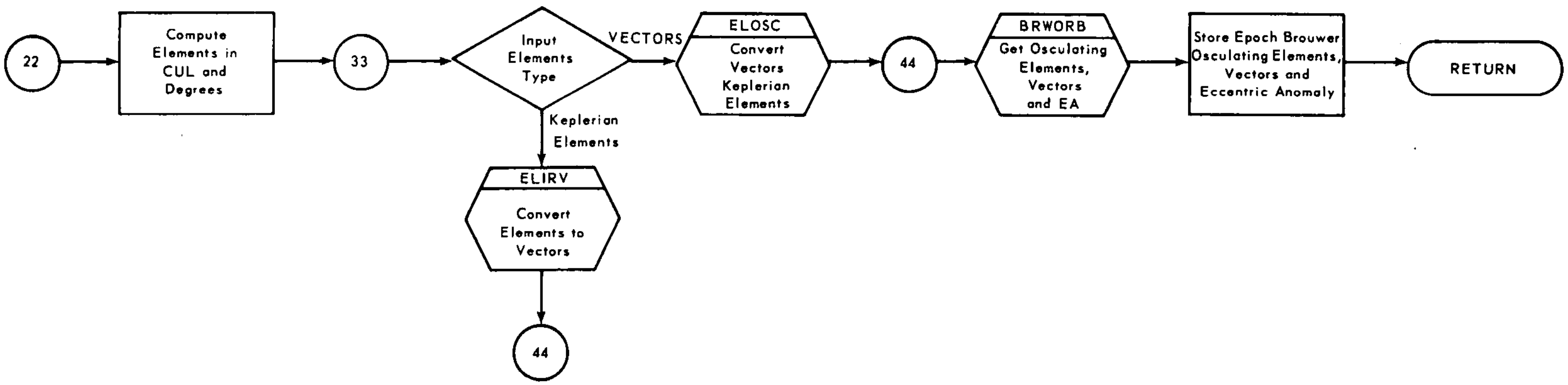
MAIN

CALLS

- DREFOD
- JDSCUT
- ELCON0
  - ELIRV
  - ELOSC
- BRWORB



ELEMLD Flowchart



ELEMLD Flowchart (continued)

GTRACE

PURPOSE

Routine to generate a one orbit ephemeris by advancing the satellite with equal intervals in geodetic latitude.

METHOD

Given a value for the geodetic latitude we wish to determine the corresponding time. A two body analysis leads to the following computational scheme.

Given: ϕ_S (geodetic latitude)

Compute geocentric latitude from

$$\phi_S' = \tan^{-1} [(1 - f)^2 \tan \phi_S]$$

$$r_c = a_e \left[\frac{1 - (2f - f^2)}{1 - (2f - f^2) \cos^2 \phi_S'}\right]$$

Compute the height above the reference ellipsoid,

$$H_S = [r^2 - r^2 \sin^2 (\phi_S - \phi_S')]^{1/2} - r_c \cos (\phi_S - \phi_S')$$

$$\Delta\phi_S' = \sin^{-1}\left[\frac{H_S}{r} \sin (\phi_S - \phi_S')\right], \quad -\frac{\pi}{2} \leq \Delta\phi_S' \leq \frac{\pi}{2}$$

with the declination given by,

$$d = \phi_S' + \Delta \phi_S'$$

and from spherical trigonometry we have for the argument of latitude

$$u = \sin^{-1}\left(\frac{\sin d}{\sin i}\right),$$

thus we have for the true anomaly

$$\nu = u - g$$

where the time of the geodetic latitude is determined from Brouwer (1959) p. 395. With the time we update the g and the process is continued until;

$$/g_{i+1} - g_i/ \leq \epsilon$$

where ϵ is some preassigned, small positive number.

CALLING SEQUENCE

CALL GTRACE (TA0, T0, REV, GDL, DLONG, HT, TGDL, DGDL, KGDL, ADGDL, NSGDL, DRG, NQ, SATID, STAR, TAR)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	TA0	T_Ω — start time of reference ellipsoid
I	T0	t_0 — epoch time
I	REV	Number of orbital revolutions
O	GDL(360)	Geodetic latitudes (ϕ)
O	DLONG(360)	Longitude of geodetic meridian east of ascending nodal meridian (λ_ϕ)
O	HT(360)	Height above meridian of satellites geodetic meridian (Ht_ϕ)
O	TGDL(360)	Time of geodetic latitude (t_ϕ)
I	DGDL	Increment in geodetic latitude by degrees ($\Delta\phi$)
O	KGDL	Number of GDL's in the interval ascending node to north point
O	ADGDL(6)	ADGDL(1-3) — $t_{☊}$, $\lambda_{☊}$, $ht_{☊}$, ADGDL(4-6) — t , λ , ht

Arguments (continued)

I/O	Variable	Description
O	NSGDL(6)	NSGDL(1-3) — t_N, λ_N, ht_N, NSGDL(4-6) — t_S, λ_S, ht_S
I	DRG(1) ↓ DRG(20)	$t_0, t_1, \ldots, t_{19}$
	DRG(21) ↓ DRG(40)	$N_{2,0}, N_{2,1}, \ldots, N_{2,19}$
	DRG(41) ↓ DRG(60)	$N_{3,0}, N_{3,1}, \ldots, N_{3,19}$
I	NQ	Number of drag inputs
I	SATID(11)	SATID(1) = satellite identification number SATID(2) = reference year SATID(11) = day count of reference date
O	STAR(300)	'*' indicates satellites in sunlight, ' ' not in sunlight
O	TAR(6)	TAR = BLANK, or TAR = *, indicates if ascending, descending nodal crossings, or north and south points are in or out of shadow

Data Statements

Variable	Definition
IT	IT /10/ max. no. of iterations
TG	tg /0.0/ Greenwich epoch time
ASTRX	/'*'/
BLANK	/' '/

Common

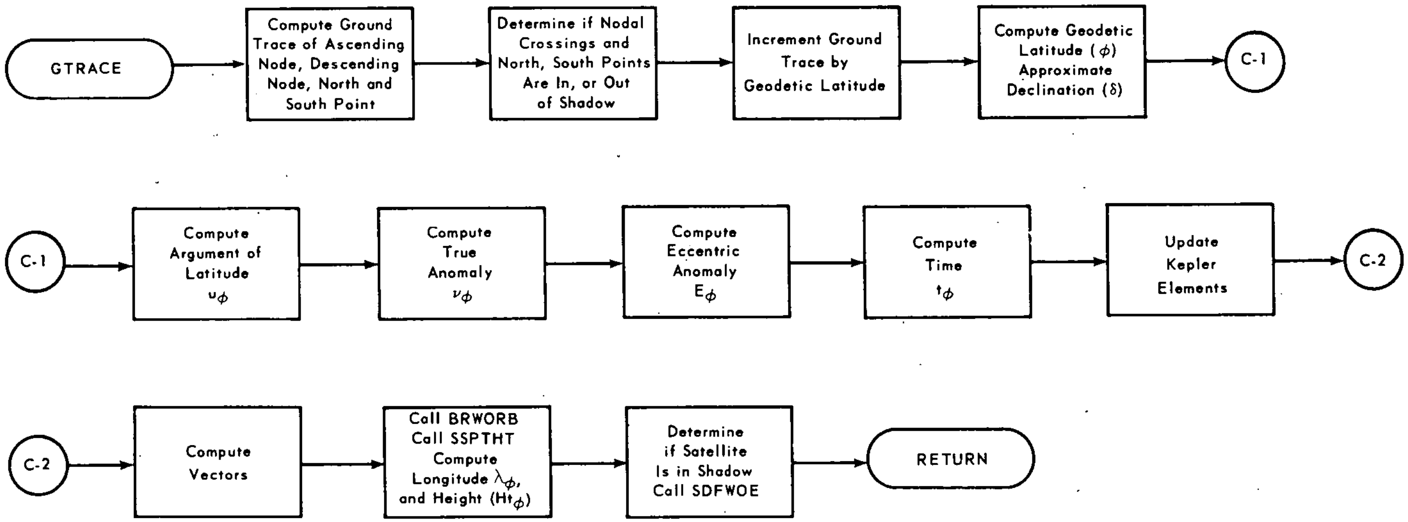
I/O	Block	Variable
I	POOL	TABLE(9) = 1/f, TABLE(24) = 2, TABLE(31) = t_0l TABLE(69) = ω_e, TABLE(59) = min/cut
I	OSCELE	ORB(6) = a, e, i, g, h, l
I	SECPRM	DPELE(6) = a", e", i", g", h", l"
I	PERTL	LDGPT = ldgPt, E_0, t_0
I	NSMAP	T_{minN}, λ_N, λ_{EN}, ϕ_N, Ht_N, t_{minS}, λ_S, λ_{ES}, ϕ_S, Ht_S
I	DHMNS	min_N, min_S, hr_N, hr_S, Dy_N, Dy_S
I	DOTELE	$l_0$dot
I	NOD	LOD = l_0D
I	NODMAP	$t_{min\Omega}$, λ_Ω, $\lambda_{E\Omega}$, ht_Ω, $t_{min\mho}$, $\lambda_\mho$, $\lambda_{E\mho}$, $ht_\mho$, $E_\mho$
I	DHMNOD	min_Ω, $min_\mho$, hr_Ω, $hr_\mho$, Dy_Ω, $Dy_\mho$

CALLED BY

MAIN

CALLS

CALL BRWORB
CALL SSPTHT
CALL SDFWOE



GTRACE Flowchart

HMSTOR

Hours, Minutes, Seconds to Radians

PURPOSE

To convert hours, minutes and seconds to radians.

METHOD

Rad = (sec/60 + minutes)/60 + hours * radians per hour

CALLING SEQUENCE

CALL HMSTOR (HH, FM, SS, RAD)

INPUT/OUTPUT

Arguments

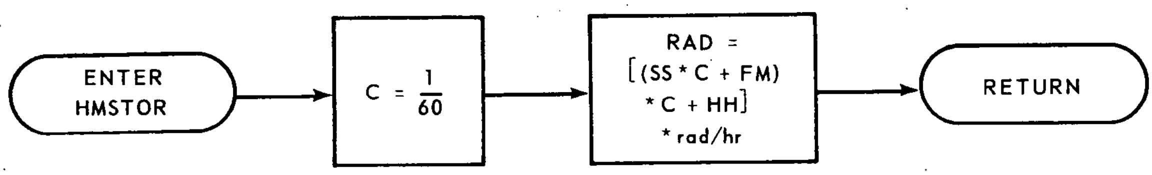
I/O	Variable	Description
I	HH	Hours
I	FM	Minutes
I	SS	Seconds
O	RAD	Radians

Common

I/O	Block	Variable
I	BPOOL	TABLE(65) = RADPHR (rad/hr)

CALLED BY

MAIN



HMSTOR Flowchart

INTPL0

Backward Difference Interpolation

PURPOSE

To interpolate for the elements a_p, e_p, i_p, l_p, g_p, h_p when given an observation time between two times on the perturbation tape.

METHOD

Backward Difference Interpolation

$$\left.\begin{array}{l} t_6 \\ t_5 \\ t_4 \\ t_3 \\ t_2 \\ t_1 \end{array}\right\} \text{times from the perturbation tape}$$

$$\left.\begin{array}{l} f(t_6) \\ f(t_5) \\ f(t_4) \\ f(t_3) \\ f(t_2) \\ f(t_1) \end{array}\right\}$$

elements from the perturbation tape at time t_i, i.e., if we are interpolating for a pert then $f(t_6) = a_6$, $f(t_5) = a_5$, $f(t_4) = a_4, \ldots.$

t = observation or request time

Δt = time increment from perturbation tape

$\Delta^K f(t_i)$ = the K^{th} difference of the elements

$$\Delta^{K-1} f(t_{i+1}) - \Delta^{K-1} f(t_i)$$

where

$$\Delta^0 f(t_i) \equiv f(t_i)$$

Difference Table

$$\begin{array}{llllll}
t_6 & f(t_6) & & & & \\
 & & \Delta f(t_5) & & & \\
t_5 & f(t_5) & & \Delta^2 f(t_4) & & \\
 & & \Delta f(t_4) & & \Delta^3 f(t_3) & \\
t_4 & f(t_4) & & \Delta^2 f(t_3) & & \Delta^4 f(t_2) \\
 & & \Delta f(t_3) & & \Delta^3 f(t_2) & \qquad \Delta^5 f(t_1) \\
t_3 & f(t_3) & & \Delta^2 f(t_2) & & \Delta^4 f(t_1) \\
 & & \Delta f(t_2) & & \Delta^3 f(t_1) & \\
t_2 & f(t_2) & & \Delta^2 f(t_1) & & \\
 & & \Delta f(t_1) & & & \\
t_1 & f(t_1) & & & &
\end{array}$$

$$(\text{elements})_\phi = f(t_6) + \Delta f(t_5)(tt0) + \Delta^2 f(t_4)\left[\frac{(tt0)(tt1)}{2}\right]$$

$$+ \Delta^3 f(t_3)\left[\frac{(tt0)(tt1)(tt2)}{6}\right] + \Delta^4 f(t_2)\left[\frac{(tt0)(tt1)(tt2)(tt3)}{24}\right]$$

$$+ \Delta^5 f(t_1)\left[\frac{(tt0)(tt1)(tt2)(tt3)(tt4)}{120}\right]$$

where

$$tt0 = t - t_6$$

$$tt1 = \Delta t + tt0$$

$$tt2 = \Delta t + tt1$$

$$tt3 = \Delta t + tt2$$

$$tt4 = \Delta t + tt3$$

CALLING SEQUENCE

CALL INTPL0 (TIME, A, B, TSUB0, DELTA)

INPUT/OUTPUT

Arguments

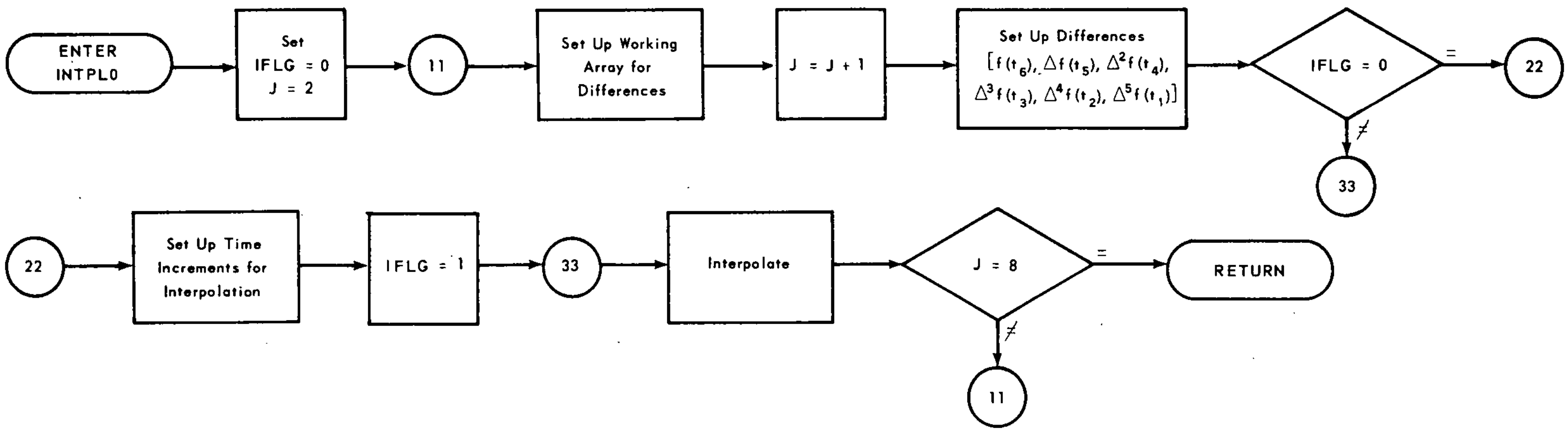
I/O	Variable	Description
I	TIME	Observation time
I	A(6, 7)	Array of observation times and elements from the perturbation tape
O	B(6)	Interpolated elements from perturbation tape for observation time — a_p, e_p, i_p, l_p, g_p, h_p
I	TSUB0	Sixth time in the time element array A
I	DELTA	Time increment between 5 times on the perturbation tape

Definition of Array A (I, J)

J \ I	1	2	3	4	5	6
1	t_1	t_2	t_3	t_4	t_5	t_6
2	a_1	a_2	a_3	a_4	a_5	a_6
3	e_1	e_2	e_3	e_4	e_5	e_6
4	i_1	i_2	i_3	i_4	i_5	i_6
5	l_1	l_2	l_3	l_4	l_5	l_6
6	g_1	g_2	g_3	g_4	g_5	g_6
7	h_1	h_2	h_3	h_4	h_5	h_6

CALLED BY

PERTF0



INTPLO Flowchart

JDSCUT

Julian Day — Seconds to Canonical Unit of Time

PURPOSE

To convert Julian days (number of days from date of reference to date of observation) and seconds to canonical units of time.

METHOD

CUT = DAYJ * SECDAY/SECCUT + SS/SECCUT

CALLING SEQUENCE

CALL JDSCUT (DAYJ, SS, CUT)

INPUT/OUTPUT

Argument

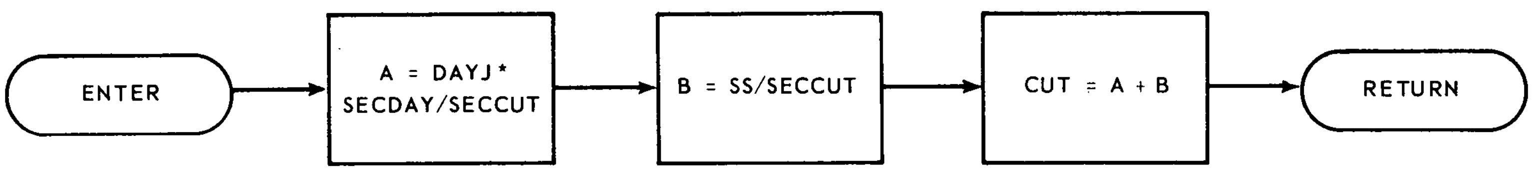
I/O	Variable	Description
I	DAYJ	Julian days
I	SS	Seconds
O	CUT	Julian days and seconds in canonical units of time

Common

I/O	Block	Variable
I	BPOOL	TABLE(5) = SECCUT
I		TABLE(30) = SECDAY

CALLED BY

DRAGLD
TIMETB



JDSCUT Flowchart

JULHMS

Julian Days — Seconds to Julian Hours, Minutes and Seconds

PURPOSE

To convert Julian days (number of days from date of reference to date of observation) and seconds to Julian days, hours, minutes and seconds.

CALLING SEQUENCE

CALL JULHMS (DAYS, SEC, RF, DAY, HH, FM, SS)

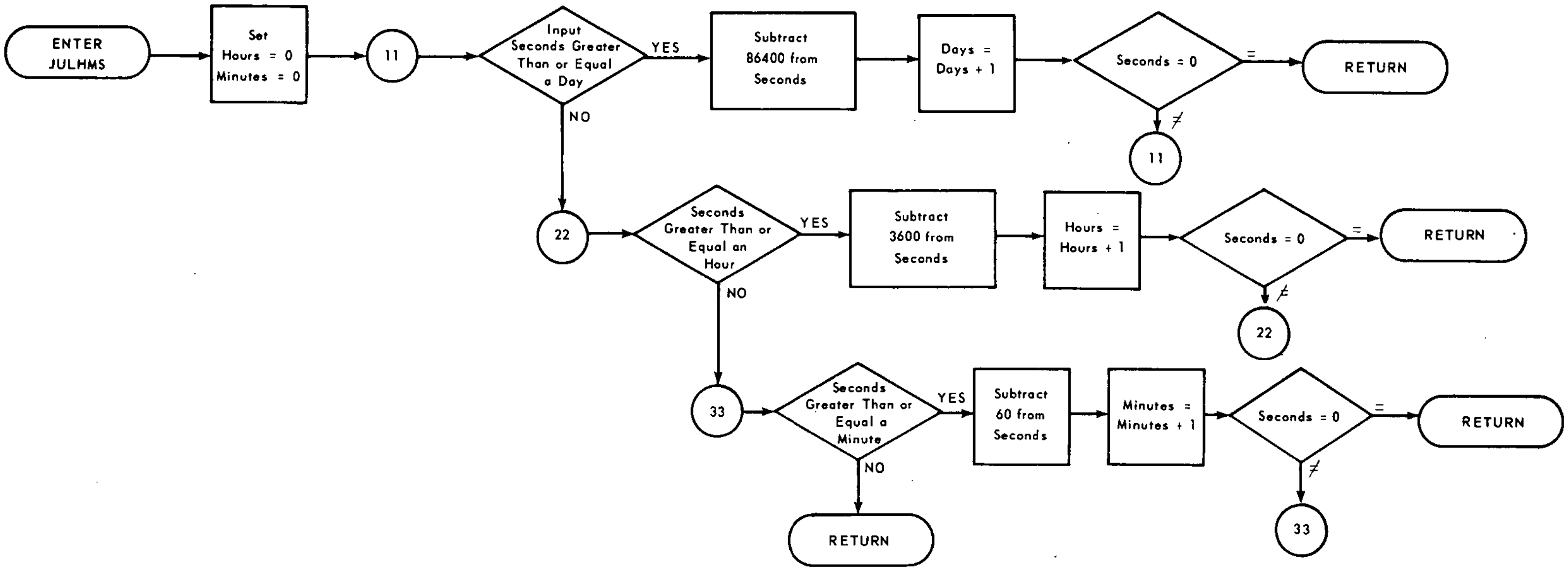
INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	DAYJ	Julian days
I	SEC	Seconds
I	RF	Rounding factor (added to SEC)
O	DAY	Julian days
O	HH	Hours
O	FM	Minutes
O	SS	Seconds

CALLED BY

SATOR
TIMETB



JULHMS Flowchart

KEPLRI

Solution of Kepler's Equation for Eccentric Anomaly

PURPOSE

To solve Kepler's equation for eccentric anomaly given mean anomaly and eccentricity by the Miles Standish algorithm.

METHOD

Kepler's equation for eccentric anomaly $M = E + e \sin E$ is solved using the Miles Standish algorithm. It is an iterative process dependent upon a tolerance value and a maximum number of iterations. Given the mean anomaly, M, and the eccentricity, e, the algorithm for computing the eccentric anomaly, E, will be:

1. Set error code = 0

   Set limit of number of iterations, MAX = 10

2. Set $E = 0$

   If $M = 0$, go to Step 13

   If $M \neq 0$, go to Step 3

3. $E_0 = M + e \sin M$

   Set number of iterations = 1

4. $F = E_0 - (e \sin E_0) - M$

5. $D = 1.0 - [e \cos (E_0 - 0.5F)]$

6. $E = E_0 - F/D$

7. If $|E_0 - E| - TOL \leq 0$, go to Step 13; otherwise continue to Step 8

8. Add 1 to number of iterations

9. If (number of iterations - MAX) ≤ 0, continue; otherwise go to Step 12

10. $E_0 = E$

11. Return to Step 4

12. Set error code = 4

13. Modulo E by 2π

14. Return to calling program

The limit of iterations through Steps 4 to 11 is 10. Thus MAX = 10. If this number is exceeded, the error code is set to 4.

TOL is the tolerance at which the last significant digit of the difference between the previous calculated eccentric anomaly and the present calculated anomaly is allowed. TOL allows an error of $\pm .05 \times 10^{-10}$.

CALLING SEQUENCE

CALL KEPLRI (MA, ECC, ERRC, E2)

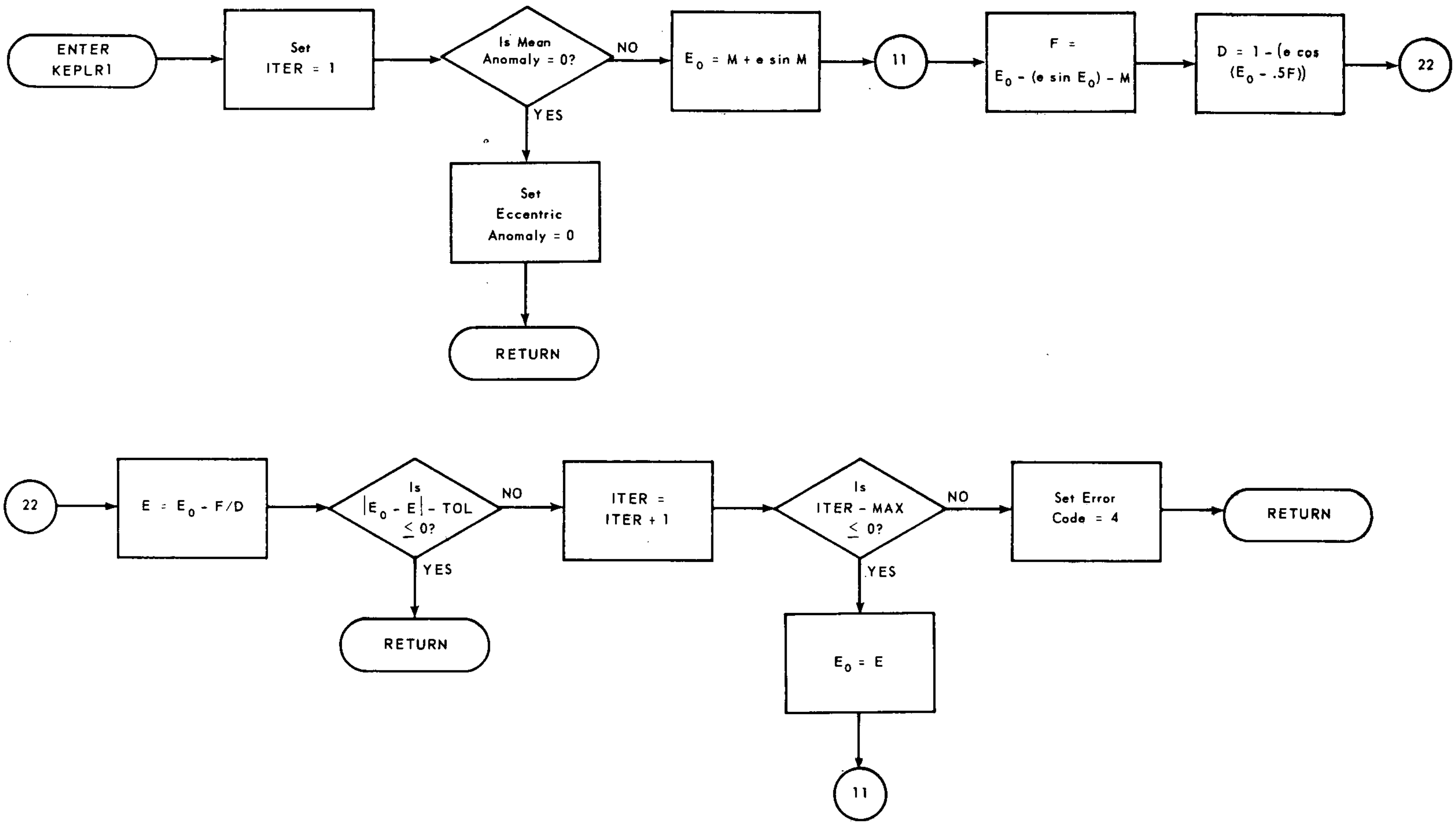
INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	MA	Mean anomaly
I	ECC	Eccentricity
O	ERRC	Error code = 0, convergence ≠ 0, no convergence
O	E2	Eccentric anomaly

CALLED BY

BRWORB
ELCON0



KEPLR1 Flowchart

LAGRN0

Lagrange's 3-Point Interpolation

PURPOSE

To interpolate using Lagrange's three-point interpolation.

METHOD

Term 1 = Y0 * (X - X1) * (X - X2) / (X0 - X1) * (X0 - X2)

Term 2 = Y1 * (X - X0) * (X - X2) / (X1 - X0) * (X1 - X2)

Term 3 = Y2 * (X - X0) * (X - X1) / (X2 - X0) * (X2 - X1)

Y = Term 1 + Term 2 + Term 3

CALLING SEQUENCE

```
CALL LAGRN0 (X, Y, X0, Y0, X1, Y1, X2, Y2)
```

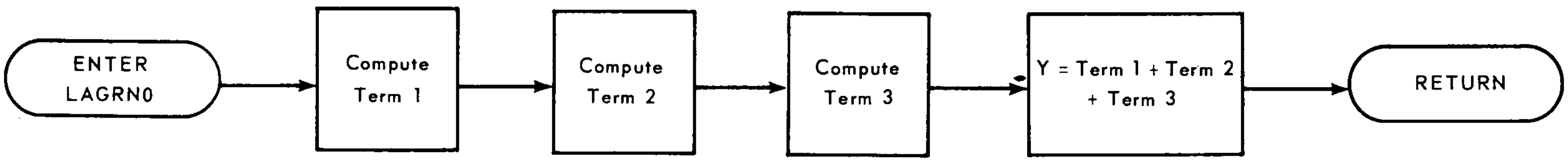
INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	X	Input request variable
O	Y	Computed F(X) for output
I	X0	First input variable
I	Y0	F (X0)
I	X1	Second input variable
I	Y1	F (X1)
I	X2	Third input variable
I	Y2	F (X2)

CALLED BY

SATOR



LAGRNO Flowchart

NODALX

PURPOSE

To determine nodal crossing times of an earth satellite.

METHOD

A two body solution is determined for the nodal crossing, the Brouwer theory is then used to update the now perturbed two-body elements in order to obtain the osculating elements corresponding to the two-body solution.

FORMULATION

The argument of perigee (g) is the angle between the direction of perigee and the ascending node.

The true anomaly F, is the angle between the direction of perigee and the radius vector of the body.

From these definitions it follows that:

$$f_i = \begin{cases} 2\pi - g_i & \text{at the ascending node} \\ \pi - g_i & \text{at the descending node} \end{cases} \tag{1}$$

and the eccentric anomaly (E) can be obtained from the relations:

$$\cos E_i = \frac{\cos \nu + e}{1 + e \cos f_i}, \quad \sin E_i = \frac{\sqrt{1 - e^2} \sin f_i}{1 + e \cos f_i} \tag{2}$$

where the time of the event is determined from Brouwer [2] p. 395. with this time we update the g in Equation (1) and the process is continued until:

$$|g_{i+1} - g_i| \leq \epsilon \tag{3}$$

where ϵ is some preassigned, small positive number.

CALLING SEQUENCE

CALL NODALX (REV, DRG, NQ, TACUT, SATID, T0, IDAD)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	REV	Number of orbital revolutions from epoch
I	DRG(1) ↓ DRG(20)	$t_0, t_1, \ldots, t_{19}$
	DRG(21) ↓ DRG(40)	$N_{2,0}, N_{2,1}, \ldots, N_{2,19}$
	DRG(41) ↓ DRG(60)	$N_{3,0}, N_{3,1}, \ldots, N_{3,19}$
I	NQ	Number of drag inputs
O	TACUT	Time of ascending nodal crossing from epoch
I	SATID(11)	SATID(1) = Satellite identification number SATID(2) = reference year SATID(11) = day count of reference date
I	T0	Epoch time
I	IDAD	= 0, time of ascending and descending nodal crossing determined = 1, time of ascending node determined = 2, time of descending node determined

Common

I/O	Block	Variable
I	BPOOL	TABLE(16) = deg/rad TABLE(23) = 2π TABLE(34) = π TABLE(31) = TOL

Common (continued)

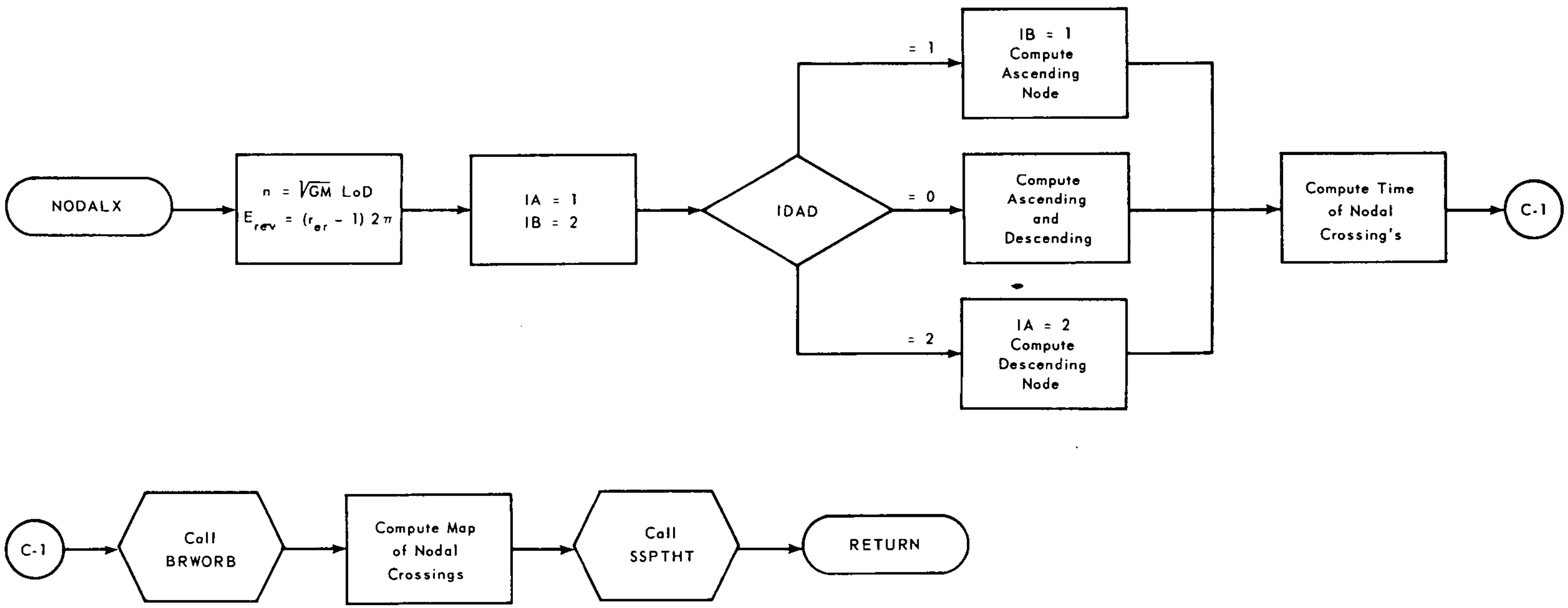
I/O	Block	Variable
I	BPOOL	TABLE(69) = ω_e TABLE(59) = min/cut TABLE(24) = μ^2
I	OSCELE	ORB(6) = a, e, i, g, h, l
I	SECPRM	DPELE(6) = a″, e″, i″, g″, h″, l″
I	NOD	LOD = l_0D
I	PERTL	LDGPT = l_{dg}Pt
O	NODMAP	$T_{min\,\Omega}$, λ_Ω, $\lambda_{E\,\Omega}$, ht_Ω, $t_{min\,\Omega}$, $\lambda_\mho$, $\lambda_{E\mho}$, $ht_\mho$, E_Ω
O	DHMNOD	min_Ω, $min_\mho$, hr_Ω, $hr_\mho$, Dy_Ω, $Dy_\mho$
	DATA	IT = 10 tg = 0.0D0

CALLED BY

MAIN
GTRACE

CALLS

CALL BRWORB
CALL SSPTHT



NODALX Flowchart

NSPT

PURPOSE

Routine to determine north point (maximum satellite geodetic latitude), and south point (minimum satellite geodetic latitude).

METHOD

A two body solution is determined for the north-south point crossing, the Brouwer theory is then used to update the now perturbed two-body elements in order to obtain the osculating elements corresponding to the times of the north-south point crossing.

FORMULATION

Two body analysis leads us to write

$$f_i = \begin{cases} \frac{\pi}{2} - g_i & \text{at the North point} \\ \frac{3\pi}{2} - g_i & \text{at the South point} \end{cases} \tag{1}$$

and the eccentric anomaly (E) can be obtained from the relations:

$$\cos E_i = \frac{\cos \nu + e}{1 + e \cos f_i}, \quad \sin E_i = \frac{\sqrt{1 - e^2} \sin f_i}{1 + e \cos f_i} \tag{2}$$

where the time of the event is determined from Brouwer (1959) p. 395. With this time we update the g in Equation (1) and the process is continued until:

$$|g_{i+1} - g_i| \leq \epsilon$$

where ϵ is some preassigned, small positive number.

CALLING SEQUENCE

CALL NSPT (REV, DRG, NQ, SATID, T0, IDNS)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	REV	Number of orbital revolutions
I	DRG(1) ↓ DRG(20)	$t_0, t_1, \ldots, t_{19}$
	DRG(21) ↓ DRG(40)	$N_{2,0}, N_{2,1}, \ldots, N_{2,19}$
	DRG(41) ↓ DRG(60)	$N_{3,0}, N_{3,1}, \ldots, N_{3,19}$
I	NQ	Number of drag inputs
I	SATID(11)	SATID(1) = Satellite identification number SATID(2) = reference year SATID(11) = day count of reference date
I	T0	Epoch time
I	IDNS	= 0, time of north point and south point determined = 1, time of north point determined = 2, time of south point determined

Common

I/O	Block	Variable
I	BPOOL	TABLE(31) = TOL TABLE(69) = ω_e TABLE(59) = min/cut TABLE(24) = μ^2
I	OSCELE	ORB(6) = a, e, i, g, h, l
I	SECPRM	DPELE(6) = a″, e″, i″, g″, h″, l″
I	PERTL	LDGPT = $l_{dg}Pt$, E_0, l_0
O	NSMAP	T_{minN}, λ_N, λ_{EN}, ϕ_N, Ht_N, t_{minS}, λ_S, λ_{ES}, ϕ_S, Ht_S

Common (continued)

I/O	Block	Variable
O	DHMNS DATA	min_N, min_S, hr_N, hr_S, Dy_N, Dy_S IT = 10 tg = 0.0D0

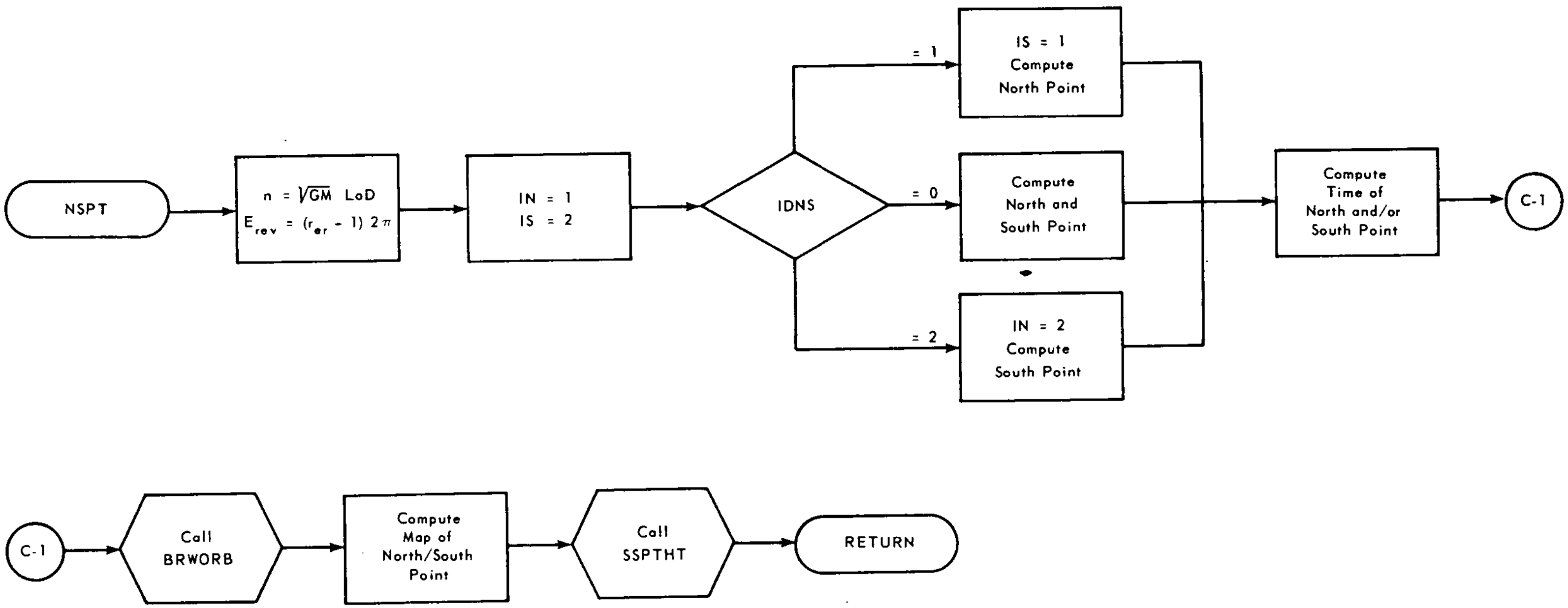
CALLED BY

MAIN
GTRACE

CALLS

CALL BRWORB
CALL SSPTHT

2



NSPT Flowchart

PAGE1

First Page Print

PURPOSE

To write elements, drags, earth constants, and harmonics on tape.

CALLING SEQUENCE

```
CALL PAGE1 (EPOCH, SRNAME, SATID, OUTPUT, NQ, DRAGDT, DRG,
            NTPQ, DATTIM, CDRAG, KDELT, NJ, ELEM0, RUNID)
```

INPUT/OUTPUT

Arguments

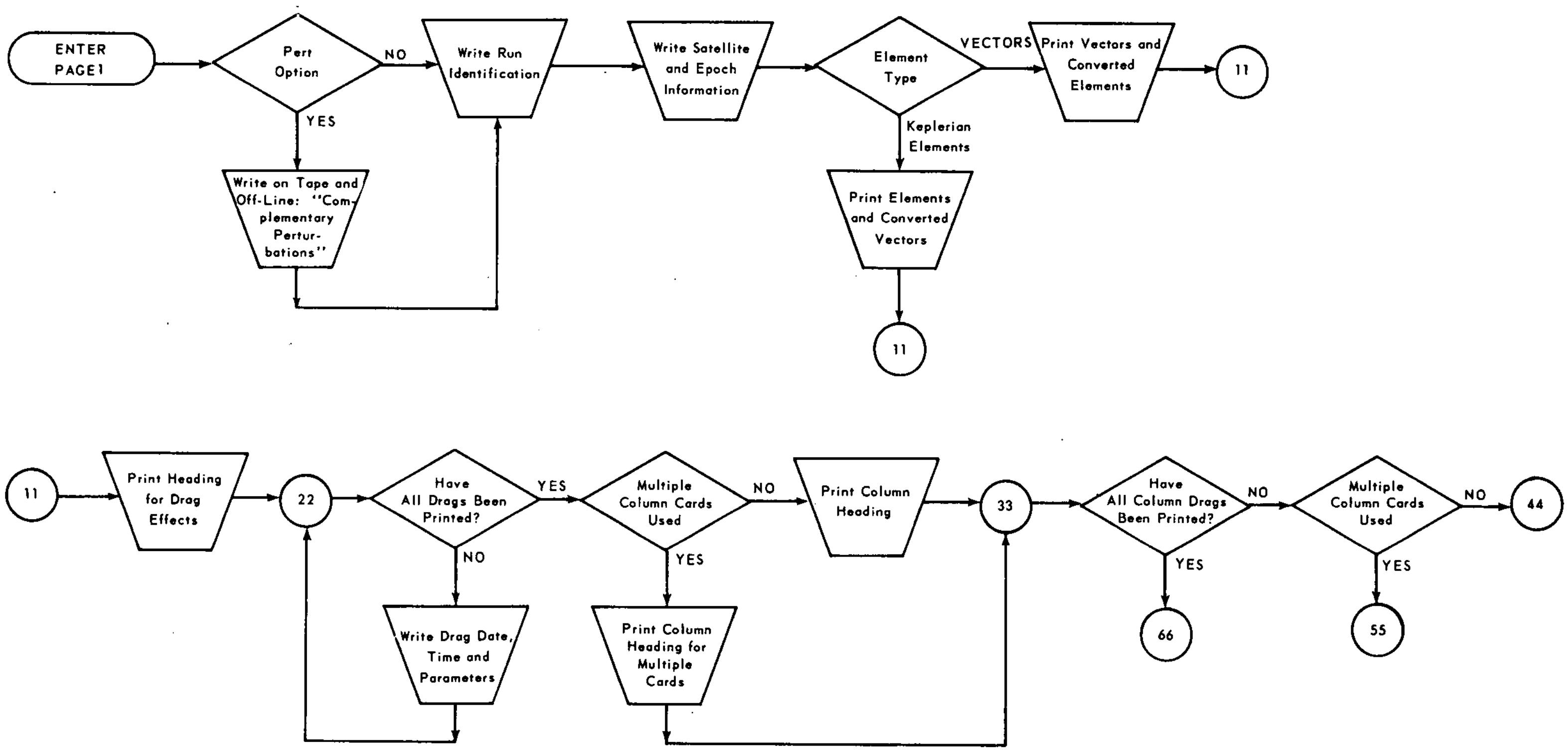
I/O	Variable	Description
I	EPOCH(10)	EPOCH(1-7) — epoch satellite ID and time EPOCH(8) = type of the epoch elements EPOCH(9) = pass number EPOCH(10) = perturbation option = 0 no perturbation = 1 use perturbation tape
I	SRNAME(3)	Name of satellite
I	SATID(10)	Reference sat ID and time
I	OUTPUT(6)	Converted epoch elements
I	NQ	Number of drag inputs
I	DRAGDT(40)	Array of packed drag date and time
I	DRG(60)	Array of drag time and parameters
I	NTPQ	Number of column times (or cards)
I	DATTIM(112)	Array of packed column date and time
I	CDRAG(112)	Array of column drag parameters
I	KDELT(4)	KDELT(1) and (3) = number of columns to be computed per card KDELT(2) and (4) = column Δt in minutes
I	NJ	Number of column times plus one
I	ELEM0(6)	Epoch elements
I	RUNID(8)	Run identification

Common

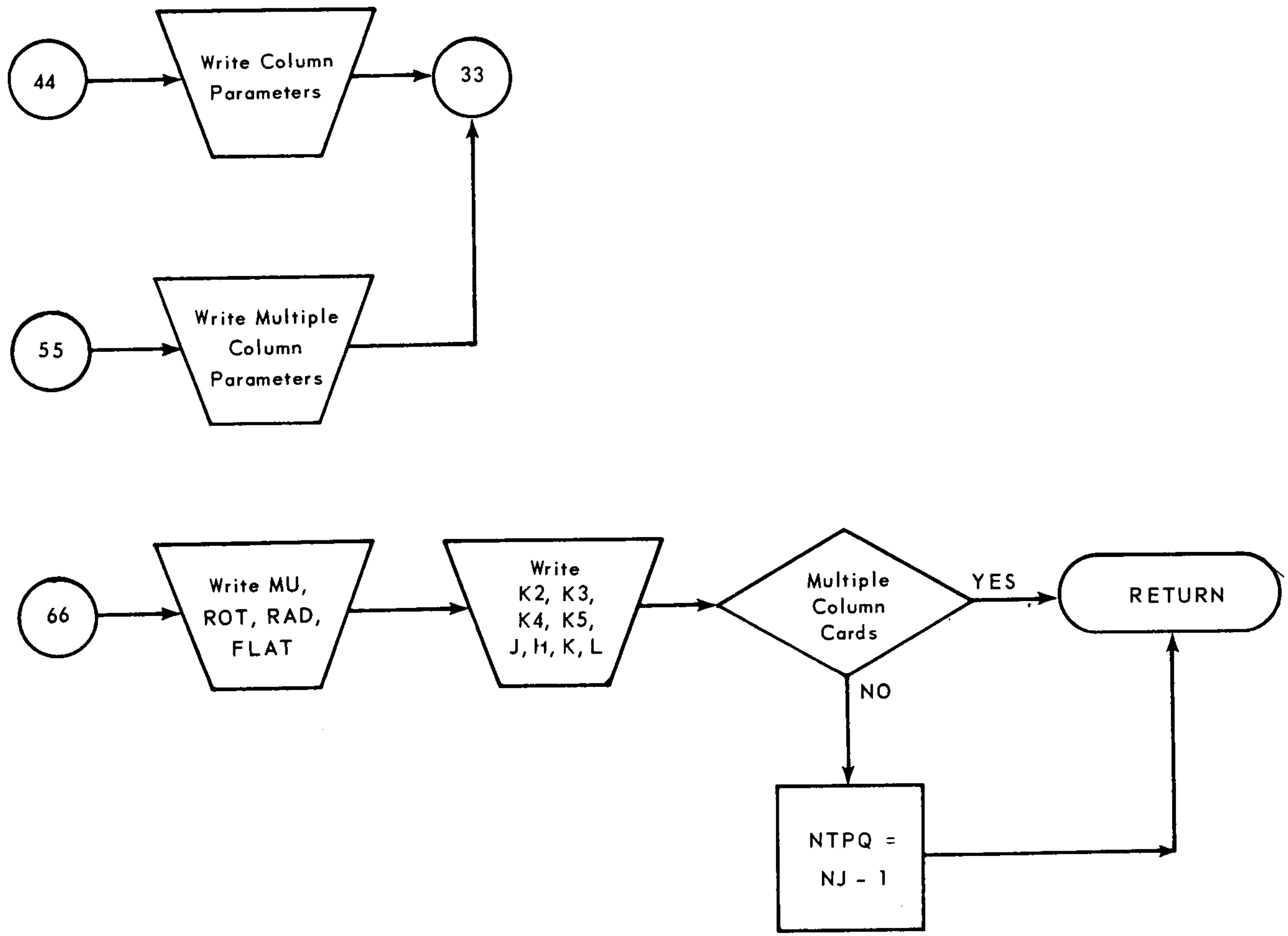
I/O	Block	Variable
I	BPOOL	TABLE(22) = RAD TABLE(41) = Mu TABLE(42) = FLAT TABLE(49) = ROT TABLE(58) = J TABLE(61) = K2 TABLE(62) = K3 TABLE(63) = K4 TABLE(64) = K5

CALLED BY

MAIN



PAGE1 Flowchart



PAGE1 Flowchart (continued)

PERTF0

Complementary Perturbations

PURPOSE

To read the complementary perturbation tape for the Brouwer Orbit Generator.

CALLING SEQUENCE

CALL PERTF0 (PLN, SATID, TIME, KMULT, B, IERR)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	PLN	Perturbation tape logical input unit > 0 read pert tape on that unit < 0 do no read pert tape = 0 error
I	SATID(11)	SATID(1) = reference satellite ID SATID(2) = year of reference SATID(3) = day count of reference date
I	TIME	Observation time
I/O	KMULT	K multiplier for ΔL drag computation
O	B(6)	Array of elements from perturbation tape for observation time — a_p, e_p, i_p, l_p, g_p, h_p
O	IERR	Error = 0 no error = 37 error in reading pert tape = 38 wrong satellite ID on pert tape

Common

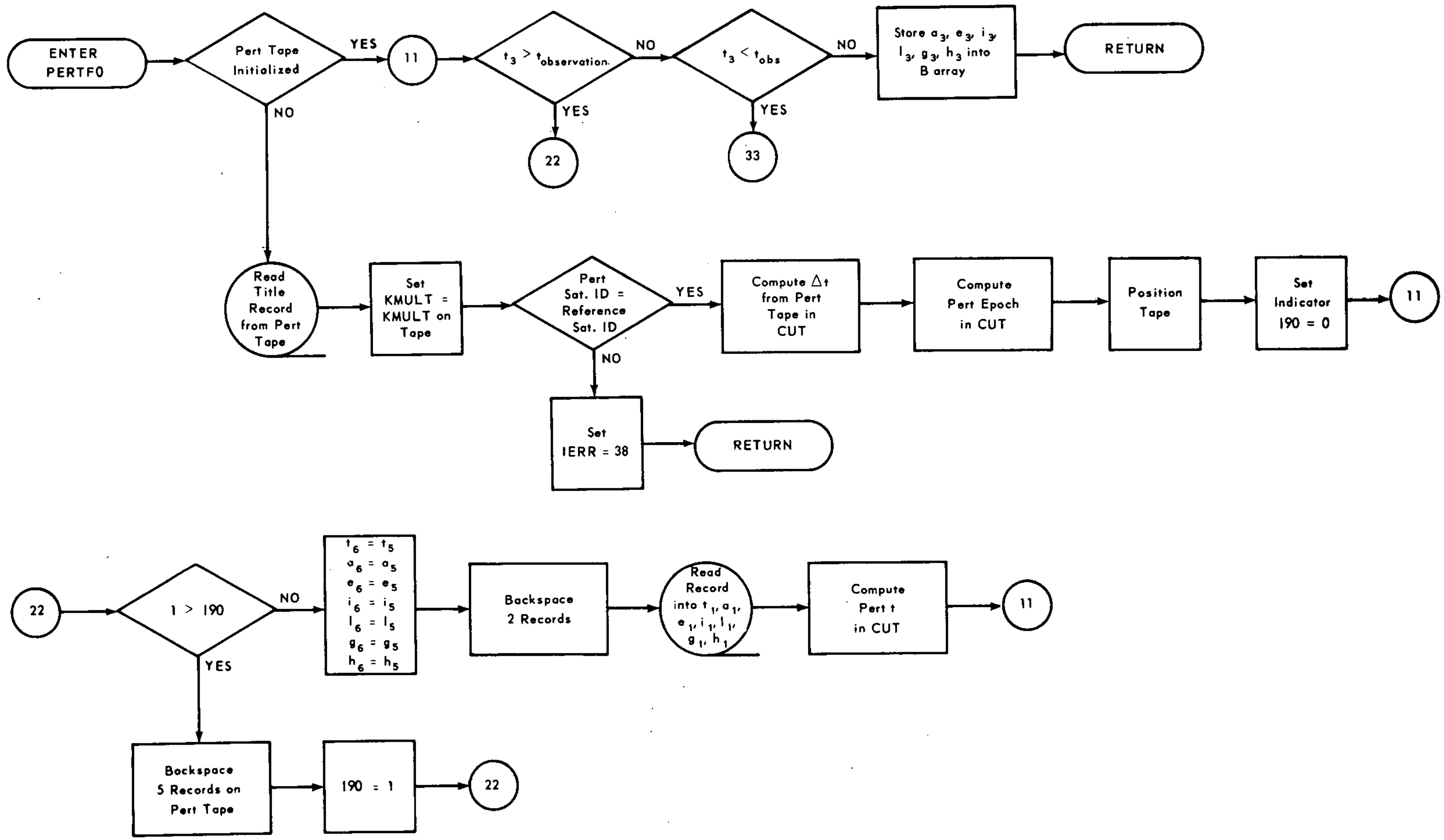
I/O	Block	Variable
I I	BPOOL	TABLE(5) = SECCUT TABLE(45) = CUTDAY

CALLED BY

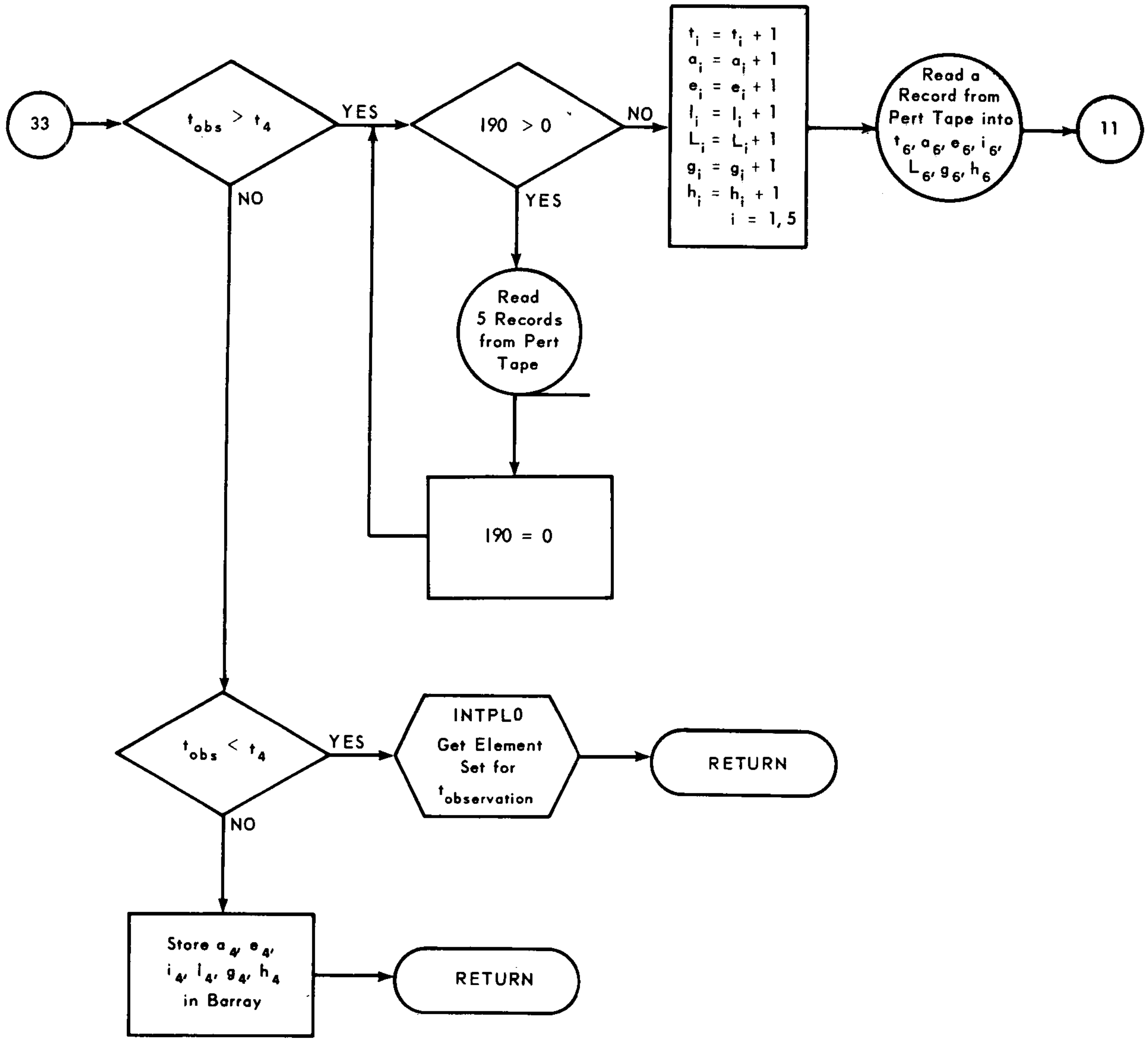
BRWORB

CALLS

DREFOD
JDSCUT
INTPL0



PERTFO Flowchart



PERTF0 Flowchart (continued)

POOL

Constants Pool

PURPOSE

To compute frequently used constants.

CALLING SEQUENCE

CALL POOL

INPUT/OUTPUT

Common

I/O	Block	Variable
I	BPOOL (BLOCK DATA)	TABLE(1) = meters/ft TABLE(2) = km/CUL TABLE(4) = km/A.U. TABLE(5) = sec/CUT TABLE(9) = 1/flattening coefficient TABLE(11) = ω_e (earth rotation in rad/sec) TABLE(12) = J_2 TABLE(13) = J_3 TABLE(14) = J_4 TABLE(15) = J_5 TABLE(16) = deg/rad TABLE(17) = deg } obliquity TABLE(18) = min } of TABLE(19) = sec } eccliptic TABLE(21) = km/mi TABLE(22) = radius of earth in CUL TABLE(24) = GM = μ^2 TABLE(30) = sec/day TABLE(32) = sec/hr TABLE(33) = deg/hr
O	BPOOL	TABLE(41) = μ TABLE(42) = Flattening coefficient

Common (continued)

I/O	Block	Variable
O	BPOOL	TABLE(43) = B (polar radius of the earth) TABLE(44) = CUL/A.U. TABLE(45) = CUT/Day TABLE(46) = CUT/hr TABLE(47) = Convert CUL/CUT to km/sec TABLE(48) = Convert CUL/CUT to km/hr TABLE(49) = ω_e (earth rotation) in rad/CUT TABLE(50) = mi/CUL TABLE(51) = Convert CUL/CUT to mi/hr TABLE(52) = e^2 TABLE(53) = e (eccentricity of earth) TABLE(54) = X component of U_2 TABLE(55) = Y component of U_2 TABLE(56) = Z component of U_2 U_2 is an orthogonal unit vector in the ecliptic plane expressed in the inertial coordinate system. U_2 is perpendicular to U_1 in the direction of positive τ. TABLE(57) = TAUDOT (mean longitude in rad/CUT) TABLE(58) = J TABLE(59) = min/CUT TABLE(60) = Convert CUL/CUT to m/sec TABLE(61) = K2 TABLE(62) = K3 TABLE(63) = K4 TABLE(64) = K5 TABLE(65) = rad/hr TABLE(66) = km/ft TABLE(67) = Obliquity of ecliptic in rad TABLE(68) = KMULT for Drag TABLE(69) = ω_e (earth rotation) in deg/min TABLE(70) = CUT/min TABLE(71) = X component of U_1 TABLE(72) = Y component of U_1 TABLE(73) = Z component of U_1 U_1 is an orthogonal unit vector in the ecliptic plane, expressed in the inertial coordinate system. U_1 is directed to the vernal equinox.

Common (continued)

I/O	Block	Variable
O	BPOOL	TABLE(74) = Tolerance for R* · U TABLE(75) = Tolerance for magnitude of RXU TABLE(76)-(80) — Not used

CALLED BY

MAIN

CALLS

DMSTOR

PQUV

PURPOSE

Introduction of the orthogonal unit vector set P,Q or U,V into the orbit plane coordinate system.

METHOD

Aligning both fundamental triads and performing the rotations through Ω, i, ω, yields the direction cosines of P,Q; substitution of u for ω yields the direction cosines for the set U,V.

FORMULATION

The direction cosines of P, and Q are given by:

$$P_1 = \cos\omega\cos\Omega - \sin\omega\sin\Omega\cos i\ , \quad Q_1 = -\sin\omega\cos\Omega - \cos\omega\sin\Omega\cos i\ ,$$

$$P_2 = \cos\omega\sin\Omega + \sin\omega\cos\Omega\cos i\ , \quad Q_2 = -\sin\omega\sin\Omega + \cos\omega\cos\Omega\cos i\ ,$$

$$P_3 = \sin\omega\sin i\ , \quad Q_3 = \cos\omega\sin i\ ,$$

and the directional cosines of U, and V are obtained by the substitution of $u = \nu + \omega$ for ω into the above equations, that is, $U = P(i, \Omega, u)$ and $V = Q(i, \Omega, u)$.

CALLING SEQUENCE

```
CALL PQUV (I, H, G, NU, P, Q, U, V)
CALL UV (I, G, H, NU, U, V)
CALL PQ (I, G, H, P, Q)
```

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	I	(i) Orbital Inclination
I	G	(ω) Argument of Perigee
I	H	(Ω) Longitude of the Ascending Node
I	NU	(ν) True Anomaly
O	U(i)	U(1), U(2), U(3) $\equiv$ U = P(i, Ω, ω)
O	V(i)	V(1), V(2), V(3) $\equiv$ V (i, Ω, ω)
O	P(i)	P, Unit Vector taken as pointing Towards Perifocus
O	Q(i)	Q, Unit Vector in the orbit plane advanced to P by a right angle in the direction of increasing true anomaly.

Common

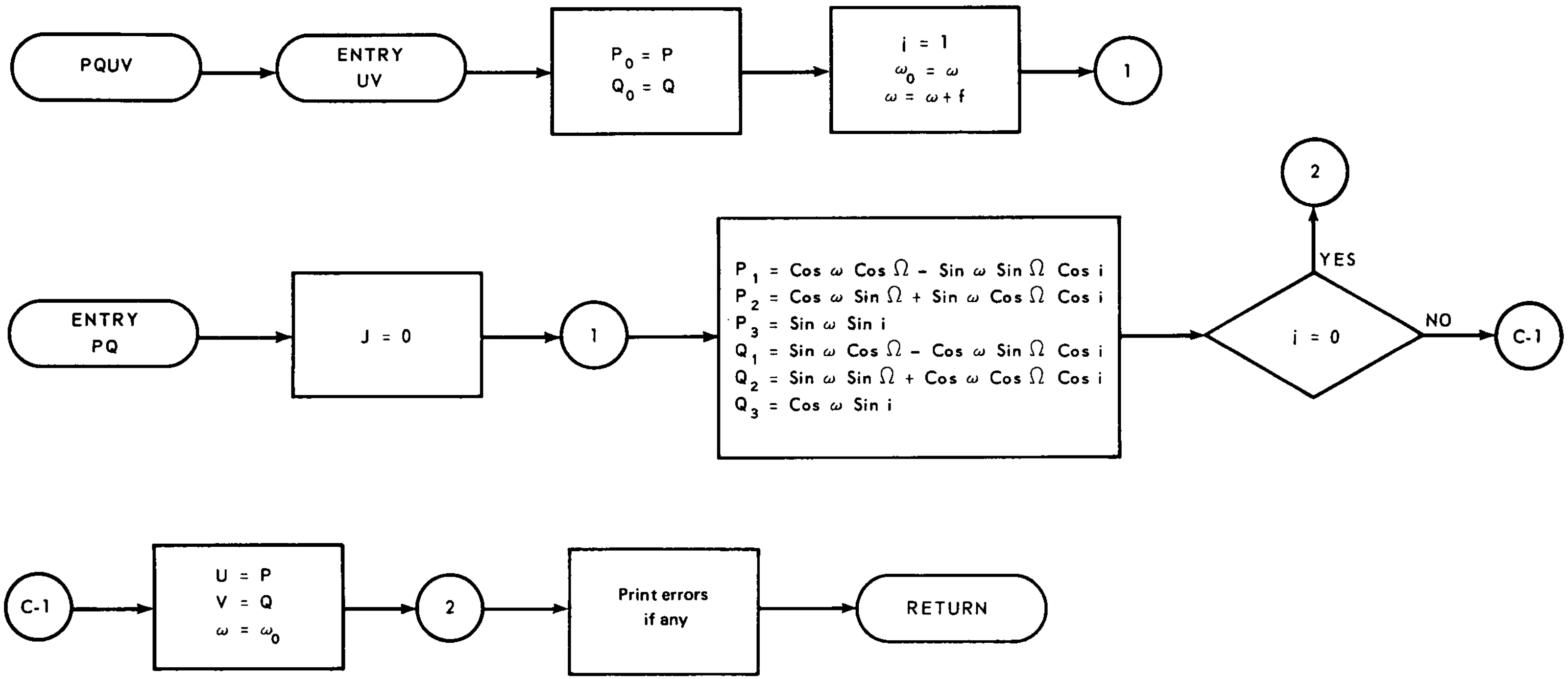
I/O	Block	Variable
I	BPOOL	TABLE(31) = ϵ $\equiv$ $.1 \times 10^{-11}$

CALLED BY

BRWORB

CALLS

VDOT



PQUV Flowchart

PREDS

Brouwer Prediction Table Bulletin

PURPOSE

To calculate precise prediction information for the orbit of a satellite.

METHOD

The satellite position can be determined approximately by means of a method based on the assumption that the quantities a (t), e (t), I (t), g (t), h (t) and n (t) are osculating elements. It is necessary to have a set of mean Brouwer elements, the epoch of such elements, a set of times (t_i) with a constant Δt, and corresponding $(N_{2,i})$'s whose value may be zero or a non-zero quantity. Other associated parameters at epoch time are computed.

For i = 0, compute

$$a(t_0) = a'' \left[1 + \gamma_2 (3\theta^2 - 1) \left(\frac{1 - \eta^3}{\eta^6} \right) \right]$$

$$n(t_0) = \sqrt{\frac{\mu}{a_0^3}}$$

$$e(t_0) = e'' + \delta_1 e(t_0) + \frac{\gamma_2}{2e''} (3\theta^2 - 1) \left(\frac{1 - \eta^3}{\eta^4} \right)$$

$$M(t_0) = l''_0 + l_1(t_0)$$

$$K = \frac{4a(t_0)}{3n(t_0)}$$

$$W = \frac{4\left(1 - e(t_0)\right)}{3n(t_0)}$$

For i > 0, compute

$$\tau_{1,i} = t_{i+1} - t_i$$

$$\tau_{2,i} = \frac{\tau_{1,i}}{2}$$

$$C_1 = \ell_1(t_{i+1}) - \ell_1(t_i)$$

$$C_2 = \ell_1(t_i + \tau_{2,i}) - \ell_1(t_i)$$

$$\delta\ell_{11,i} = \frac{[C_1 \tau_{2,i}^2 - C_2 \tau_{1,i}^2]}{[\tau_{1,i} \tau_{2,i} (\tau_{2,i} - \tau_{1,i})]}$$

$$M_i(t) = M_{2,i}(t - t_i)^2 + M_{1,i}(t - t_i) + M_{0,i}$$

$$M_{0,i} = \ell_i'' + \ell_1(t_i); \quad \text{for } i = 0 \quad M(t_i) = M_{0,i}$$

$$M_{1,i} = \dot{\ell}_0'' + \delta\ell_{11,i} + 2\sum_{j=1}^{i} N_{2,j-1}(t_j - t_{j-1})$$

$$a(t_{i+1}) = a(t_0) - K\Sigma N_{2,i}\, \tau_{1,i} + \Delta a$$

$$e(t_{i+1}) = e(t_0) + \delta_1 e(t_{i+1}) - \delta_1 e(t_0) - W\Sigma N_{2,i}\, \tau_{1,i} + \Delta e$$

$$I(t_{i+1}) = I'' + \delta_1 I(t_{i+1})$$

$$g(t_{i+1}) = g'(t_{i+1})$$

$$h(t_{i+1}) = h'(t_{i+1})$$

$$\dot{\omega}(t_i) = \frac{1}{2(t_{i+1} - t_i)} \quad -3\omega(t_0) + 4\omega(t_1) - \omega(t_2)$$

$$\dot{\Omega}(t_i) = \frac{1}{2(t_{i+1} - t_i)} \quad -3\Omega(t_0) + 4\Omega(t_1) - \Omega(t_2)$$

$$\text{Period, nodal } (t_0) = \frac{2\pi}{M_{1,\phi} + \dot{\omega}(t_\phi)}$$

$$\text{Period, anomalistic } (t_i) = \frac{2\pi}{M_{1,i}}$$

$$\dot{P}_{a,i} = \frac{-M_{2,i} P_{a,i}^{2}}{\pi}$$

$$\text{Height of perigee} = a(1 - e) - 1$$

$$\text{Height of apogee} = a(1 + e) - 1$$

$$\text{Velocity of perigee} = \frac{\mu}{\sqrt{a}} \left(\sqrt{\frac{1+e}{1-e}}\right)$$

$$\text{Velocity of apogee} = \frac{\mu}{\sqrt{a}} \bigg/ \sqrt{\frac{1+e}{1-e}}$$

$$TP = \frac{t_2 + [2(2\pi - M_{0,2})]}{\left[M_{1,2}\left(1 + \sqrt{1 + [4M_{2,2}(2\pi - M_{0,2})] \;/M_{1,2}^{2}}\right)\right]}$$

From BRWORB, compute

$$\ell_1 \text{ at } (t_i + T_{2,i})$$

$$\delta_1 e,\ \delta_1 I,\ \ell_1,\ g',\ h',\ \Delta a,\ \Delta e \text{ at } (t_{i+1})$$

CALLING SEQUENCE

CALL PREDS (T0, TPQ, NJ, CDRAG, DRG, EL, PA, PADOT, PNA, TP, NN, MI, ELEM0, NQ, SATID)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	T0	Epoch time
I	TPQ(56)	Column elements times
I	NJ	Number of columns to be computed
I	CDRAG(112)	Column drag table
I	DRG(60)	Brouwer drag time and parameters table
O	EL(8, 56)	Array of Bulletin prediction elements — a_i, e_i, I_i, Ω_i, ω_i, $M_{0,i}$, $M_{1,i}$, $M_{2,i}$ where i = 1 - 56
O	PA(56)	Array of Bulletin prediction anomalistic periods
O	PADOT(56)	Array of prediction anomalistic period derivatives
O	PNA(8)	PNA(1) = nodal period
		PNA(2) = prediction $\dot{\omega}$
		PNA(3) = prediction $\dot{\Omega}$
		PNA(4) = perigee height
		PNA(5) = apogee height
		PNA(6) = geocentric latitude of perigee
		PNA(7) = perigee velocity
		PNA(8) = apogee velocity
O	TP	Time of perigee
O	NN	Index for column times
O	MI	Index for column prediction elements
I	NQ	Number of drag inputs
I	SATID(11)	SATID(1) = reference satellite ID
		SATID(2) = year of reference
		SATID(11) = day count of reference date

Common

I/O	Block	Description
I	BPOOL	TABLE(24) = BK
		TABLE(34) = π
		TABLE(41) = μ
I	ETAP	ETA3 - η^3)
		ETA4 - η^4)
		ETA6 - η^6)
I	GMPR	GM2 - γ_2)
I	LPPRM	DEL1E - $\delta_1 e$
		DEL1I - $\delta_1 i$
		L_i - L_1
		GP - g'
		HP - h'
I	SECPRM	DPELE(6) - Brouwer mean elements
I	DOTELE	L0DOT - $\dot{L}_0$
I	THETAP	M1P3T2 - $3\theta^2 - 1$
I	DELKEP	DKEP(1) - Δa_{pert}
		DKEP(2) - Δe_{pert}
I	PRTKEP	PKEP(3) - $\ell_0 + \Delta \ell$

TAPE OUTPUT

Prediction Space Elements

Epoch: Calendar Date

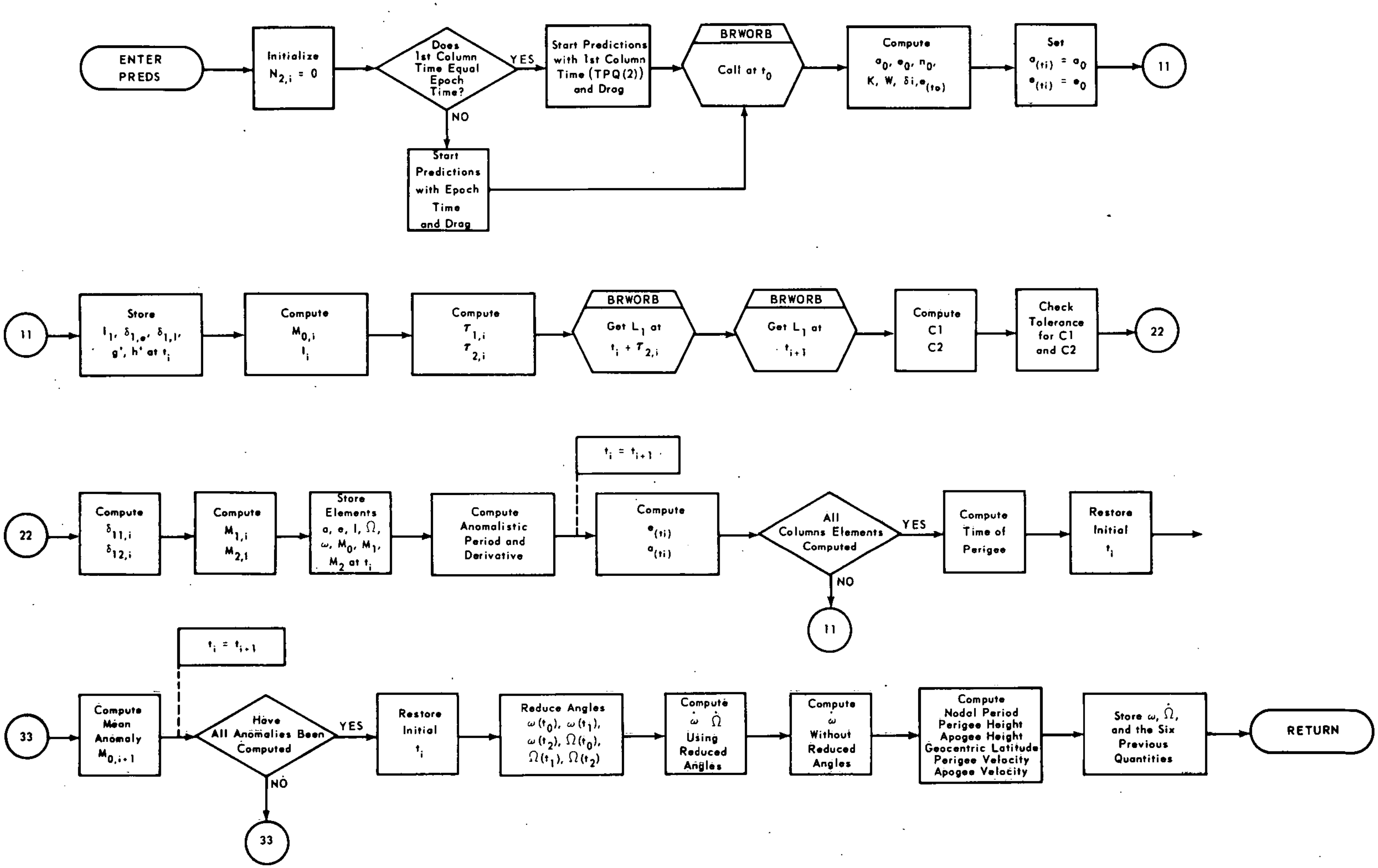
Epoch: Julian Date for Space		t'_1	t_2	t_3
Period	minutes	P_1	P_2	P_3
Period derivative	microdays/day	$\dot{P}_1$	$\dot{P}_2$	$\dot{P}_3$
Eccentricity		e_1	e_2	e_3
Inclination	degrees	i_1	i_2	i_3
Right ascension of ascending node	degrees	Ω_1	Ω_2	Ω_3
Argument of perigee	degrees	ω_1	ω_2	ω_3
Mean anomaly	degrees	M_1	M_2	M_3
Semi-major axis	earth radii	a_1	a_2	a_3

CALLED BY

MAIN

CALLS

BRWORB
REDUCE



PREDS Flowchart

PRINT

Brouwer Prediction Print

PURPOSE

To write pertinent prediction information for the orbit of a satellite.

CALLING SEQUENCE

```
CALL PRINT (NC, NQ, SRNAME, EPOCH, ETIME, NN, MI, PA, PADOT,
            EL, PNA, TPQ, SATID, SECDRG, DATTIM, DRG, OSC0,
            PV, ISSUE, NEPASS, T0, ELEM0)
```

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	NC	Number of columns to be printed
I	NQ	Number of drag inputs
I	SRNAME(3)	Satellite name
I	EPOCH(10)	Epoch time and information
I	ETIME	Epoch hours, minutes, seconds in seconds
I	NN	Index for column times
I	MI	Index for column prediction elements
I	PA(56)	Array of anomalistic periods
I	PADOT(56)	Array of anomalistic period derivatives
I	EL(8, 56)	Array of Bulletin prediction elements — a_i, e_i, I_i, Ω_i, ω_i, $M_{0,i}$, $M_{1,i}$, $M_{2,i}$ where i = 1, 56
I	PNA(8)	PNA(1) = nodal period PNA(2) = prediction $\dot{\Omega}$ PNA(3) = prediction $\dot{\omega}$ PNA(4) = perigee height PNA(5) = apogee height PNA(6) = geocentric latitude of perigee PNA(7) = perigee velocity PNA(8) = apogee velocity
I	TPQ(56)	Array of column elements times

Arguments (continued)

I/O	Variable	Description
I	SATID(11)	SATID(1) = reference satellite ID SATID(2) = year of reference SATID(11) = day count of reference date
I	SECDRG(112)	SECDRG(1), (3), . . ., (111) = seconds from columns time SECDRG(2), (4), . . ., (112) = total column time (hours, minutes, seconds) in seconds
I	DATTIM(112)	Packed column date and time
I	DRG(60)	Drag time and parameters table
I	OSC0(6)	Epoch Brouwer osculating elements
I	PV(6)	Epoch Brouwer position and velocity vectors
I	ISSUE(4)	Date of issue
I	NBPASS	Initial pass number
I	T0	Epoch in Canonical Unit of Time
I	ELEM0(6)	Epoch elements — a, e, i, g, h, m

Common

I/O	Block	Variable
I	BPOOL	TABLE(1) = meters/ft TABLE(2) = km/CUL TABLE(5) = sec/CUT TABLE(16) = deg/rad TABLE(23) = 2π TABLE(25) = knots/mi/hr TABLE(26) = km/N.M. TABLE(28) = GM (km^3/sec^2) TABLE(30) = sec/day TABLE(34) = π TABLE(35) = min/day TABLE(41) = μ TABLE(45) = cut/day TABLE(49) = ω_e (earth rotation) in rad/CUT TABLE(50) = mi/CUL TABLE(51) = CUL/CUT to mi/hr TABLE(57) = TAUDOT

Common (continued)

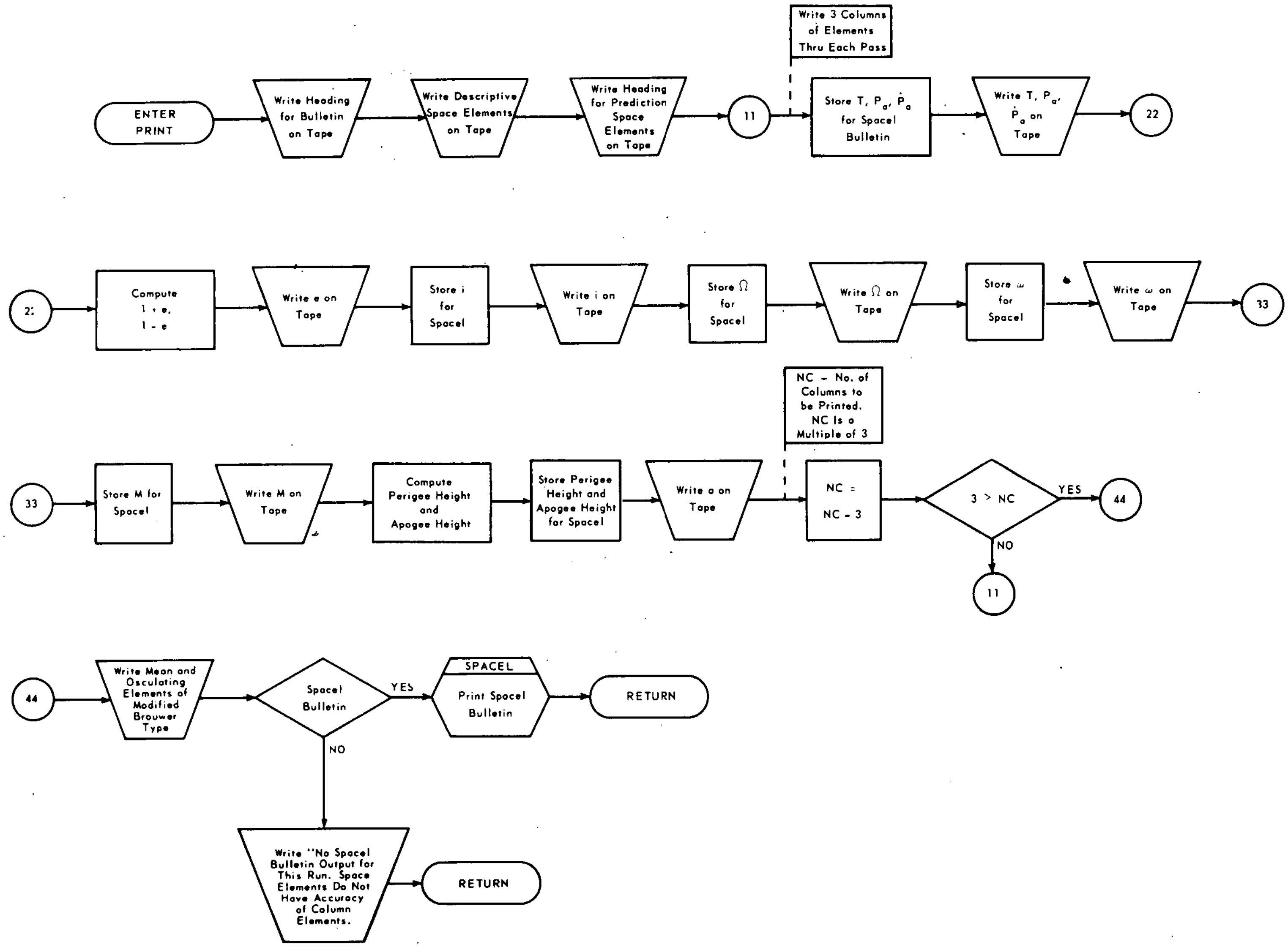
I/O	Block	Variable
I	BPOOL	TABLE(59) = min/CUT TABLE(60) = CUL/CUT to m/sec TABLE(65) = rad/hr TABLE(66) = km/ft TABLE(67) = obliquity of ecliptic in rad
I	RADIAN	TAU = τ, satellite degrees, minutes, seconds in rad AMBDA = λ, satellite hour, minutes, seconds in rad

CALLED BY

MAIN

CALLS

DREFOD
REDUCE
DATAN0
SPACEL



PRINT Flowchart

REDUCE

Reduce Angle

PURPOSE

To reduce an angle between 0 and 2π.

CALLING SEQUENCE

REDUCE (Z, PI2)

Note that REDUCE is a function.

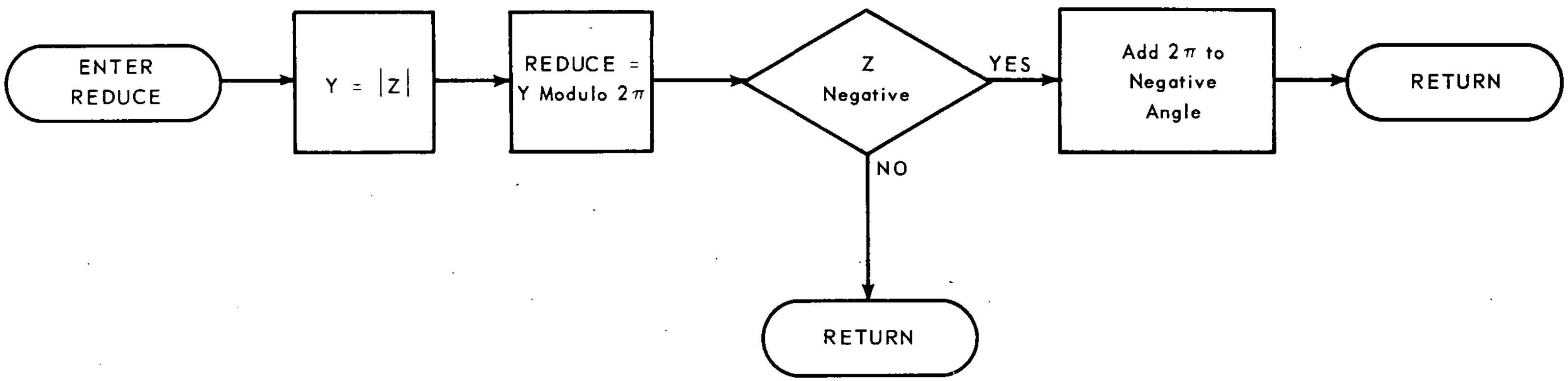
INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	Z	Angle to be reduced
I	PI2	2π - 360° in radians
O	REDUCE	Reduced-angle Z

CALLED BY

BRWORB
DAF
DRAG
PREDS
PRINT
SATOR



REDUCE Flowchart

SDFWOE

Sunlight Determination

PURPOSE

To determine whether a satellite is in sunlight or darkness (due to the earth's shadow) at a given time. An option is available to consider the effects of an oblate earth in making this determination.

METHOD

Given:

$\underline{r}$ = the position vector of the satellite in the inertial coordinate system, measured in CUL, and having components X, Y, and Z.

τ = the longitude of the sun on reference date, in radians.

$\dot{\tau}$ = the motion of tau, in radians per CUT.

TIME = $t - t_0$ = the time in CUT, measured from reference date, at which the sunlight determination is to be made.

U_1 and U_2 = orthogonal unit vectors in the ecliptic plane, expressed in the inertial coordinate system. U_1 is directed to the vernal equinox and U_2 is perpendicular to U_1 in the direction of positive τ (U_1 = 1, 0, 0; U_2 = 0, cos ϵ, sin ϵ where ϵ = obliquity of ecliptic).

f = the flattening coefficient of the ellipsoid of reference.

Compute:

$\underline{r}^*$ = the unit satellite position vector

$T = \tau + \dot{\tau}\,(t - t_0)$

$\underline{U} = \underline{U}_1 \cos T + U_2 \sin T$, having coordinates u, v, w

If $|\underline{r} \times \underline{U}| < T_1$, where $T_1 = 1 - f\,(Z + W\sqrt{r^2 - 1})^2$, or a constant, and if $\underline{r}^* \cdot \underline{U} \leq T_2$, then the satellite is in darkness. Otherwise, it is in sunlight.

CALLING SEQUENCE

CALL SDFWOE (TIME, R, IX, RMAG)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	TIME	Time at which sunlight determination is made
I	R(3)	Position vector of the satellite — X, Y, Z
O	IX	Sunlight Determination = 0, satellite is in darkness = 1, satellite is in sunlight
I	RMAG	Magnitude of position vector R

Common

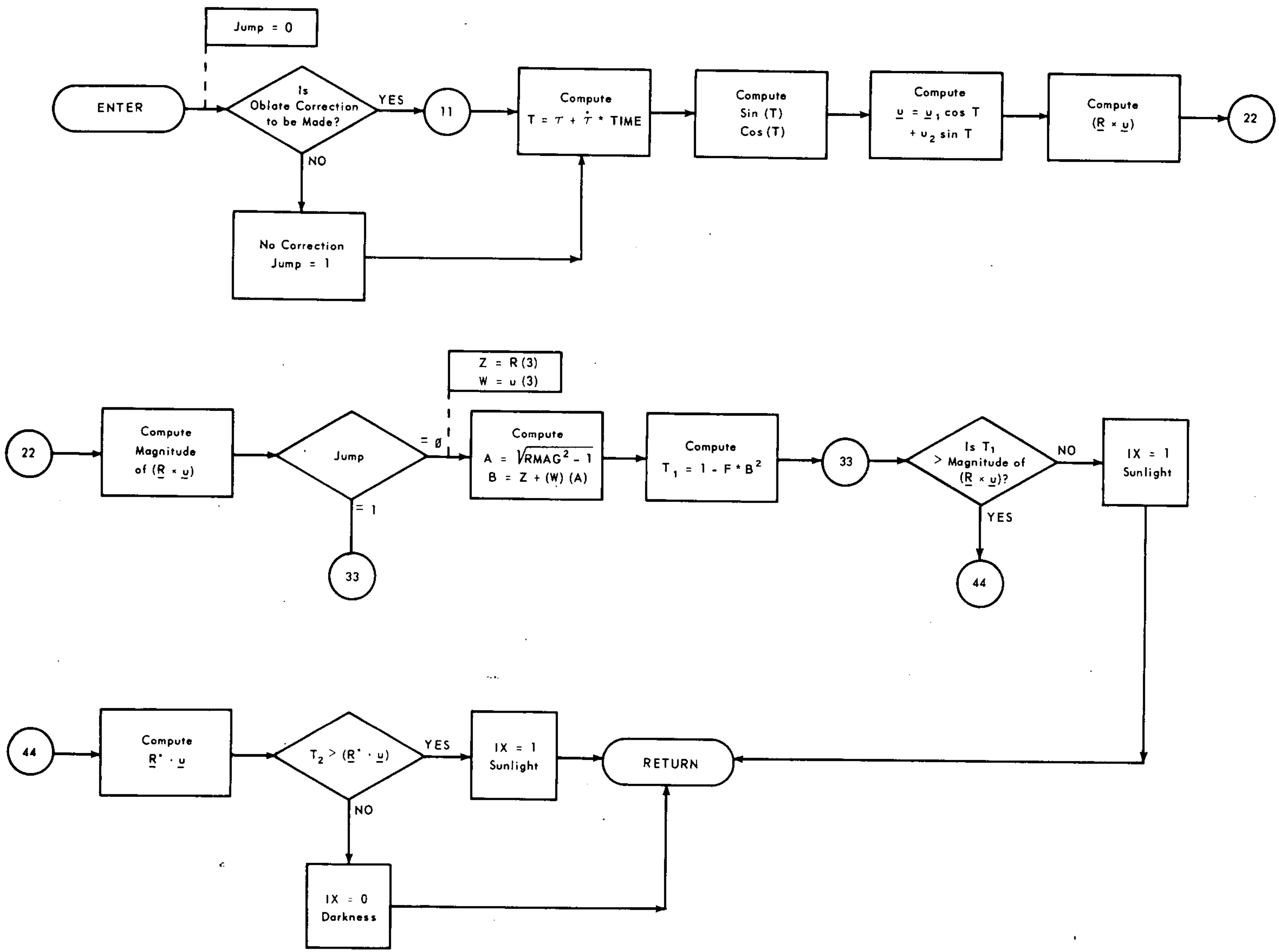
I/O	Block	Variable
I	BPOOL	TABLE(42) = F
I		TABLE(54) = X component of U_2
I		TABLE(55) = Y component of U_2
I		TABLE(56) = Z component of U_2
I		TABLE(57) = TAUDOT ($\dot{\tau}$)
I		TABLE(71) = X component of U_1
I		TABLE(72) = Y component of U_1
I		TABLE(73) = Z component of U_1
I		TABLE(74) = T2 (tolerance for R* · U)
I/O		TABLE(75) = T1 (tolerance for magnitude of RXU)
I	RADIAN	TAU (τ)

CALLED BY

GTRACE

CALLS

VECTOR
- VADD
- VDOT
- VMAG
- VPROD
- VUNIT
- VCROSS



SDFWOE Flowchart

SPACEL

Spacel Bulletin

PURPOSE

To provide key space element information in a condensed form.

CALLING SEQUENCE

CALL SPACEL (ISSUE, SPAC, DRG, NQ, T0, TPQ, NBPASS, NSPACE, SATID)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	ISSUE(4)	Issue Date
I	SPAC(487)	May consist of 54 of the following set of elements depending on the number of elements columns to be computed SPAC(1) = time SPAC(2) = anomalistic period SPAC(3) = derivative of anomalistic period SPAC(4) = perigee height SPAC(5) = apogee height SPAC(6) = inclination SPAC(7) = right ascension of ascending node SPAC(8) = argument of perigee SPAC(9) = mean anomaly Last SPAC(N) = 9999999999999999 (end of spacel)
I	DRG(60)	Drag time and parameters table
I	NQ	Number of drag inputs
I	T0	Epoch time
I	TPQ(56)	Table of column elements times
I	NBPASS	Request pass number
I	NSPACE	Number of days from space reference date (Sept. 18, 1957) to issue date

Arguments (continued)

I/O	Variable	Description
I	SATID(11)	SATID(1) - satellite ID number SATID(2) - year of reference SATID(11) - day count of reference date

Common

I/O	Block	Variable
I	OSCELE	OS(6) = Brouwer osculating elements
I	BPOOL	TABLE(2) = Km/CUL TABLE(16) = deg/rad TABLE(23) = 2 π TABLE(24) = BK TABLE(34) = π TABLE(40) = NSPAC = 0, no spacel osculating epoch elements output = 1, spacel osculating epoch elements output TABLE(41) = μ TABLE(59) = min/CUT

TAPE OUTPUT

```
                        GODDARD SPACE FLIGHT CENTER
                             SPACEL BULLETIN
                               MAR  3,1971
                               J.D.S. 4914

SATDESG NAME SL NRDN SBDAT  INJ.D.S. RVNEI OMAG KG/M2 RFDKCMFCW  CCNC
J.D.S. PERAN MOD  PER CERI PHTEQR APHTEQR INMCD RAANOD ARGPER MANCM C
UT2W   10.000 MIN MICROD/D KMX10  KMX10   1000G DEGRS  DEGRS  DEGRS S
X100   X1.000.000 X10.000  298.25 6378166 X1000 X1000  X1000  X1000 C

6806602 INJUN5 UW 3338  4914 3914 397 112921292
490600 011828889 3-000004C5 006701 0025327 80668 345393 092867 2075214
491300 011828848 4-00000438 006703 0025325 80668 340103 078814 2850103
492000 011828804 2-00000467 006709 0025318 80668 334814 064753 0026103
490600 011816131 1-00000393 006618 0025348C80665S345391C09 127U2072374
```

The first line of data contains the satellite identification number, satellite name and other information from the Spacel input card.

The following lines of data each contain:

1. Date measured from the Julian Date of Space

2. Anomalistic period in minutes, modulo 10,000, $X10^6$

3. Period derivative, microdays/day, $X10^4$

4. Perigee height relative to equatorial radius, kilometers, X10. Flattening = 1/298.25

5. Apogee height relative to equatorial radius, kilometers, X10. Equatorial radius = 6378.166

6. Inclination in degrees, modulo 100, X1000

7. Right ascension of ascending node in degrees, X1000

8. Argument of perigee in degrees, X1000

9. Mean anomaly in degrees, X1000

10. Check sum of line (last digit), modulo 10.

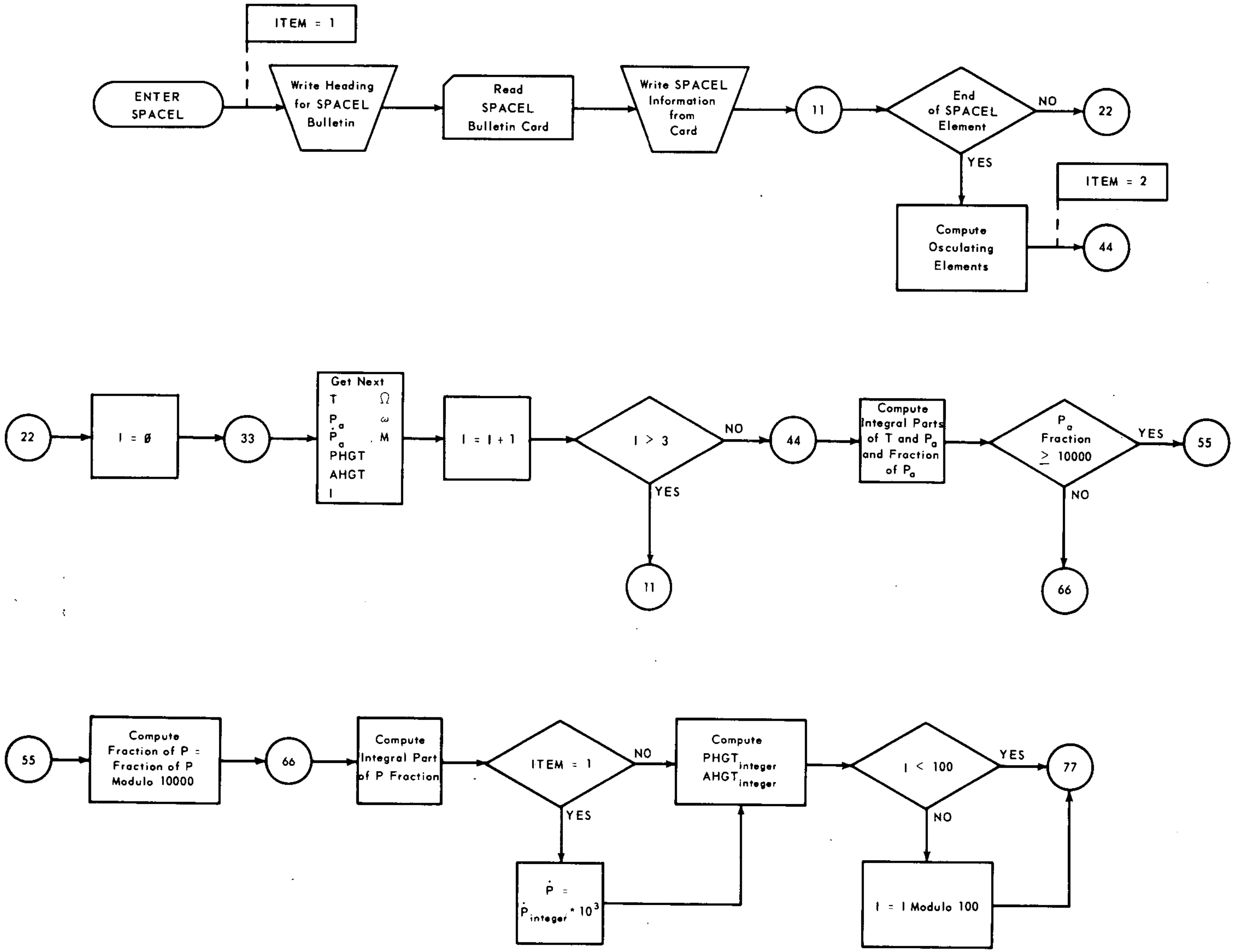
The last test line is computed by using the osculating elements at the start request time.

CALLED BY

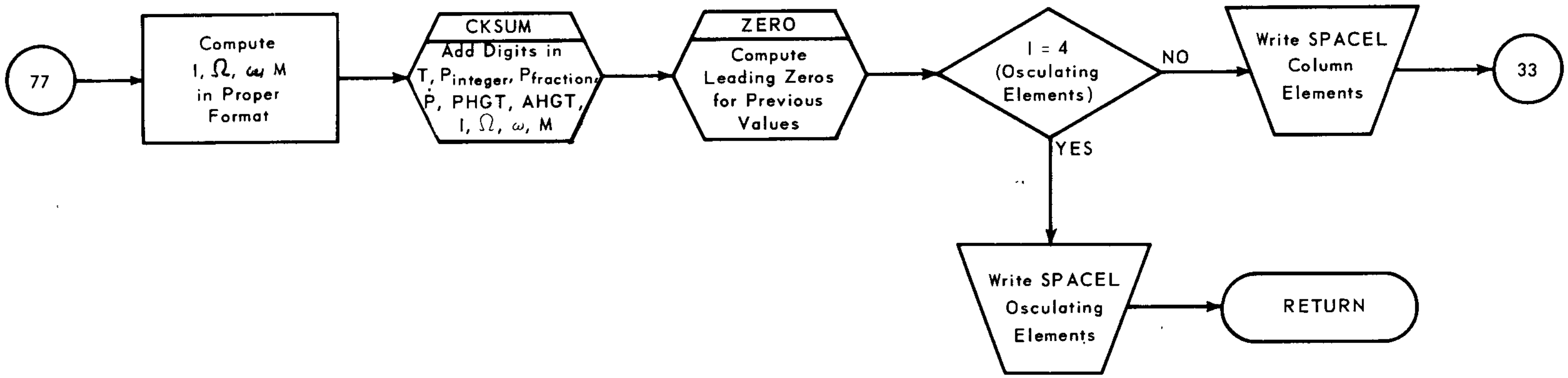
PRINT

CALLS

CKSUM
ZERO
BRWORB



SPACEL Flowchart



SPACEL Flowchart (continued)

PURPOSE

This routine determines sub-satellite point and height, i.e., a transformation from cartesian coordinates to position in the latitude-longitude coordinate system.

METHOD

As a first approximation the geocentric latitude is set equal to the satellite's declination, an iterative procedure is then employed to determine the geodetic latitude and height.

FORMULATION

$$\text{Sin}\ \delta = \frac{Z}{r}, \quad -\frac{\pi}{2} \le \delta \le \frac{\pi}{2}$$

$$\lambda'_E = a - \theta g - \omega_e t, \quad \lambda_E = \text{mod}\,(\lambda'_E, 2\pi), \quad 0 \le \lambda_E \le 2\pi$$

Set $\phi'_S = \delta$, where δ has already been determined, and continue calculating with

$$r_c = a_e \left[\frac{1 - (2f - f^2)}{1 - (2f - f^2)\cos^2 \phi'_S}\right]^{1/2} \tag{1}$$

$$\phi_S = \tan^{-1}\left[\frac{\tan \phi'_S}{(1 - f)^2}\right], \quad -\frac{\pi}{2} \le \phi_S \le \frac{\pi}{2}$$

$$H_S = [r^2 - r_c^2 \sin^2 (\phi - \phi'_S)]^{1/2} - r_c \cos(\phi_S - \phi'_S)$$

$$\Delta\phi'_S = \sin^{-1}\left[\frac{H_S}{r}\sin(\phi_S - \phi'_S)\right], \quad -\frac{\pi}{2} \le \Delta\phi'_S \le \frac{\pi}{2}.$$

Recalculate $\phi_s' = \delta - \Delta\phi_s'$ and return to Eq. (1). Repeat this loop until ϕ_s' no longer varies. This process is exact and rapidly convergent, and at the same time yields the ground trace geodetic latitude, ϕ.

CALLING SEQUENCE

```
CALL SSPTHT (WEDT, R, RMAG, RTASC, DEC, GEODL, GEOCL, LONG,
             ELONG, HEIGHT)
```

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	WEDT	ω_e (t - t_0) Earth's Rotation from Start Date
I	R(3)	X, Y, Z Satellite Position Vector
I	RMAG	Magnitude of Sat. Radial Vector
O	RTASC	Right Ascension — Deg.
O	DEC	Declination — Deg.
O	GEODL	Geodetic Latitude — Deg.
O	GEOCL	Geocentric Latitude — Deg.
O	LONG	Longitude $-\pi \leq$ LONG $\leq \pi$ measured from the Greenwich Meridian
O	ELONG	East Longitude (λ_E) — Deg. 0, 2π measured Eastward from Greenwich Meridian
O	HEIGHT	HEIGHT — Above the reference ellipsoid in km

Common

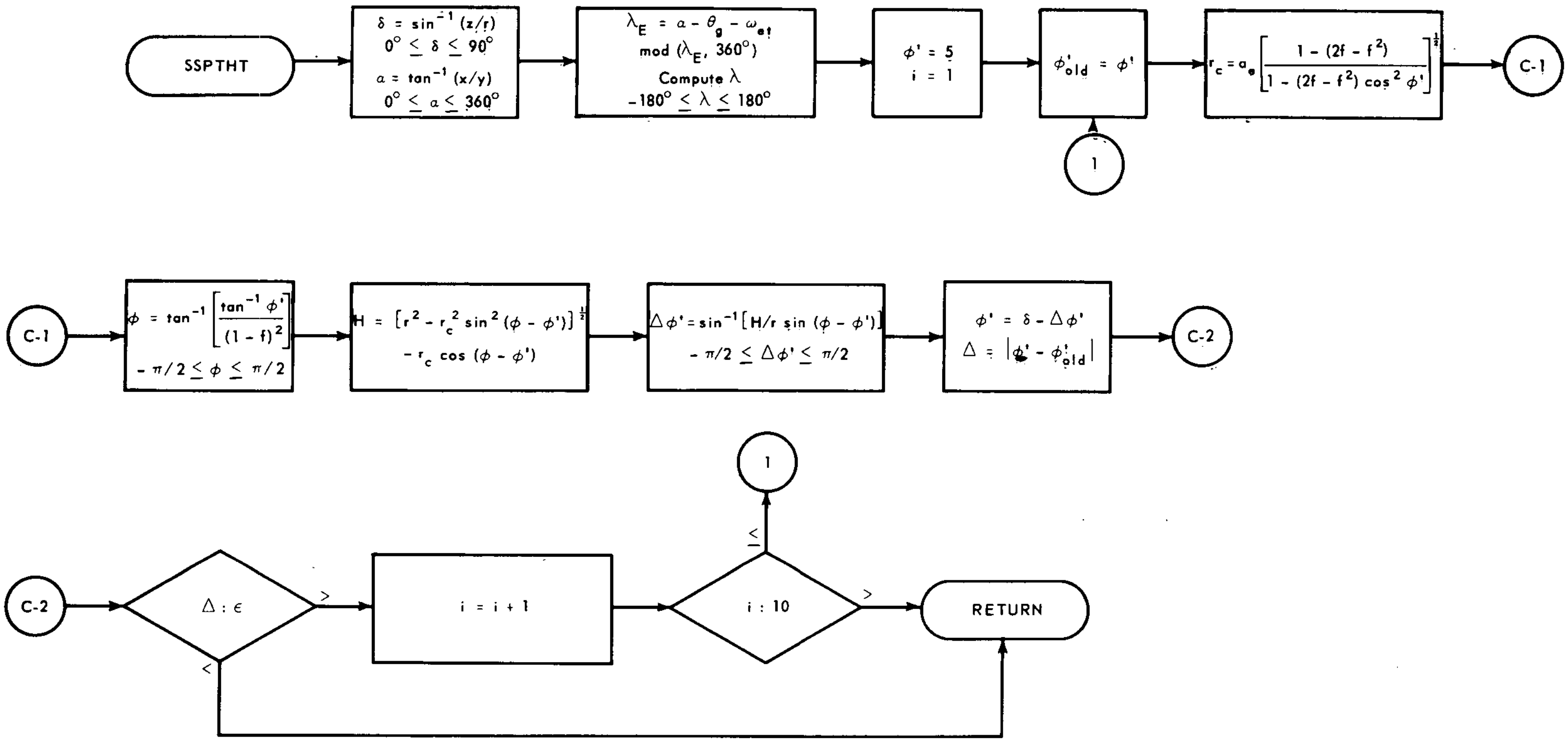
I/O	Block	Variable
I	SDT	GST — Greenwich Sidereal Time
I	BPOOL	TABLE(31) = $\epsilon \equiv .1 \times 10^{-11}$
		TABLE(9) = 1/f
		TABLE(2) = km/E.R.
		TABLE(42) = f
		TABLE(52) = $2f - f^2$

CALLED BY

GTRACE
NODALX
NSPT

CALLS

None



SSPTHT Flowchart

TIMETB

Brouwer Column Elements Time Table and Drag Load

PURPOSE

To handle the input of the column elements times and drags.

CALLING SEQUENCE

CALL TIMETB (SATID, NTPQ, KDELT, DATTIM, SECDRG, TPQ, CDRAG, NERROR, NJ)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	SATID(11)	SATID(1) = satellite ID number SATID(2) = year of reference SATID(11) = day count of reference date
O	NTPQ	Number of column times (or cards)
O	KDELT(4)	KDELT(1) and (3) - Number of columns to be computed per card (maximum of 2 cards) KDELT(2) and (4) - Column ΔT in minutes $\times$ 100
O	DATTIM(112)	DATTIM(1,3,5 ... 111) - Packed column date DATTIM(2,4,6 ... 112) - Packed column time
O	SECDRG(112)	SECDRG(1,3,5 ... 111) - Column seconds SECDRG(2,4,6 ... 112) - Column hr, min, sec in seconds
O	TPQ(56)	Column times in CUT
O	CDRAG(112)	Column drag parameters ($N_{2,q}$, $N_{3,q}$)
O	NERROR	Error indicator = 0 no error = -1 error on column card
O	NJ	Number of column times plus one

Common

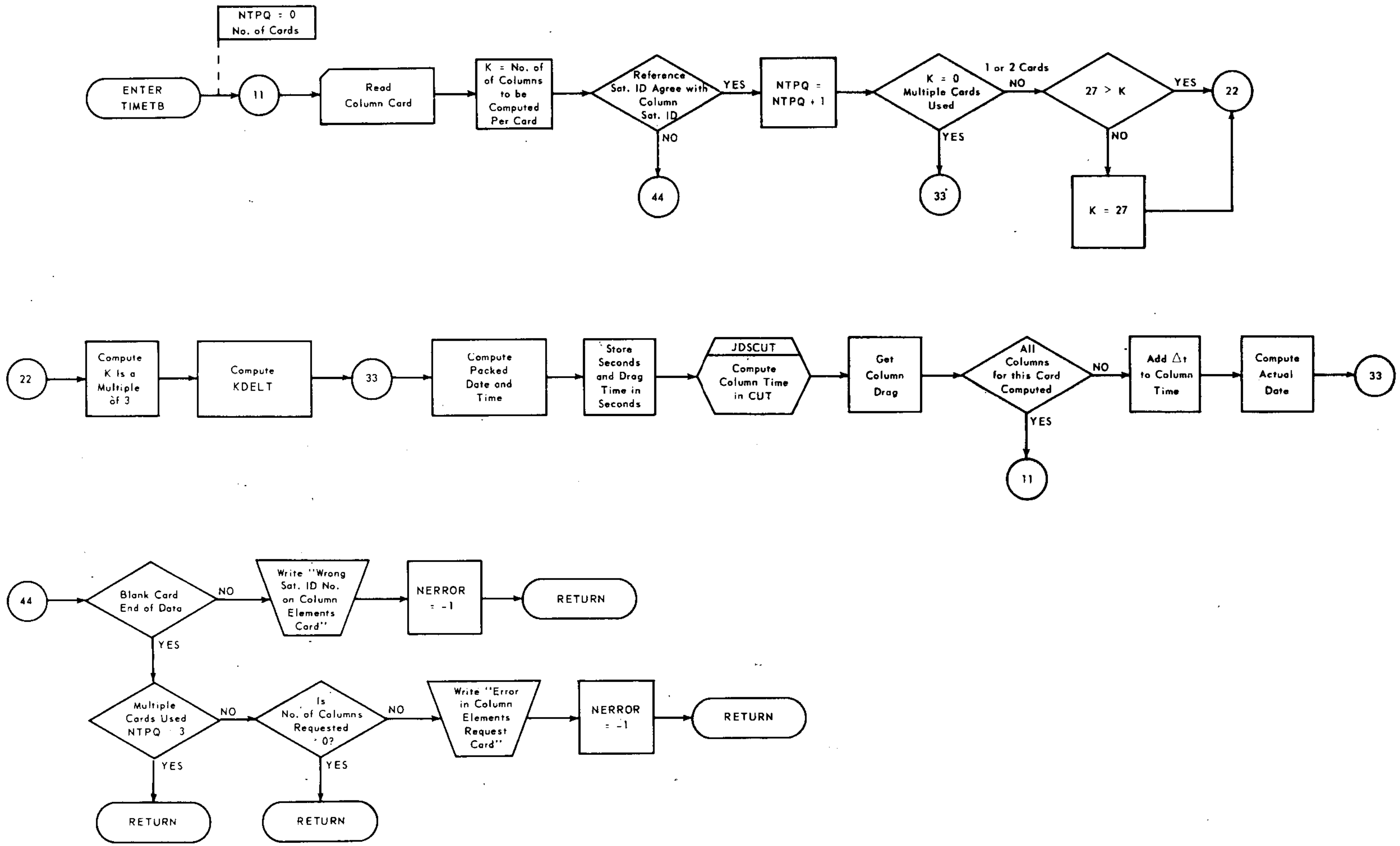
I/O	Block	Variable
I	BPOOL	TABLE(5) = sec/CUT TABLE(30) = sec/day

CALLED BY

MAIN

CALLS

DREFOD
JDSCUT
JULHMS
DATE



TIMETB Flowchart

UTGST

PURPOSE

This routine calculates the Greenwich sidereal time.

METHOD

Calculate the Greenwich sidereal time at 0^{hr} U.T. of Date and add the amount of rotation in the hours, minutes, and seconds elapsed since 0^{hr} U.T. of Date.

FORMULATION

The Greenwich sidereal time at 0^{hr} U.T. is given by

$$\theta g_0 = 99.^\circ6909833 + 36000.^\circ7689\ T_u + 0.^\circ00038708\ T_u^2$$

where the time is measured in centurie as

$$T_u = \frac{J.D. - 2415020.0}{36525}$$

and we have for the Greenwich sidereal time

$$\theta g = \theta g_0 + \omega_e (t - t_0)$$

where ω_e is the earth's rotation in deg/min

$(t - t_0)$ is the number of minutes elapsed since 0^{hr} U.T.

CALLING SEQUENCE

CALL UTGST (YY, MM, DY, HR, MIN, SEC)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	YY	Year
I	MM	Month
I	DY	Day
I	HR	Hour
I	MIN	Minute
I	SEC	Second

Common

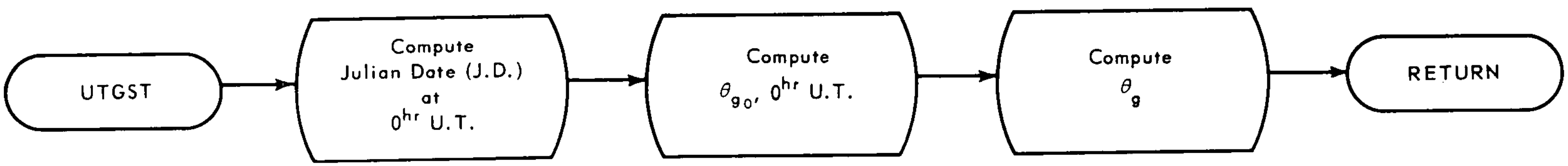
I/O	Block	Variable
O	SDT	GST, GST0 - (θg, θg_0)
I	BPOOL	TABLE(69) - ω_e

CALLED BY

MAIN

CALLS

None



UTGST Flowchart

UVIJK

PURPOSE

Maps the radius vector to the satellite from the orbital (orthogonal set u, v , w) to the equatorial coordinate system.

METHOD

Call subroutine UV (I, G, H, NU, U, V) to obtain u, v unit vectors in the orbital plane then calculate the positional vector and the velocity vector in the inertia system.

FORMULATION

$$r = r u, r = a(1 - e \cos E)$$

$$v_r = \sqrt{\mu a} / r \; e \; \text{Sin} \; \dot{E}, \quad v_T = \frac{\sqrt{\mu a (1 - e^2)}}{r}$$

$$\dot{r} = v_r u + v_T v$$

CALLING SEQUENCE

CALL UVIJK (A, ECC, I, G, H, F, E, R, DR, U, V, RMAG, DRMAG)

INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	A	Semimajor axis (e.r.)
I	ECC	Eccentricity
I	I	Orbital inclination
I	G	Argument of perigee
I	H	Longitude of the ascending node
I	F	True anomaly
I	E	Eccentric anomaly

Arguments (continued)

I/O	Variable	Description
O	R	Sat. radial vector
O	DR	Sat. vel. vector
O	U	P(I, G & F, H) $\equiv$ r/r
O	V	Q(I, G & F, H)
O	RMAG	r magnitude of radial vector
O	DRMAG	v magnitude of vel. vector

Common

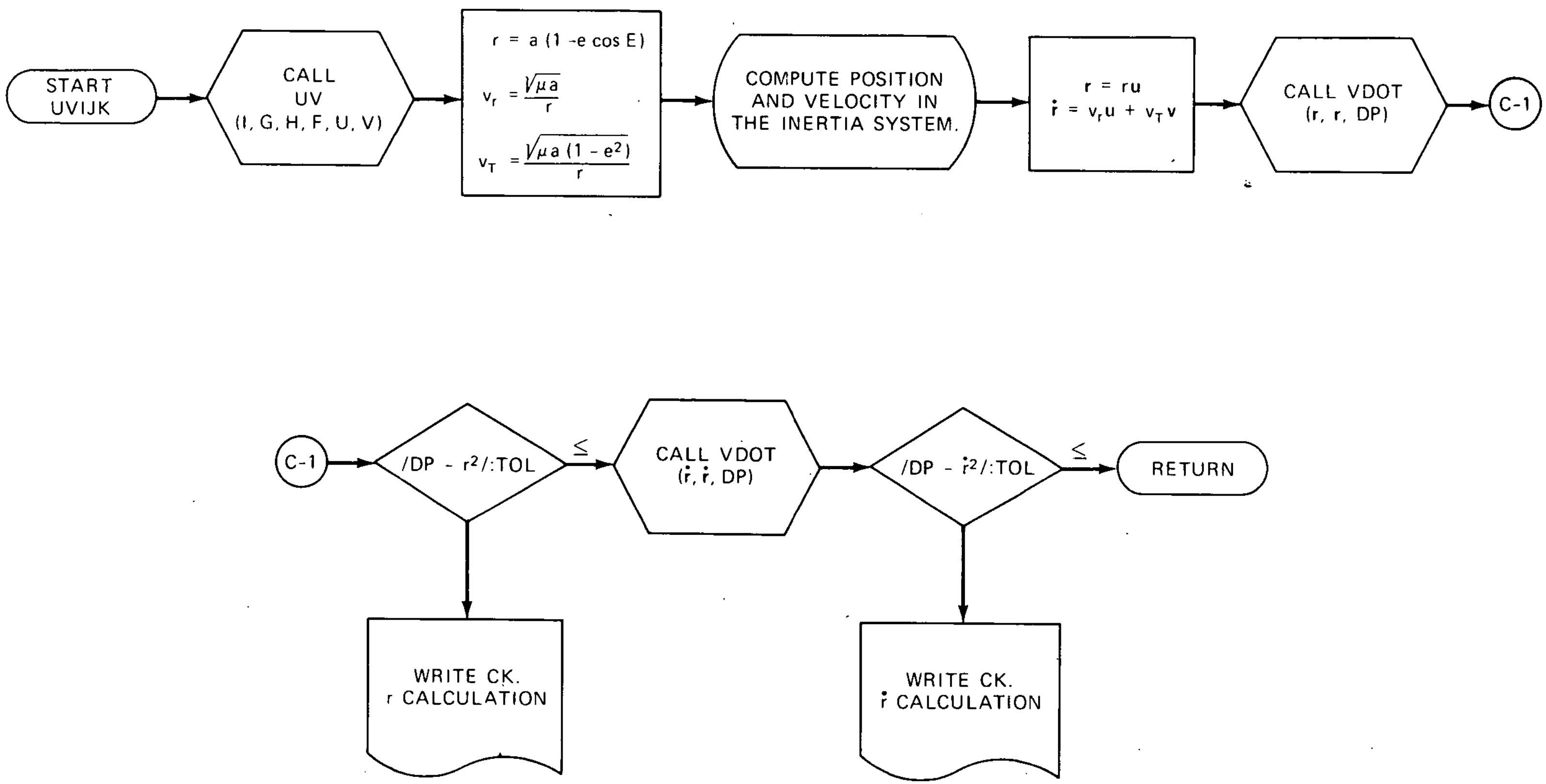
I/O	Block	Variable
I	BPOOL	TABLE(31) = $\epsilon \equiv .1 \times 10^{-11}$
I	BPOOL	TABLE(41) $\equiv \mu$
O	VTVR	VT(3) Transverse velocity component vector
O	VTVR	VR(3) Radial velocity component vector

CALLED BY

BRWORB

CALLS

VDOT



UVIJK Flowchart

VECTOR

Vector Operations Package

PURPOSE

VECTOR performs the following vector operations:

- Performs addition of two vectors.
- Computes the cross product of two vectors.
- Computes the dot product of two vectors.
- Computes the magnitude of a vector.
- Computes the product of a scalar and a vector.
- Performs subtraction of two vectors.
- Computes the unit vector along a given vector.

METHOD

VADD — Performs addition of two vectors.

The vector sum, $\underline{S} = (S_1, S_2, S_3)$, of the two given vectors, $\underline{A} = (A_1, A_2, A_3)$ and $\underline{B} = (B_1, B_2, B_3)$, is computed as follows:

$$S_1 = A_1 + B_1$$

$$S_2 = A_2 + B_2$$

$$S_3 = A_3 + B_3$$

VCROSS — Computes the cross product of two vectors.

The cross product vector, $\underline{C} = (C_1, C_2, C_3)$, of the two given vectors, $\underline{A} = (A_1, A_2, A_3)$ and $\underline{B} = (B_1, B_2, B_3)$, is computed as follows:

$$C_1 = A_2 B_3 - A_3 B_2$$

$$C_2 = A_3 B_1 - A_1 B_3$$

$$C_3 = A_1 B_2 - A_2 B_1$$

VDOT — Computes the dot product of two vectors.

The dot product, $\underline{A} \cdot \underline{B}$, of the two given vectors, $\underline{A} = (A_1, A_2, A_3)$ and $\underline{B} = (B_1, B_2, B_3)$, is given by:

$$A \cdot B = A_1 B_1 + A_2 B_2 + A_3 B_3$$

VMAG — Computes the magnitude of a vector.

The magnitude A of the given vector, $\underline{A} = (A_1, A_2, A_3)$, is computed as follows:

$$A = (A_1^2 + A_2^2 + A_3^2)^{1/2}$$

VPROD — Computes the product of a scalar and a vector.

The product vector, $P = (P_1, P_2, P_3)$, of the scalar, a, and the vector, $A = (A_1, A_2, A_3)$, is computed as follows:

$$P_1 = a A_1$$

$$P_2 = a A_2$$

$$P_3 = a A_3$$

VSUB — Performs subtraction of two vectors.

The vector difference, $\underline{D} = (D_1, D_2, D_3)$, of the two given vectors, $\underline{A} = (A_1, A_2, A_3)$ and $\underline{B} = (B_1, B_2, B_3)$, is computed as follows:

$$D_1 = A_1 - B_1$$

$$D_2 = A_2 - B_2$$

$$D_3 = A_3 - B_3$$

VUNIT — Computes the unit vector along a given vector.

The unit vector $\underline{A}^* = (A_1^*, A_2^*, A_3^*)$ along the vector $\underline{A} = (A_1, A_2, A_3)$ is given by:

$$A_1^* = \frac{A_1}{|\underline{A}|}$$

$$A_2^* = \frac{A_2}{|\underline{A}|}$$

$$A_3^* = \frac{A_3}{|\underline{A}|}$$

where

$$|\underline{A}| = (A_1^2 + A_2^2 + A_3^2)^{1/2}$$

CALLING SEQUENCE

```
CALL VADD (A, B, APLUSB)
CALL VCROSS (A, B, ACRSSB)
CALL VDOT (A, B, ADOTB)
CALL VMAG (A, AMAG)
CALL VPROD (A, SCALAR, PROD)
CALL VSUB (A, B, AMNSB)
CALL VUNIT (A, AUNIT)
```

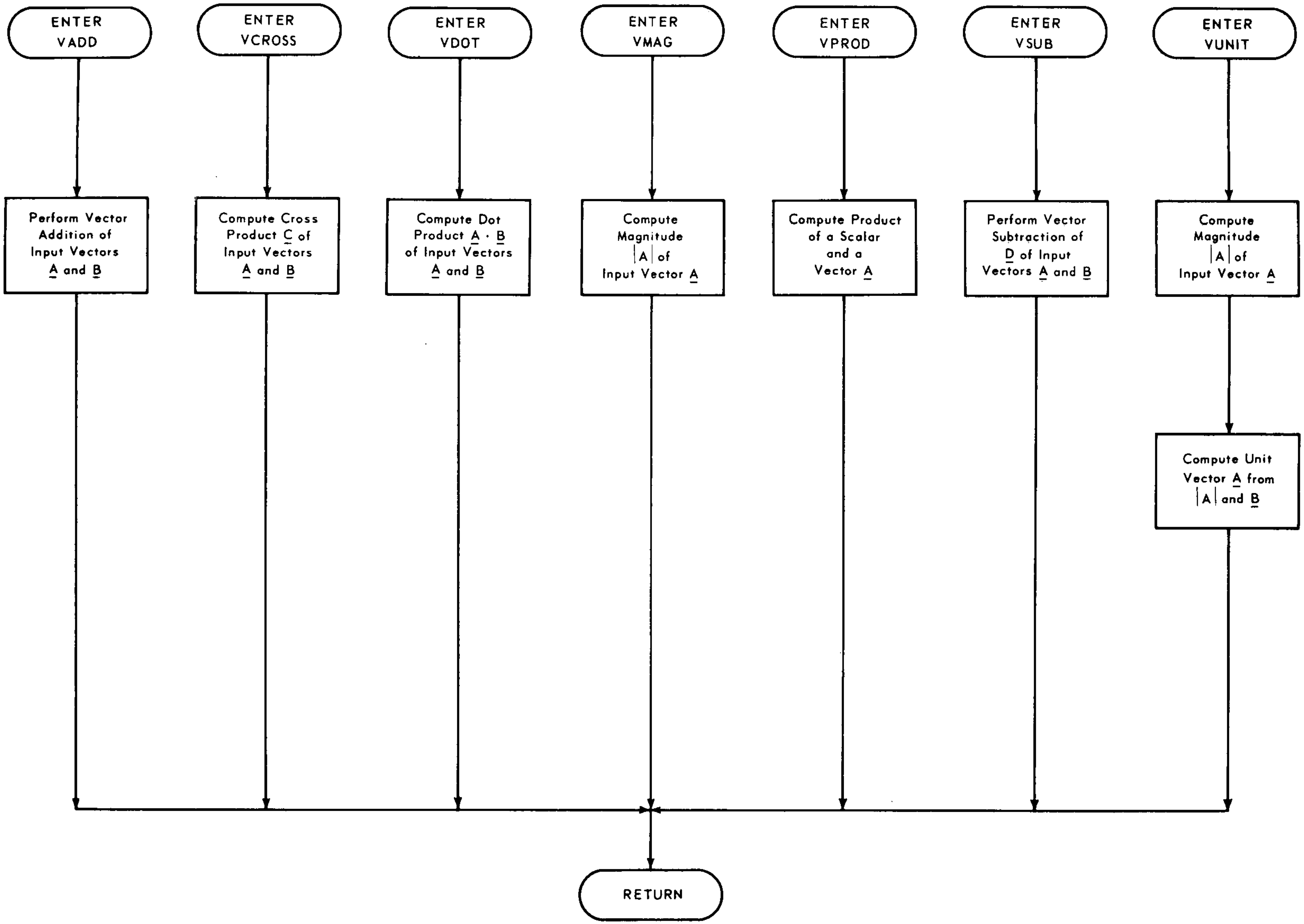
INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	A(3)	Input vector on which a vector operation is to be performed
I	B(3)	Input vector on which vector operation is to be performed
O	APLUSB	Vector sum of A and B
O	ACRSSB	Cross product of vectors A and B
O	ADOTB	Dot product of vectors A and B
O	AMAG	Magnitude of A
I	SCALAR	Scalar input to be multiplied by the vector A
O	PROD	Product of the scalar and vector A
O	AMNSB	Vector difference of A and B
O	AUNIT	Unit vector along vector A

CALLED BY

ELCON0
PQIJK
PQUV
SDFWOE
UVIJK



VECTOR Flowchart

WMAPLD

World Map Request Load

PURPOSE

To handle input for the world map (equator crossings and one orbit ephemeris).

CALLING SEQUENCE

CALL WMAPLD (REQUST, START, END, SATID, JDREQ, RUNID, NERROR)

INPUT/OUTPUT

Arguments

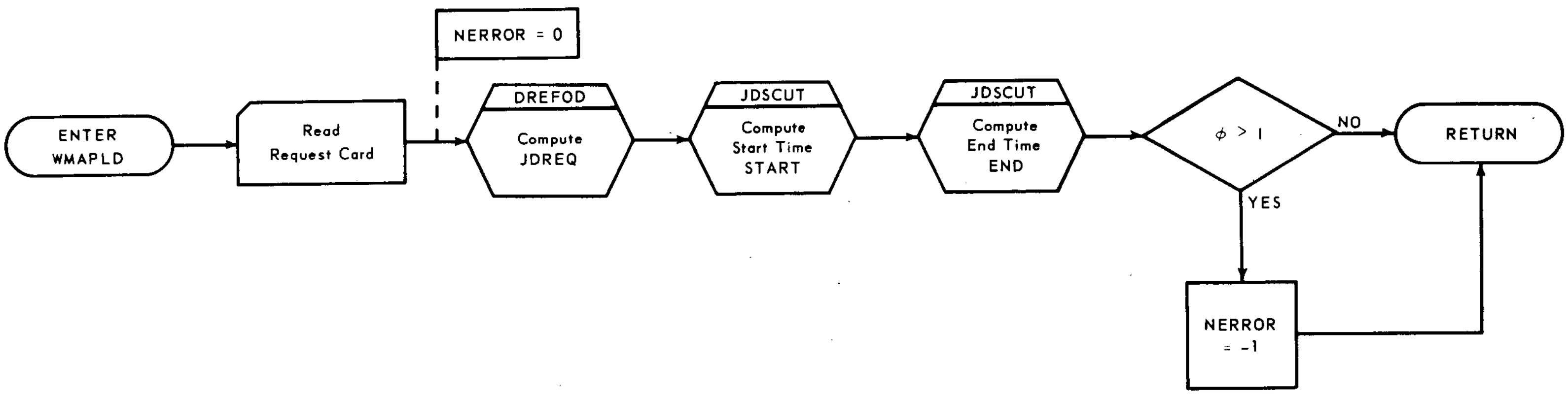
I/O	Variable	Description	
O	REQUST(15)	REQUST(1) = Year REQUST(2) = Month REQUST(3) = Day REQUST(4) = Hour REQUST(5) = Minutes REQUST(6) = Seconds	Start Time of WMAP Request
		REQUST(7) = Year REQUST(8) = Month REQUST(9) = Day REQUST(10) = Hour REQUST(11) = Minutes REQUST(12) = Seconds	End Time of WMAP Request
		REQUST(13) = Latitude increment REQUST(14) = Inclination REQUST(15) = Pass number	
O	START	Start time of request in CUT	
O	END	End time of request in CUT	
I	SATID(11)	SATID(2) = Reference year SATID(11) = Day count of reference date	
O	JDREQ	Number of days from date of reference to start date of request	
O	NERROR	Error indicator = 0 no error = -1 latitude increment > inclination	

CALLED BY

MAIN

CALLS

DREFOD
JDSCUT



WMAPLD Flowchart

ZERO

Zero Print

PURPOSE

To print leading zeroes of an integer on the IBM 360 computer.

CALLING SEQUENCE

CALL ZERO (N, IIN, AREA)

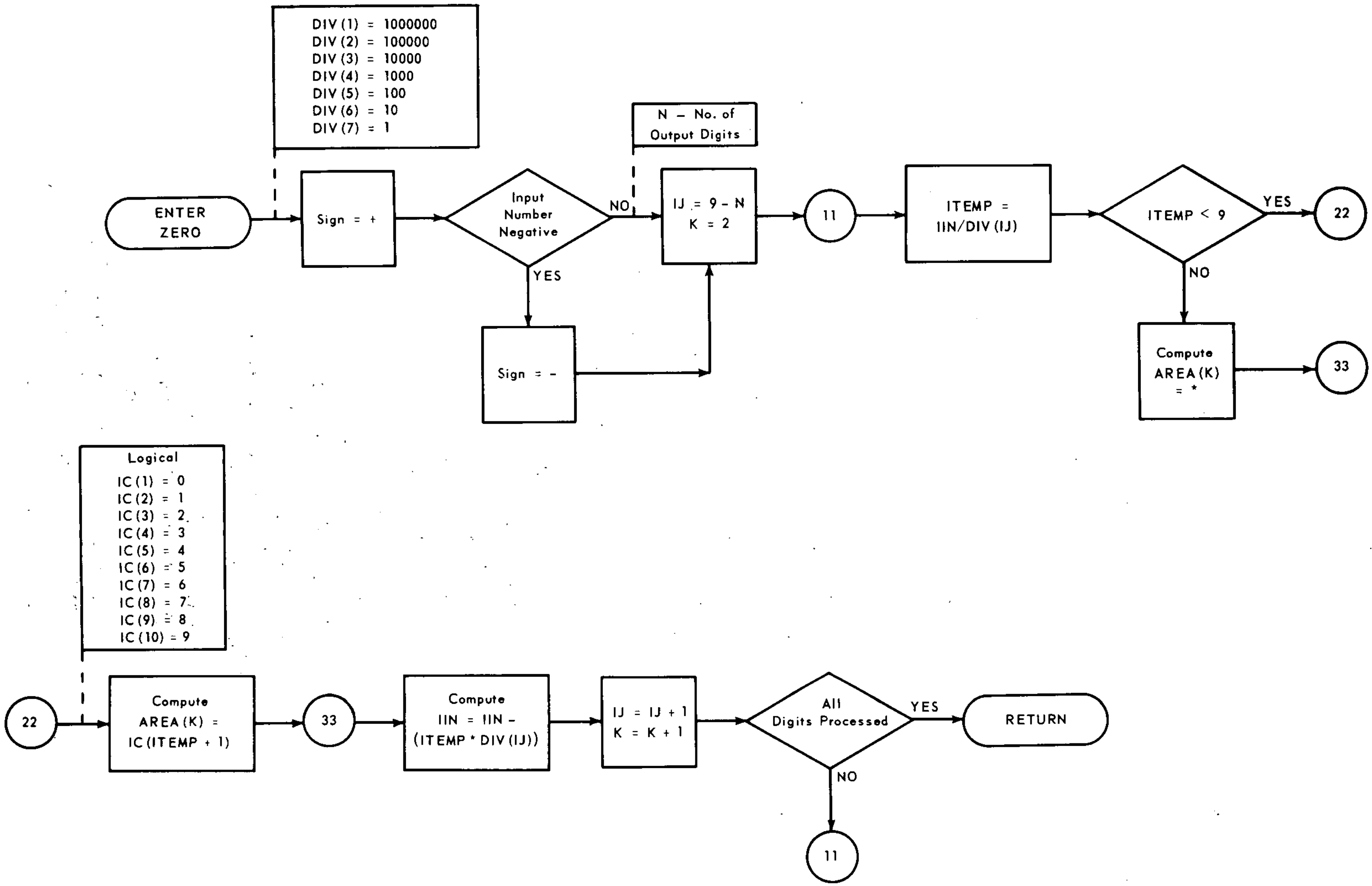
INPUT/OUTPUT

Arguments

I/O	Variable	Description
I	N	Number of output digits (including the sign) that is desired — maximum is 8
I	IIN	Input number
O	AREA(8)	AREA(1) = Sign of the output number AREA(2)-(8) = digits of output number including leading zeroes.

CALLED BY

SPACEL



ZERO Flowchart

BLOCK DATA

PURPOSE

To assign values to frequently used constants which do not have to be computed.

OUTPUT

Common

Block	Variable
BPOOL	TABLE(1) = meter/ft TABLE(2) = km/CUL TABLE(3) = mile/nautical mile TABLE(4) = km/A.U. TABLE(5) = sec/CUT TABLE(6) = velocity of light (km/sec) TABLE(7) = sun mass/earth mass TABLE(8) = earth mass/moon mass TABLE(9) = 1/f (flattening coefficient) TABLE(10) = Pressure of sunlight TABLE(11) = ω_e - earth rotation (rad/sec) TABLE(12) = J_2 TABLE(13) = J_3 TABLE(14) = J_4 TABLE(15) = J_5 TABLE(16) = deg/rad TABLE(17) = Deg TABLE(18) = Min Obliquity of Ecliptic TABLE(19) = Sec TABLE(20) = Mean long. of sun (deg/day) TABLE(21) = km/mile TABLE(22) = Radius of earth in CUL TABLE(23) = 2π TABLE(24) = GM = μ^2 TABLE(25) = knots/mi/hr TABLE(26) = km/n.m. TABLE(27) = Lunar distance (CUL) TABLE(28) = GM (km^3/sec^2)

Common (continued)

Block	Variable
BPOOL	TABLE(29) = Solar distance (CUL) TABLE(30) = sec/day TABLE(31) = Tolerance for orbit generator TABLE(32) = sec/hr TABLE(33) = deg/hr TABLE(34) = π TABLE(35) = min/day TABLE(36) = ID for sator code TABLE(37) = Radio frequency TABLE(38) = Radio frequency TABLE(39) = Radio frequency TABLE(40) = SPACEL osculating epoch elements output option = 0 do not compute SPACEL osculating elements = 1 compute SPACEL osculating elements

C. COMMON BLOCK VARIABLE DESCRIPTION

The following section contains the COMMON block descriptions of the COMMON areas used in the Goddard Brouwer Orbit Bulletin program. These descriptions include the variables contained in these areas, their meaning, and the subroutine which defines each variable.

1. BULLETIN COMMON Blocks

This section contains a description of all the COMMON areas used in the BULLETIN program.

/BPOOL/

COMMON/BPOOL/TABLE(80)

Variable	Value	Description	Program Where Defined
TABLE		Table of Constants	
TABLE(1)	.30480	meters/foot	BLOCK DATA
TABLE(2)	.6378.1660	kilometers/Canonical Unit of Length	BLOCK DATA
TABLE(3)	1852.0	meters/nautical mile	BLOCK DATA
TABLE(4)	149598600.0	kilometers/astronomical unit	BLOCK DATA
TABLE(5)	806.812418099482	seconds/Canonical Unit of Time	BLOCK DATA
TABLE(6)	299792.5	velocity of light in km/sec	BLOCK DATA
TABLE(7)	332948.55	ratio of sun mass/earth mass	BLOCK DATA
TABLE(8)	81.3	ratio of earth mass/moon mass	BLOCK DATA
TABLE(9)	298.250	1/flattening coefficient (f)	BLOCK DATA
TABLE(10)	.000045	pressure of sunlight	BLOCK DATA
TABLE(11)	.0000729211510	ω_e - earth rotation in rad/sec	BLOCK DATA
TABLE(12)	.001082480	J_2	BLOCK DATA
TABLE(13)	-.00000256	J_3	BLOCK DATA
TABLE(14)	-.00000184	J_4	BLOCK DATA
TABLE(15)	-.00000006	J_5	BLOCK DATA
TABLE(16)	57.29577951308232	degrees/radian	BLOCK DATA
TABLE(17)	23.0	degrees } Obliquity of Ecliptic	BLOCK DATA
TABLE(18)	26.0	minutes } Obliquity of Ecliptic	BLOCK DATA
TABLE(19)	34.795	seconds } Obliquity of Ecliptic	BLOCK DATA
TABLE(20)	.9856470	mean longitude of sun in deg/day	BLOCK DATA
TABLE(21)	1.609344	kilometers/mile	BLOCK DATA
TABLE(22)	1.0	R - radius of the earth in CUL (e.r.)	BLOCK DATA
TABLE(23)	6.283185307179586	2π (360° in radians)	BLOCK DATA

/BPOOL/ (continued)

Variable	Value	Description	Program Where Defined
TABLE(24)	1.0	GM = μ^2 (Gaussian constant)	BLOCK DATA
TABLE(25)	1.152	knots/mile/hr	BLOCK DATA
TABLE(26)	1.852	kilometers/nautical mile	BLOCK DATA
TABLE(27)	60.266011	lunar distance in CUL	BLOCK DATA
TABLE(28)	398603.2	GM* (km^3/sec^2)	BLOCK DATA
TABLE(29)	234658.04	solar distance in CUL	BLOCK DATA
TABLE(30)	86400.0	seconds/day	BLOCK DATA
TABLE(31)	.000000000001	tolerance	BLOCK DATA
TABLE(32)	3600.0	seconds/hour	BLOCK DATA
TABLE(33)	15.0	degrees/hour	BLOCK DATA
TABLE(34)	3.141592653589793	π (180° in radians)	BLOCK DATA
TABLE(35)	1440.0	minutes/day	BLOCK DATA
TABLE(36)	0.0	indicator for sater code = 0 compute sater code > 0 no sator code	BLOCK DATA
TABLE(37)	0.0	radio frequency	BLOCK DATA
TABLE(38)	0.0	radio frequency	BLOCK DATA
TABLE(39)	0.0	radio frequency	BLOCK DATA
TABLE(40)	1.0	indicator for SPACEL osculating elements = 1 compute osculating elements = 0 no SPACEL osculating elements	BLOCK DATA
TABLE(41)	1.0	μ	POOL
TABLE(42)	f	flattening coefficient	POOL
TABLE(43)	(1 - f) * R	B - polar radius of the earth	POOL
TABLE(44)	(km/A.U.)/(km/CUL)	CUL/astronomical unit	POOL
TABLE(45)	(sec/day)/(sec/CUT)	CUT/day	POOL
TABLE(46)	(sec/hr)/(sec/CUT)	CUT/hr	POOL
TABLE(47)	(km/CUL)/(sec/CUT)	Convert CUL/CUT to kilometers/second	POOL
TABLE(48)	(km/CUL)/(sec/CUT) * (sec/hr)	Convert CUL/CUT to kilometers/hour	POOL
TABLE(49)	ω_e in rad/sec * (sec/CUT)	earth rotation in rad/CUT	POOL
TABLE(50)	(km/CUL)/(km/mi)	miles/CUL	POOL
TABLE(51)	(mi/CUL) * (CUT/hr)	Convert CUL/CUT to miles/hour	POOL
TABLE(52)	$2f - f^2$	e^2 - eccentricity of the earth squared	POOL
TABLE(53)	e	e - eccentricity of the earth	POOL
TABLE(54)	0.0	X component of U2	POOL
TABLE(55)	cos ϵ	Y component of U2	POOL

/BPOOL/ (continued)

Variable	Value	Description	Program Where Defined
TABLE(56)	sin ϵ	Z component of U2	POOL
TABLE(57)	rate of change of the mean long. of sun in rad/CUT	$\dot{\tau}$ - rate of change of the mean longitude of sun in rad/CUT	POOL
TABLE(58)	$J_2 * R^2 * 3/2$	J	POOL
TABLE(59)	(sec/CUT)/60	minutes/CUT	POOL
TABLE(60)	(km/CUL)/(sec/CUT) * 1000	Convert CUL/CUT to meters/second	POOL
TABLE(61)	$J_2 * R^2/2$	K_2	POOL
TABLE(62)	$-J_3 * R^3$	K_3	POOL
TABLE(63)	$-J_4 * R^4 * (3/8)$	K_4	POOL
TABLE(64)	$-J_5 * R^5$	K_5	POOL
TABLE(65)	(deg/hr)/(deg/rad)	radian/hour	POOL
TABLE(66)	(meters/ft) * 1000	kilometers/foot	POOL
TABLE(67)	.40915751	ϵ - obliquity of ecliptic in radians	POOL
TABLE(68)	1.0	KMULT for drag	POOL
TABLE(69)	ω_e in rad/sec * (deg/rad) * 60	earth rotation in degrees/minutes	POOL
TABLE(70)	1/(min/CUT)	CUT/minute	POOL
TABLE(71)	1.0	X component of U1	POOL
TABLE(72)	0.0	Y component of U1	POOL
TABLE(73)	0.0	Z component of U1	POOL
TABLE(74)	0.0	tolerance for R · U	POOL
TABLE(75)	1.0	tolerance for magnitude RXU	POOL
TABLE(76)-(80)	0.0	not used	POOL

/DAFPRM/

COMMON/DAFPRM/LDAF(13)

Variable	Description	Program Where Defined
LDAF(13)	Intermediate values from BRWORB used in computing the Data Acquisition Facility Parameters	BRWORB

$$LDAF_1 = \left\{ \frac{1}{8} \gamma_2' e'' \eta^2 [1 - 11\theta^2 - 40\theta^4 (1 - 5\theta^2)^{-1}] \right.$$

$$\left. - \frac{5}{12} \frac{\gamma_4'}{\gamma_2'} e'' \eta^2 [1 - 3\theta^2 - 8\theta^4 (1 - 5\theta^2)^{-1}] \right\}$$

$$LDAF_2 = \left\{ \frac{1}{4} \frac{\gamma_3'}{\gamma_2'} \eta^2 \sin I'' \right.$$

$$\left. + \frac{5}{64} \frac{\gamma_5'}{\gamma_2' \eta^2} \sin I'' (4 + 3e''^2) [1 - 9\theta^2 - 24\theta^4 (1 - 5\theta^2)^{-1}] \right\}$$

$$LDAF_3 = - \frac{35}{384} \frac{\gamma_5'}{\gamma_2'} e''^2 \eta^2 \sin I'' [1 - 5\theta^2 - 16\theta^4 (1 - 5\theta^2)^{-1}]$$

$$LDAF_4 = \left\{ \frac{1}{8} \gamma_2' \eta^3 [1 - 11\theta^2 - 40\theta^4 (1 - 5\theta^2)^{-1}] \right.$$

$$\left. - \frac{5}{12} \frac{\gamma_4'}{\gamma_2'} \eta^3 [1 - 3\theta^2 - 8\theta^4 (1 - 5\theta^2)^{-1}] \right\}$$

$$LDAF_5 = \left\{ - \frac{1}{4} \frac{\gamma_3'}{\gamma_2'} \frac{\eta^3}{e''} \sin I'' \right.$$

$$\left. - \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} \frac{\eta^3}{e''} \sin I'' (4 + 9e''^2) [1 - 9\theta^2 - 24\theta^4 (1 - 5\theta^2)^{-1}] \right\}$$

$$LDAF_6 = \frac{35}{384} \frac{\gamma_5'}{\gamma_2'} \eta^3 e'' \sin I'' [1 - 5\theta^2 - 16\theta^4 (1 - 5\theta^2)^{-1}]$$

$$LDAF_7 = \left\{ -\frac{1}{16}\gamma_2' \left[+ (2 + e''^2) - 11 (2 + 3e''^2)\theta^2 - 40 (2 + 5e''^2)\theta^4 (1 - 5\theta^2)^{-1} \right.\right.$$

$$\left. - 400 e''^2 \theta^6 (1 - 5\theta^2)^{-2} \right] + \frac{5}{24}\frac{\gamma_4'}{\gamma_2'} \left[2 + e''^2 - 3 (2 + 3e''^2)\theta^2 \right.$$

$$\left.\left. - 8 (1 + 5e''^2)\theta^4 (1 - 5\theta^2)^{-1} - 80 e''^2 \theta^6 (1 - 5\theta^2)^{-2} \right] \right\}$$

$$LDAF_8 = \left\{ \frac{1}{4}\frac{\gamma_3'}{\gamma_2'} \left(\frac{\sin I''}{e''} - \frac{e''\theta^2}{\sin I''} \right) + \frac{5}{64}\frac{\gamma_5'}{\gamma_2'} \right.$$

$$\times \left[\left(\frac{\eta^2 \sin I''}{e''} - \frac{e''\theta^2}{\sin I''} \right) (4 + 3e''^2) + e'' \sin I'' (26 + 9e''^2) \right] \left[1 - 9\theta^2 \right.$$

$$\left. - 24\theta^4 (1 - 5\theta^2)^{-1} \right] - \frac{15}{32}\frac{\gamma_5'}{\gamma_2'} e''\theta^2 \sin I'' (4 + 3e''^2)$$

$$\left. \left[3 + 16\theta^2 (1 - 5\theta^2)^{-1} + 40\theta^4 (1 - 5\theta^2)^{-2} \right] \right\}$$

$$LDAF_9 = \left\{ -\frac{35}{1152}\frac{\gamma_5'}{\gamma_2'} \left[e'' \sin I'' (3 + 2e''^2) - \frac{e''^3 \theta^2}{\sin I''} \right] \left[1 - 5\theta^2 \right.\right.$$

$$\left. - 16\theta^4 (1 - 5\theta^2)^{-1} \right] + \frac{35}{576}\frac{\gamma_5'}{\gamma_2'} e''^3 \theta^2 \sin I'' \left[5 + 32\theta^2 (1 - 5\theta^2)^{-1} \right.$$

$$\left.\left. + 80\theta^4 (1 - 5\theta^2)^{-2} \right] \right\}$$

$$LDAF_{10} = \left\{ -\frac{1}{8}\gamma_2' e''^2 \theta \; [11 + 80\theta^2 (1 - 5\theta^2)^{-1} + 200\theta^4 (1 - 5\theta^2)^{-2}] \right.$$

$$\left. + \frac{5}{12}\frac{\gamma_4'}{\gamma_2'} e''^2 \theta \; [3 + 16\theta^2 (1 - 5\theta^2)^{-1} + 40\theta^4 (1 - 5\theta^2)^{-2}] \right\}$$

$$LDAF_{11} = + \left\{ \frac{1}{4}\frac{\gamma_3'}{\gamma_2'}\frac{e''\theta}{\sin I''} + \frac{5}{64}\frac{\gamma_5'}{\gamma_2'}\frac{e''\theta}{\sin I''} (4 + 3e''^2) \; [1 - 9\theta^2 \right.$$

$$- 24\theta^4 (1 - 5\theta^2)^{-1}] + \frac{15}{32}\frac{\gamma_5'}{\gamma_2'} e''\theta \sin I'' \; (4 + 3e''^2)$$

$$\left. [3 + 16\theta^2 (1 - 5\theta^2)^{-1} + 40\theta^4 (1 - 5\theta^2)^{-2}] \right\}$$

$$LDAF_{12} = \left\{ -\frac{35}{1152}\frac{\gamma_5'}{\gamma_2'}\frac{e''^3\theta}{\sin I''} \; [1 - 5\theta^2 - 16\theta^4 (1 - 5\theta^2)^{-1}] \right.$$

$$\left. - \frac{35}{576}\frac{\gamma_5'}{\gamma_2'} e''^3 \theta \sin I'' \; [5 + 32\theta^2 (1 - 5\theta^2)^{-1} + 80\theta^4 (1 - 5\theta^2)^{-2}] \right\}$$

$$LDAF_{13} = \frac{e''}{\eta^2 \tan I''}$$

/DELKEP/

COMMON/DELKEP/DKEP(6)

Variable	Description	Program Where Defined
DKEP(6)	Perturbation Δa, Δe, Δi, Δg, Δh, Δl	BRWORB

$$\Delta X = X_{t0} - X_{obs}$$

where

X_{t0} = value of X on the pert tape at epoch

X_{obs} = value of X on the pert tape at the requested time

/PIND/

COMMON/PIND/NPT

Variable	Description	Program Where Defined
NPT	Perturbation tape logical number	MAIN - Initializes
	> 0 read pert tape	ELEMLD
	< 0 do not read pert tape	
	$= 0$ error	

/PRTKEP/

COMMON/PRTKEP/PKEP(3)

Variable	Description	Program Where Defined
PKEP(1)	$g_0 + \Delta g$	BRWORB
PKEP(2)	$h_0 + \Delta h$	
PKEP(3)	$l_0 + \Delta l$	

where

X_0 = value of X at epoch

$\Delta X = X_{t0} - X_{obs}$

X_{t0} = value of X on the pert tape at epoch

X_{obs} = value of X on the pert tape at the requested time

/RADIAN/

COMMON/RADIAN/TAU, AMBDA

Variable	Description	Program Where Defined
TAU	τ - longitude (in radians) of the sun on reference date	MAIN
AMBDA	λ - hour angle (in radians) of the first point of Aries on reference date	MAIN

2. BULLETIN COMMON Block Cross Reference Table

This section contains a cross reference table describing the COMMON area structure in the BULLETIN program.

BULLETIN COMMON CROSS REFERENCE TABLE

SUBROUTINES

COMMON BLOCKS	MAIN	BRWORB	CHANPL	CKSUM	DAF	DATANØ	DATE	DAYCT	DMSTOR	DRAG	DRAGLD	DREFOD	ELCONØ	ELEMLD	GTRACE	HMSTOR	INTPLØ	JDSCUT	JULHMS	KEPLRI	LAGRNØ	NODALX	NSPT	PAGEI	PERTFØ	POOL	PQUV	PREDS	PRINT	REDUCE	SDFWOE	SPACEL	SSPTHT	TIMETB	UTGST	UVIJK	VECTOR	WMAPLD	ZERO	BLOCK DATA
BPOOL	X	X	X		X				X				X	X	X	X		X				X	X	X	X	X	X	X	X		X	X	X	X	X	X				X
DAFPRM		X			X																																			
DELKEP		X																										X												
DHMNOD	X														X							X																		
DHMNS															X								X																	
DOTELE		X			X										X							X	X					X												
ETAP		X																										X												
GMPR		X																										X												
LPPRM		X													X													X												
NOD		X													X							X	X																	
NODMAP	X														X							X																		
NSMAP															X								X																	
OSCELE		X												X	X							X	X					X				X								
PERTL		X												X	X							X	X																	
PIND	X	X												X																										
PRTKEP		X																										X												
RADIAN	X																												X		X									
SDT																																	X		X					
SECPRM		X												X	X							X	X					X												
THETAP		X			X																							X												

D. ABBREVIATIONS

The following abbreviations and symbols are used in this program.

a	Semi-major Axis
B	Polar Radius of Earth
CUL	Canonical Unit of Length (CUL = earth radius)
CUT	Canonical Unit of Time
e	Eccentricity
E	Eccentricity Anomaly
f	Flattening Coefficient (1/295.25)
g	Brouwer's Notation for Argument of Perigee
h	Brouwer's Notation for Right Ascension of Ascending Node
i	Inclination
K	Brouwer's Notation for Zonal harmonics
ℓ	Brouwer's Notation for Mean Anomaly
$\Delta\ell$	Correction to Brouwer's Mean Anomaly
M	Mean Anomaly
N(2,Q)	First Order Drag Coefficients
N(3,Q)	Second Order Drag Coefficients
P_a	Anomalistic Period
$\dot{P}_a$	Derivative of Anomalistic Period
$\underline{r}$	Satellite Position Vector
$\underline{r}^*$	Unit Satellite Position Vector
T_0	Epoch — Time of Elements
T(P,Q)	Time of Drags
$\left.\begin{matrix} X \\ Y \\ Z \end{matrix}\right\}$	Satellite Position Vectors

$\dot{X}$, $\dot{Y}$, $\dot{Z}$	Satellite Velocity Vectors
Ω	Right Ascension of Ascending Node
$\dot{\Omega}$	Derivative of Right Ascension of Ascending Node
ω	Argument of Perigee
$\dot{\omega}$	Derivative of Argument of Perigee
ω_e	Rotation of Earth
ν	True Anomaly
λ	Hour Angle (in radians)
τ	Longitude (in radians) of Sun on Reference Date
$\dot{\tau}$	Motion of τ
θ	Elevation
π	180° in radians
μ	Gravitational Constant × Mass of Earth (Usually = 1)

E. REFERENCES

1. Method of Orbit Determination — Escobal, Pedro Ramon: John Wiley and Sons, Inc., 1965.

2. Mathematics of Orbit Determination — Siry, Joseph W.: GSFC Publication X-547-64-151, June 1964.

3. Brouwer-Lyddane Orbit Generator Routine — Galbreath, E. A.: GSFC Publication X-553-70-223, June 1970.

4. Definitive Orbit Determination System: Module Performance and Design Descriptions, Volume II — IBM Corporation, under NASA Contract No. NAS 5-10022, November 1968.

BROUWER BULLETIN ROUTINE

III. OPERATING INSTRUCTIONS

This routine provides an economical means of disseminating pertinent spacecraft orbital information to observing stations and other interested persons. The Bulletin information includes the general characteristics of the orbit of the satellite, revolution numbers, as well as data useful for certain prediction purposes. An ephemeris is furnished to those who utilize the spacecraft for scientific, technological, and other purposes. Sufficient information from which the pointing angles may be determined from standard transformations is also included.

The Bulletin routine reads input data from cards and, optionally, from the complementary perturbation tape. An output tape is produced containing pertinent spacecraft orbital information.

A. REQUIREMENTS AND OPTIONS

A production run requires a program tape containing the Bulletin and ancillary routines in the object module. The program tape is compiled using the appropriate source deck and the Fortran H compiler of an IBM S/360 model 75 or model 95. Other requirements include three 9-track tape drives or two 9-track tape drives and one 7-track tape drive, a card reader, and an on-line printer. Data cards are prepared as specified in Section III B-2 (Input Card Format).

Options are available in the program to load drag data from cards, to use the complementary perturbation tape, and to add the data acquisition facility parameters. In addition, this program has a change of constants capability. By use of the change of constant cards, any of the eighty values in TABLE can be changed if the user desires. The first forty values in TABLE must be changed by the first change of constant card and the last forty values by the second change of constant card. TABLE(80) is listed in COMMON/BPOOL/ in Section II C-1.

There are special options which may be indicated by the change of constant cards.

1. The sator output is suppressed by setting TABLE(36) equal to +1.

2. The radio frequencies are stored in TABLE(37), (38) and (39). These locations are now set to zero but any or all may be changed.

3. The SPACEL osculating epoch elements output is suppressed by setting TABLE(40) equal zero.

4. When creating the perturbation tape, drag can be included in the computation of the elements. Drag data can also be loaded from card to provide corrections to the Brouwer elements. The Bulletin user may desire to use drag from card only if no drag is on the perturbation tape or he may desire to use drag from tape and card. This option is controlled by TABLE(68), delta M drag multiplier. TABLE(68) is presently set equal to +1, which causes the drag data from card to be used whether or not drag is included on the pert tape. If TABLE(68) is set to 0, drag data from card is used only when drag is not included on the pert tape. If KMULT, which is on the pert tape equals +1, no drag is included on tape, and if KMULT equals 0, drag is included.

B. INPUT

Two types of input data are provided.

1. Fixed — formatted cards are used to input values of the epoch elements, observation times and various options.

2. The complementary perturbation tape provides corrections used by the Brouwer Orbit Generator; its optional use is controlled by the PERT option on the elements time card.

1. Limitations

There are two limitations on the card input.

a. 27 is the maximum number of columns to be computed from a single column card (see option 1 for card h). If the user inputs a number larger than 27, an error will not be generated but the number will be reduced to 27.

b. For SPACEL elements output, column elements time must be equal to a multiple of 0.05 day.

2. Input Card Order

a. Run identification

b. Change of constant card(s) followed by blank, or blank if no constant is to be changed

c. Satellite identification

d. Drag card(s) followed by blank, or blank if no drag is used

e. Change of constant card(s) followed by blank, or blank if no constant is to be changed

f. Elements time (Epoch)

g. Elements (2)

h. Column elements time and drag data card(s) followed by a blank.

Option 1 — 1 or 2 cards specifying the number of columns and the delta T desired for each card

Option 2 — 3K + 1 cards spaced at equal time interval, K = 1 to 18

i. Date of issue

j. Remarks

k. Bulletin request

l. Spacel bulletin

n. Data Acquisition Facility (DAF) parameters card or blank if not requesting DAF parameters

3. Card Format

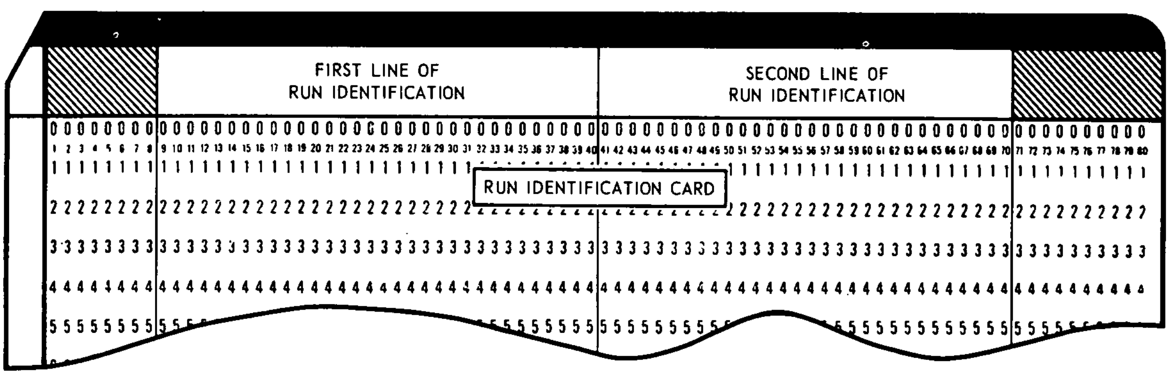
Format Specification Interpretation

Key: n, m = integer numbers
b = a blank space

Format Code	Interpretation
In	digits with no decimal point right adjusted in a field of n columns example: 35 in an I3 format: b35

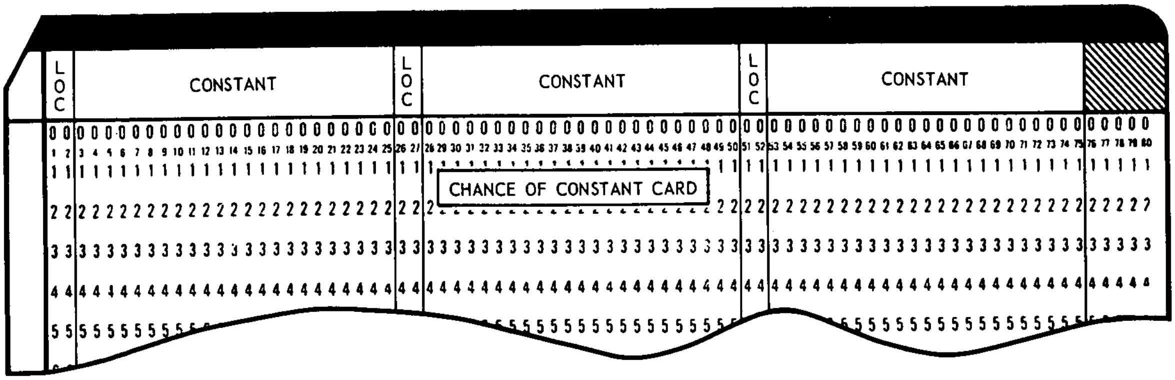
Format Code	Interpretation
Fn.m	digits with a decimal point anywhere in a field of n columns or digits punched with no decimal point, in which case the point will be assumed between the m - 1th and mth column of the field example: 40.1 in an F5.2 format: b40.1 or 40.1b or b401b
Dn.m	digits with a decimal point anywhere in a field of n columns <u>or</u> digits right justified in a field of n columns with an exponent of the form D ± XX, where XX is the power of 10 to which the number is raised. If there is no decimal point it will be assumed to be m places to the left of the "D". example: 40.1 in a D8.5 format: b40.1bbb or 40.1 D + 00 or 401.D - 01, etc.
An	n alphanumeric characters

a. Run Identification Card



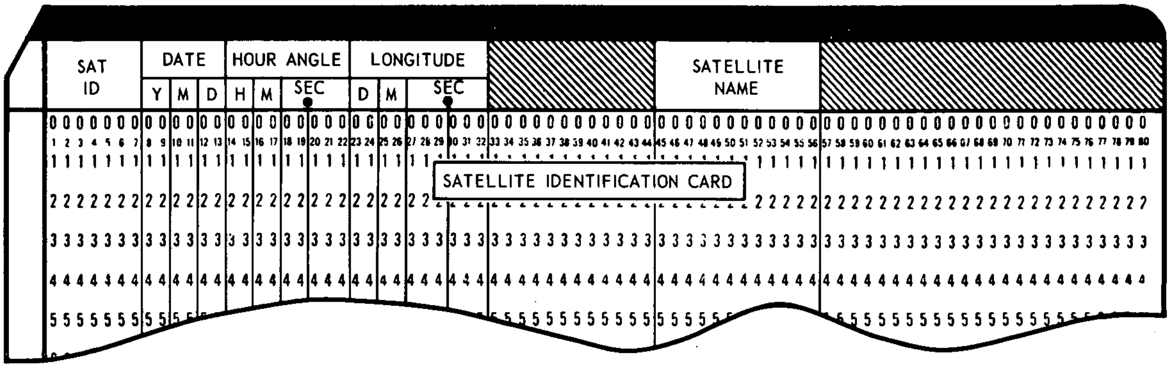
Card Col.	Format	Field Description
1-8	bbb . . . b	Leave blank
9-40	A40	First line of run identification
41-70	A40	Second line of run identification
71-80		Not used

b and e. Change of Constant Card



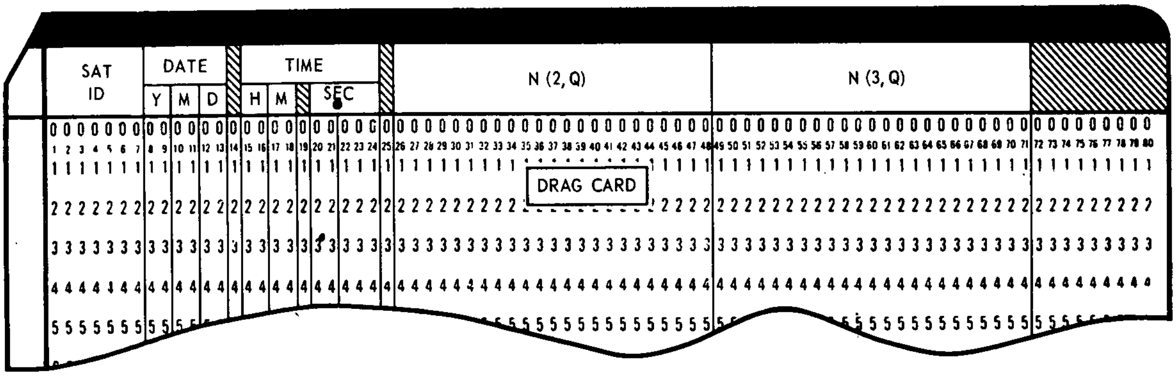
Card Col.	Format	Field Description
1-2	I2	Table location to be changed
3-25	D23.16	Constant to be inserted in above location
26-27	I2	Table location to be changed
28-50	D23.16	Constant to be inserted in above location
51-52	I2	Table location to be changed
58-75	D23.16	Constant to be inserted in above location
76-80		Not used

c. Satellite Identification Card



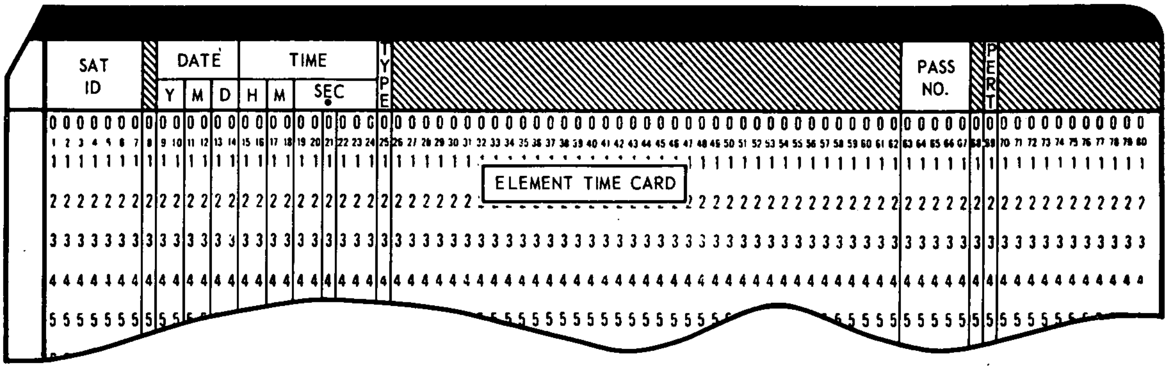
Card Col.	Format	Field Description
1-7	I7	Satellite identification number
8-13	I6	Date of reference: year, month, day
14-22	I9	Hour angle of the first point of Aries on above date (λ): hours, minutes, seconds
23-32	I10	Longitude of Sun (τ): degrees, minutes, seconds
33-44	b	Leave blank
45-56	A12	Satellite name
57-80		Not used

d. Drag Card



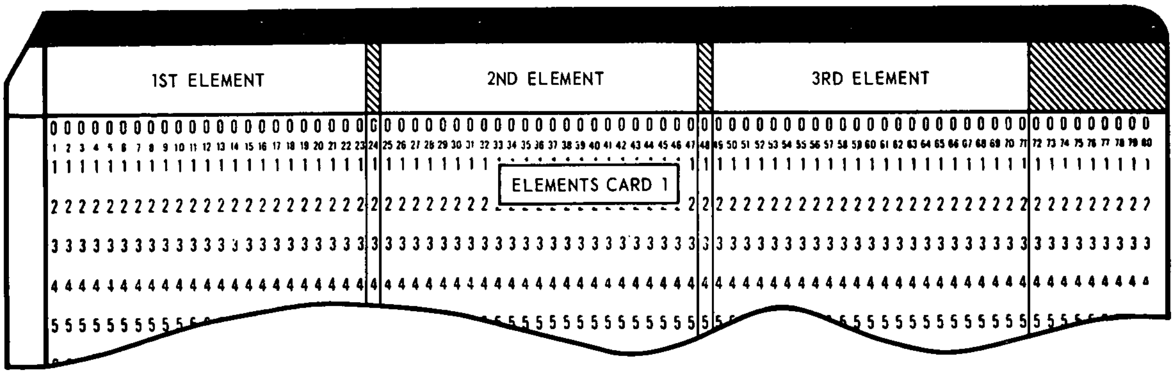
Card Col.	Format	Field Description
1-7	I7	Satellite Identification number
8-13	I6	Date of Drag: year, month, day
14	b	Leave blank
15-18	I4	Time of Drag: hours, minutes
19	b	Leave blank
20-24	I5	Seconds
25	b	Leave blank
26-48	D23.16	N(2,Q) First Brouwer drag parameter
49-71	D23.16	N(3,Q) Second Brouwer drag parameter
72-80		Not used

f. Element Time Card



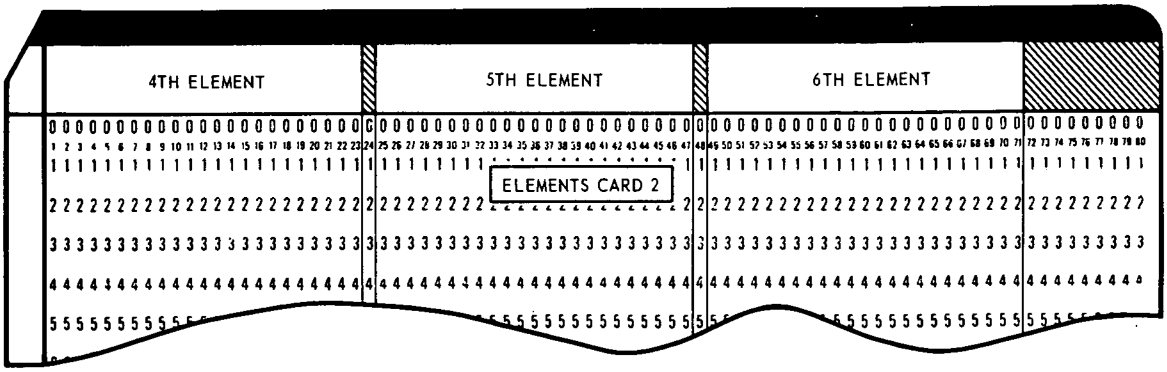
Card Col.	Format	Field Description
1-7	I7	Satellite Identification Number
8	b	Leave blank
9-14	I6	Date of elements: year, month, day
15-18	I4	Time of elements: hours, minutes
19-24	F6.3	Seconds
25	I1	Input element type code: 1 = type 1 elements on next 2 cards 2 = type 2 elements on next 2 cards
26-62	bbb . . . b	Leave blank
63-67	I5	Pass number of elements
68	b	Leave blank
69	I1	Perturbation tape option 1 = pert tape is used blank = no perturbation
70-80	Not used	

g. Elements Card 1



Card Col.	Format	Field Description	
		Type 1	Type 2
1-23	D23.16	X (CUL or km)	a (CUL or km)
24	b		
25-47	D23.16	Y (CUL or km)	e
48	b		
49-71	D23.16	Z (CUL or km)	i (radians or degrees)
72-80		Not used	

g. Element Card 2

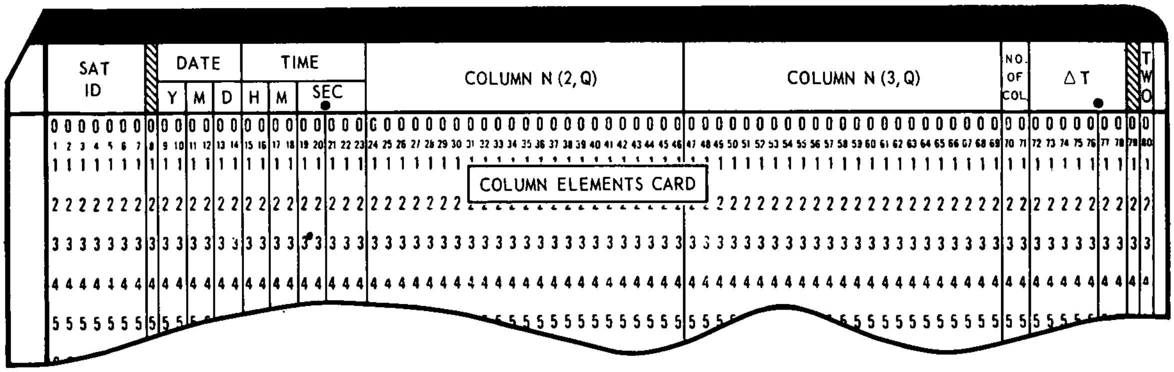


Card Col.	Format	Field Description	
		Type 1	Type 2
1-23	D23.16	$\dot{X}$ (CUL/CUT or km/sec)	M (radians or degrees)
24	b		
25-47	D23.16	$\dot{Y}$ (CUL/CUT or km/sec)	ω (radians or degrees)
48	b		
49-71	D23.16	$\dot{Z}$ (CUL/CUT or km/sec)	Ω (radians or degrees)
72-80		Not used	

Cards 1 and 2 will have one of the above two formats (type 1 or type 2) depending on the type specified in column 25 of the elements time card.

Elements on card 1 and card 2 must be of the same units (CUL - radians or km - degrees).

h. Column Elements Time and Drag Data Card



Card Col.	Format	Field Description
1-7	I7	Satellite Identification Number
8	b	Leave blank
9-14	I6	Date of column elements: year, month, day
15-23	I9	Time of column elements: hours, minutes, seconds
24-46	D23.16	N (2,Q) First column drag parameter
47-69	D23.16	N (3,Q) Second columns drag parameter
70-71*	I2	Number of columns to be computed
72-78	I7	Column delta T in minutes
79	b	Leave blank
80	I1	Punch if two cards are to be read. Blank if only one card is to be read.

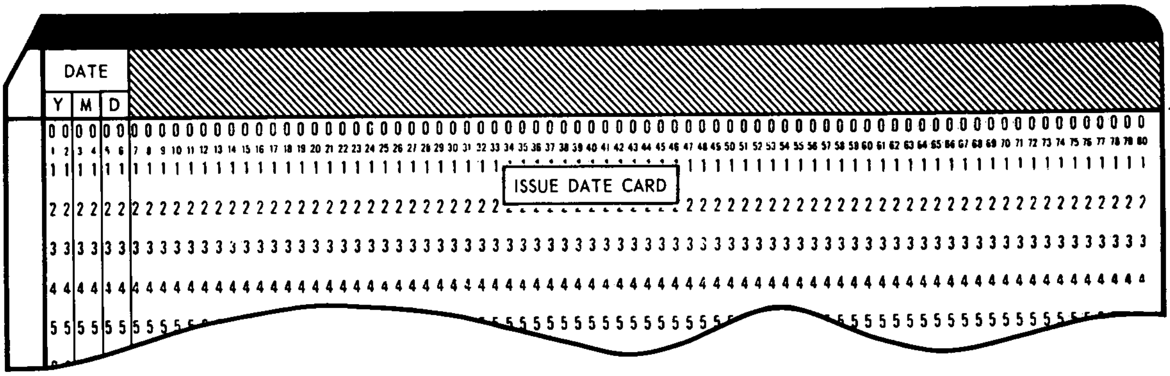
Note: For spacel elements, column time must be equal to a multiple of 0.05 day.

*Columns 70-80 are optional.

Option 1 – If columns 70-80 are used, one or two cards are needed, specifying the number of columns and delta T desired for each card. If two cards are used, column 80 of the first card must be punched.

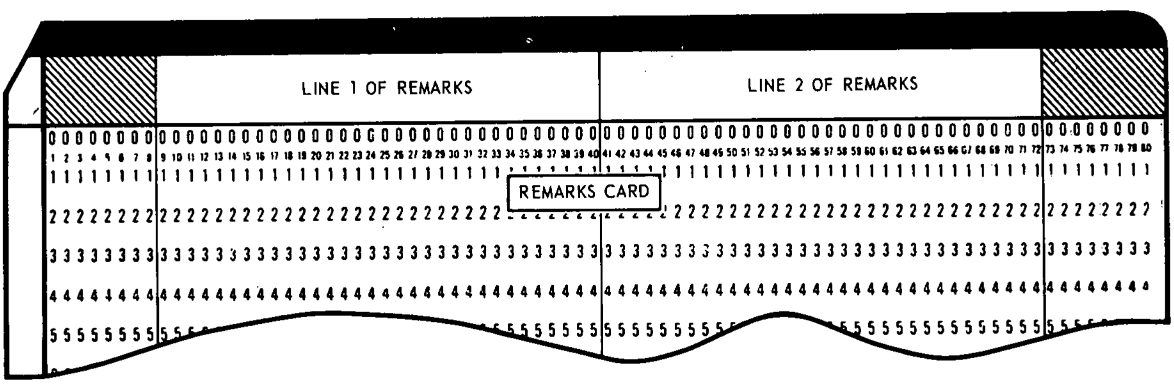
Option 2 – If columns 70-80 are not used, 3K + 1 column cards, spaced at equal time interval, must be loaded (K = 1, 18).

i. Issue Date of Bulletin Card



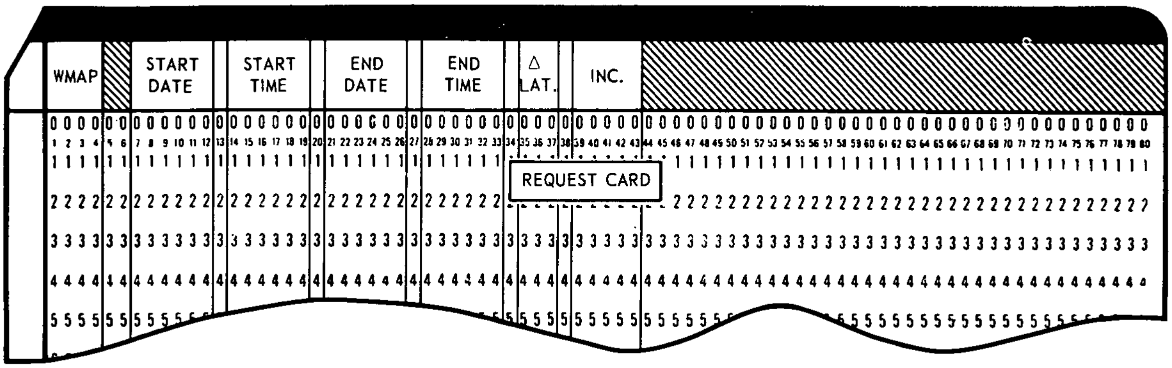
Card Col.	Format	Field Description
1-6	I6	Issue Date of Bulletin: year, month, day
7-80		Not used

j. Bulletin Remarks Card



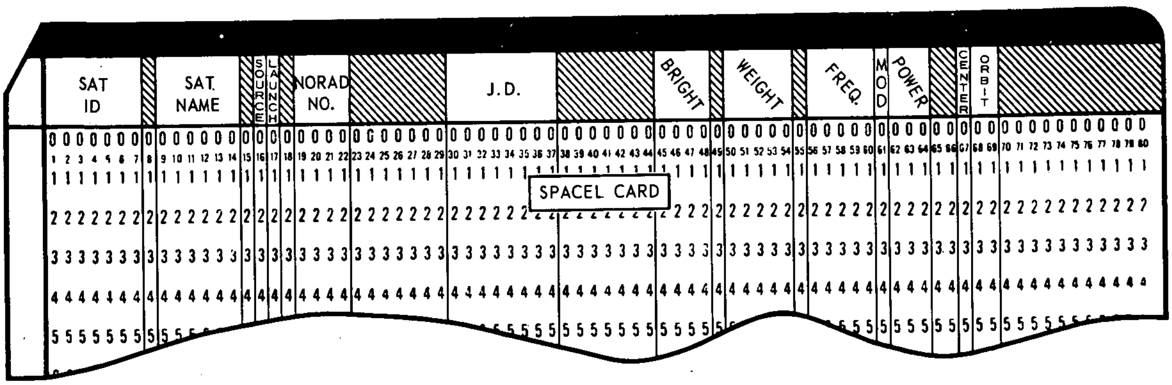
Card Col.	Format	Field Description
1-8	bbb . . . b	Leave blank
9-40	A40	Line 1 of Remarks
41-72	A40	Line 2 of Remarks
73-80		Not used

k. Bulletin Request Card



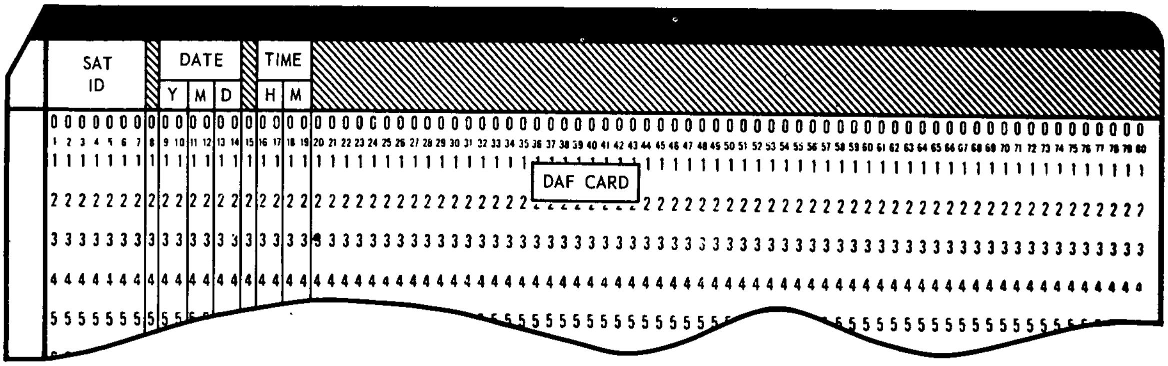
Card Col.	Format	Field Description
1-4	A4	The word WMAP
5-6	bb	Leave blank
7-12	I6	Starting Date: year, month, day
13	b	Leave blank
14-19	I6	Starting Time: hours, minutes, seconds
20	b	Leave blank
21-26	I6	Ending Date: year, month, day
27	b	Leave blank
28-33	I6	Ending Time: hours, minutes, seconds
34	b	Leave blank
35-37	I3	Latitude increment (degrees)
38	b	Leave blank
39-43	I5	Inclination (.01 degrees)
44	b	Leave blank
45-49	I5	Pass number
50-80		Not used

1. Spacel Bulletin



Card Col.	Format	Field Description
1-7	I7	Satellite Identification Number
8	b	Leave blank
9-14	A6	Abbreviation of popular name of spacecraft
15	b	Leave blank
16	A1	Source of spacecraft
17	A1	Launching site
18	b	Leave blank
19-22	A4	Norad number of object
23-29	bbb . . . b	Leave blank
30-37	F8.3	Initial Julian Date of Space associated with the first time the spacecraft achieved its orbit
38-44	b	Leave blank
45-48	A4	Brightness
49	b	Leave blank
50-54	A5	Ratio of spacecraft weight to reference weight in kilograms per square meters
55	b	Leave blank
56-60	A5	Radio frequency in decakilocycles
61	A1	Type of modulation
62-64	A3	Transmitted Power in Centiwatts
65-66	b	Leave blank
67	A1	Center of Attraction
68-69	A3	Orbit number
70-80		Not used

m. Data Acquisition Facility Parameter Request Card



Card Col.	Format	Field Description
1-7	I7	Satellite Identification Number
8	b	Leave blank
9-14	I6	Date of observation: year, month, day
15	b	Leave blank
16-19	I4	Time of observation: hours, minutes
20-80		Not used

```
        INJUN-5 BROUWER BULLETIN                                                    RUN ID
05+0.806812420000000D+03                                                            CONST
                                                                                    BLANK
68066027102010842116633112826600                          INJUN-5                   SAT ID
6806602710220 0000-00000 +0.160390000000000D-08                                     DRAG
                                                                                    BLANK
                                                                                    CONST
6806602 710220000000.0002                                                           EPOCH
+0.125108451194000D+01 +0.115761700223000D+00 +0.140793793054000D+01               ELEM 1
+0.172733786918000D+01 +0.606780704152000D01 +0.348707929833000D+00               ELEM 2
6806602 71022300000000+0.160390000000000D-08                                     031008000
710303                                                                              BLANK
        INJUN-5 BROUWER BULLETIN                                                    ISSUE
WMAP  710223 000000 710302 081500 010 04090 11292                                   REMARKS
6806602 INJUN5 UW 3338  4914 3914 3977.842 11292                                    REQUEST
                                                                                    SPACEL
                                                                                    DAF
```

Figure 2. Listing of Sample Input Data

4. Perturbation Observation Tape Format

The complementary perturbation tape provides corrections used by the Brouwer Orbit Generator and the Bulletin Prediction. Its optional use is controlled by the PERT option on the elements time card (card f). A punch in column 69 indicates that the tape is to be used. The pert tape is a 9-track binary tape consisting of one header record followed by seven or more data records.

See Section III-C for the job control language cards required in a production run of the Bulletin including perturbations.

Table 1

Format of Perturbation Observation Tape

Header Record

Word Number	Word Contents
0	Fortran word count
1	Time increment — days
2	Month
3	Day
4	Year
5	Satellite Identification Number
6	Input semi-major axis — e.r.
7	Input eccentricity
8	Input inclination
9	Input right ascension of the ascending node — degrees
10	Input argument of perigee — degrees
11	Input mean anomaly — degrees
12	Input time from midnight — days
13	Input period — minutes
14	Number of records on tape excluding header and trailer records
15	Delta mean anomaly option indicator (KMULT) (1 — delta drag mean anomaly not computed on tape 0 — delta drag mean anomaly computed on tape)

Table 1 (continued)

Date Record

Word Number	Word Contents
0	Fortran word count
1	Time in seconds from epoch
2	a (semi-major axis) — e.r.
3	e (eccentricity)
4	i (inclination) $-\pi/2 \leq i \leq \pi/2$
5	ΔM (delta mean anomaly change from T_0) $\phi \leq \Delta M \leq 2\pi$
6	ω (argument of perigee) $\phi \leq \omega \leq 2\pi$
7	Ω (right ascension of the ascending node) $\phi \leq \Omega \leq 2\pi$

Sentinel Record

Word Number	Word Contents
0	Fortran word count
1	$.9999999999999999 \times 10^{30}$
2-8	Irrelevant

End of File after sentinel record.

C. SET UP AND RUNNING PROCEDURE

1. Requirements

IBM S/360 model 75 or model 95, three tape drives including three 9-track or two 9-track and one 7-track, on-line card reader, and on-line printer.

2. Tape Assignments

Table 2

Tape Assignments

Tape Function	Tape Description		
Read Only Tapes	9T		Program Tape*
	9T	Unit 4	Perturbation Tape (Optional)
Generated Tape to be Saved	7T or 9T	Unit 9	Bulletin Output Tape

*The program tape contains the Bulletin and ancillary routines in the object module. Presently the tape contains two sequential data sets, the source file and the object module which was compiled from the source coding using the Fortran H compiler of an IBM S/360 model 75 or model 95.

3. Card Reader

Reads input data cards and required JCL cards.

4. On-Line Printer

Indicates whether a constant has been changed or not and writes the initial conditions and error messages. (Refer to Section III D.)

No special paper, loop, or board requirements.

See Section III B for a detailed description of the data cards and perturbation tape required.

5. IBM S/360 Job Control Language Cards

```
//G5DBMBUL JOB
// EXEC LINKGO,REGION.GO=300K
//LINK.SYSLIN DD UNIT=2400-9,DISP=(OLD,PASS),LABEL=(2,BLP),
//             DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200,DEN=2),
//             VOLUME=SER=1647G
//GO.FT04F001 DD UNIT=2400-9,DISP=(OLD,PASS),LABEL=(,BLP),
//             DCB=(RECFM=VS,BLKSIZE=128,LRECL=124,DEN=2,
//             VOLUME=SER=XXXXX
//GO.FT09F001 DD UNIT=2400-7,DISP=(NEW,PASS),LABEL=(,BLP),
//             DCB=(RECFM=FA,BLKSIZE=120,TRTCH=ET,DEN=1),
//             VOLUME=SER=
//GO.SYSUDUMP DD SYSOUT=A
//GO.DATA5 DD *
                              ** DATA CARDS **
                              ** DATA CARDS **
/*
//
```

D. OUTPUT

The Bulletin output is generated on an on-line printer and a 9-track or 7-track tape which is assigned to tape unit 9. The initial conditions, changed constants, and error messages are printed on both the on-line printer and tape.

1. On-Line Printer

The on-line printer is used to write run identification data, initial conditions data, changed constants, and error messages. A sample on-line printout is shown in Figure 3. Tables 3 and 4 list normal statements and error statements, respectively.

Table 3

Normal Statements

Statement	Explanation
No DAF Parameters Computed In This Run	User does not desire to print DAF parameters and has blank input DAF card.
TABLE(XX) = YYYY	Specified location XX of TABLE now equals indicated value YYYY.
End Bulletin Run	Program has followed normal path.

```
  TABLE( 5)= 0.8C68124200CC0000D 03


R183 D.P. BROUWER BULLETIN FOLTINE
    INJUN-5 BROUWER BULLETIN


                 INJUN-5 BRCUWER EULLETIN


 ID.NO.   REF.DATE LAMBDA  HMS TAU       DMS  SATELLITE
 6806602 71  2  1  8 42 11663 311 28 26600                INJUN-5

INPUT QUANTITIES FROM CARDS

EPOCH    71  2 20  0  0      0

        A                 E                 I                S CMEGA          C OMEGA             M
 0.12510845D 01 0.11576170D 00 0.14079379D 01 0.17273379C 01 0.60678070D 01 0.34870793D 00

CONVERTED QUANTITIES
        X                 Y                 Z                XCOT             YDOT             ZDOT
-0.58119192D 00 0.28055751D 00 0.91206554D 00-0.84603389C C0 0.98460400D-01-0.51502878D 00

DRAG EFFECTS      T (P,Q)        N (2,Q)         N (3,C)
               710220      0   0.16039000D-08   0.0

COLUMN TABLE      T(P,Q)         N(2,Q)          N(3,Q)          K(I) MIN*100
               710223      C   C.16039000D-08   0.0               3  1008000

EARTH CONSTANTS       ML            ROTATION          RACIUS          FLATNESS
               0.1C000C00D C1   0.58833690D-01   0.10000000D 01   0.33528919D-02

HARMONICS
      K2                   K3                   K4                   K5
  0.54124000D-03       0.25600000D-05       0.69000000C-06       0.60000000D-07

      J                    H                    K                    L
  0.162372C0D-C2       C.0                  0.0                  0.0


INPUT UNITS -- CUL AND RADIANS
          A                        E                       I
 0.12510845119400000D 01 0.11576170022300000D 00 0.14079379305400000D 01
        S OMEGA                 C CMEGA                    M
 0.17273378691800000D 01 0.6C678070415200000D 01 0.34870732983300000C 00

CONVERTED QUANTITIES -- KM AND CEGREES
          A                        E                       I
 0.79796246971823010D 04 0.11576170022300000D 00 0.80668901236325240D 02
        S OMEGA                 C CMEGA                    M
 0.98969169697134700D 02 0.34765973437885820D 03 0.19979492662174950C 02


 BROUWER  DAF PARAMETERS
NO DAF PARAMETERS COMPLTED IN THIS RUN

END BULLETIN RUN
```

Figure 3. Sample On-Line Printout

Table 4

Error Statements

Statement	Explanation
Incorrect Elements SAT. ID.	Input satellite ID does not agree with elements time satellite ID.*
Wrong SAT. ID. on Drag Card Drag Load Unsuccessful	Input satellite ID does not agree with drag satellite ID.
Error in Column Elements Request Card Column Time Table Load Unsuccessful	The format of the column elements time and drag data card is incorrect. When using option 2 for the format, columns 70-80 must be used.
Wrong SAT. ID. on Column Elements Card Column Time Table Load Unsuccessful	Input satellite ID does not agree with column elements time satellite ID.
Elements Type Equals Zero	The element type on the elements time card must be either 1 or 2 to indicate the type of elements used. Refer to Section III B-3 for the format and description of the elements time card.
Latitude Increment Exceeds Inclination	The latitude increment can not exceed the inclination on the Bulletin request card.
Tape Check on Perturbation Tape	An uncorrectable error occurred when reading the perturbation tape. If tape is the correct tape to be used, rerun job.
Perturbation SAT. ID.	Input satellite ID does not agree with pert tape satellite ID.
Incorrect Data to CHANPL	The location of the constant to be changed is not in the range of the Table (0 thru 80).
Error in DAF SAT. ID.	Input satellite ID does not agree with DAF satellite ID.

Table 4 (Continued)

Statement	Explanation
Error, Year of Reference, XXXX, Greater Than Observation Year, XXXX	Error occurred in subroutine DREFOD. The year of reference must always be less than or equal to the observation year.
No SPACEL Bulletin Output For This Run SPACEL Elements Do Not Have Accuracy of Column Elements	The column elements time is not equal to a multiple of 0.05 day.

2. Output Tape Format

The Bulletin tape output consists of the following sections:

1. Title Page
2. Initial Conditions
3. Space Elements
4. Spacel Bulletin
5. Equator Crossings
6. One Orbit Ephemeris
7. Sator Code
8. Data Acquisition Facility Parameters

The Spacel Bulletin, Sator Code and Data Acquisition Facility Parameters are printed according to user option. The other sections are always printed.

A listing of the sample BCD output tape is shown in Figure 4. The title page contains the satellite identification, start and end times for computing equator crossings and user remarks.

Input values of some of the pertinent parameters appear in the initial conditions as listed in Figure 4a. If the PERT tape is used, the first line printed is "Complementary Perturbations".

Figure 4b contains space elements which indicate mean characteristics of the orbit at the epoch. The subsection entitled "Descriptive Space Elements" contains various derived quantities which are of interest to observers at the earth's surface. "Prediction Space Elements" provides elements for use when approximate satellite positions are needed.

Osculating Space Elements and their Cartesian equivalents are listed in Figure 4c. The Cartesian equivalents are obtained using the given values of GM and the value of the earth's equatorial radius. The double prime elements at the epoch are also listed and the position and velocity vectors are computed in several units.

Key space element information contained in Figures 4b and 4c is combined and furnished in condensed form in the Spacel Bulletin, Figure 4d. Note that the last digit of each line is a counter to be used by observation stations and other interested persons. The counter is the sum of all digits in its line modulo ten. The last line of the Spacel Bulletin contains osculating space elements at the first requested time of the prediction space elements.

The subsection entitled "Equator Crossings" contains each ascending nodal crossing from the requested start time to the end time, its revolution number, its date and time, and its west longitude in degrees as indicated in Figure 4e.

Figure 4f contains a one orbit ephemeris for the middle nodal crossing shown in Figure 4e. The ephemeris gives the satellite positions at regular intervals according to the requested latitude increment. Time is specified in terms of minutes from the time of the ascending nodal crossing. Longitude is given in degrees and decimal fractions. Height above the ellipsoid is given in terms of a decimal fraction of a kilometer. Times when the satellite is not in the earth's shadow are indicated by means of an asterisk following the height.

Figure 4g contains the Brouwer Data Acquisition Facility Parameters.

3

```
R183 D.P. BROUWER BULLETIN

6806602                              INJUN-5

           FROM  710223        0
             TO  710302    81500

INJUN-5 BROUWER BULLETIN
```

Figure 4. Listing of Sample Output Tape

```
           INJUN-5 BROUWER BULLETIN


ID.NO.    REF.DATE LAMBDA  HMS TAU      DMS  SATELLITE
6806602 71  2  1  8 42 11663 311 28 26600              INJUN-5

INPUT QUANTITIES FROM CARDS

EPOCH    71  2 20  0  0     0

      A               E                 I                S OMEGA          C OMEGA               M
0.125108450 01 0.115761700 00 0.140793790 01 0.172733790 01 0.606780700 01 0.348707930 00

CONVERTED QUANTITIES
      X                Y                 Z                 XDOT              YDOT               ZDOT
-0.581191920 00 0.280557510 00 0.912065540 00-0.346033880 00 0.984604000-01-0.515028780 00

DRAG EFFECTS     T (P,Q)         N (2,Q)          N (3,Q)
              710220     C    0.160390000-08    0.0

COLUMN TABLE     T(P,Q)          N(2,Q)           N(3,Q)          K(I) MIN*100
              710223     C    0.160390000-08    0.0                3  1008000

EARTH CONSTANTS        MU            ROTATION         RADIUS            FLATNESS
             0.100000000 01   0.588336900-01   0.100000000 01   0.335289190-02

HARMONICS
       K2                       K3                      K4                      K5
  0.541240000-03       0.256000000-05       0.690000000-06       0.600000000-07

        J                       H                       K                       L
  0.162372000-02       0.0                  0.0                  0.0




INPUT UNITS -- CUL AND RADIANS
        A                          E                           I
 0.125108451194000000 01 0.115761700223000000 00 0.140793790540000000 01
     S OMEGA                   C CMEGA                         M
 0.172733786918000000 01 0.606780704152000000 01 0.348707929833000000 00

CONVERTED QUANTITIES -- KM AND DEGREES
        A                          E                           I
 0.797962469718230100 04 0.115761700223000000 00 0.805689012363252400 02
     S OMEGA                   C OMEGA                         M
 0.989691696971347000 02 0.347659734378858200 03 0.199794926621749500 02
```

Figure 4a

GODDARD SPACE FLIGHT CENTER
GODDARD ORBIT BULLETIN
MAR 3,1971

SATELLITE INJUN-5

SPACE ELEMENTS

EPOCH		YRMODYHRMMSS.SSSS	
CALENDAR DATE		71 220 0 0 0. 0	UT2W
JULIAN DATE FOR SPACE		4903. 00	UT2W
PERIOD,ANOMALISTIC		118.289055	MIN
PERIOD DERIVATIVE		-0.03807	MICRODAYS/DAY
ECCENTRICITY		0.11669938	
INCLINATION		80.66783	DEG
RIGHT ASCENSION OF ASCENDING NODE		347.65948	DEG
RT.ASC.OF ASC. NODE DERIVATIVE		-0.25188	DEG/DAY
ARGUMENT OF PERIGEE		98.88999	DEG
ARGUMENT OF PERIGEE DERIVATIVE		-0.28681	DEGDAY
MEAN ANOMALY		20.05704	DEG
SEMI MAJOR AXIS	1.2510762 ER	0.79795717	DECAMEGAMETERS

DESCRIPTIVE SPACE ELEMENTS

EPOCH		YRMODYHRMMSS.SSSS	
CAL DAT		71 220 0 0 0. 0	UT2W
J.D.S.		4903. 00	UT2W
PERIOD,NODAL		118.296797	MIN
PERIGEE HEIGHT	670.1946 KM	416.4396	ST MI
APOGEE HEIGHT	2532.6167 KM	1573.6951	ST MI
NODE-SUN-ANGLE,RAA NODE MINUS RA SUN		15.37707	DEG
LONGITUDE OF ASCENDING NODE		161.61571	DEG
LATITUDE OF PERIGEE,GEOCENTRIC		77.138428	DEG
VELOCITY AT PERIGEE	7.946854 KM/SC	17776.606	ST MI/HR
VELOCITY AT APOGEE	6.285900 KM/SC	14061.159	ST MI/HR

PREDICTION SPACE ELEMENTS

EPOCH		T- 1	T- 2	T- 3
		YRMODYHRMMSS.SSSS	YRMODYHRMMSS.SSSS	YRMODYHRMMSS.SSSS
CAL DAT	UT2W	710223 0. 0	710302 0. 0	710309 0. 0
J.D.S.	UT2W	4906.000000000	4913.000000000	4920.000000000
PERIOD	MIN	118.288893	118.288484	118.288042
PERIOD DER	MD/D	-0.04053	-0.04385	-0.04674
ECCENTRICITY		0.11671034	0.11668890	0.11660359
INCLINATION	DEG	80.667821	80.667843	80.667935
RA ASC NODE	DEG	345.392596	340.103199	334.813777
ARG PERIGEE	DEG	92.867035	78.813560	64.752881
MEAN ANOM	DEG	207.520943	285.010408	2.610200
SEMIMAJ AXIS	ER	1.2510750	1.2510722	1.2510694

Figure 4b

OSCULATING SPACE ELEMENTS

```
EPOCH                                         YRMODYHRMMSS.SSSS
 CAL DAT                                      71 220 0 0 0.    0 UT2W
 J.D.S.                                         4903.         00  UT2W

OSCULATING SPACE ELEMENTS
 PERIOD                                          118.116750      MIN
 ECCENTRICITY                                      0.1159741
 INCLINATION                                      80.66564       DEG
 RIGHT ASCENSION OF ASCENDING NODE               347.65290       DEG
 ARGUMENT OF PERIGEE                              98.50309       DEG
 MEAN ANOMALY                                     20.39206       DEG

OSCULATING CARTESIAN QUANTIES
 X     -0.37110174  DECAMEGAMETERS              -0.58183142    ER
 Y      0.17900367  DECAMEGAMETERS               0.28065069    ER
 Z      0.58105528  DECAMEGAMETERS               0.91100684    ER
 VX    -0.57792410  DMM/CENTIDAY                -0.84612362    ER/CUT
 VY     0.06729921  DMM/CENTIDAY                 0.09853102    ER/CUT
 VZ    -0.35186586  DMM/CENTIDAY                -0.51515764    ER/CUT
GM      0.29755569  DMM3/CD2                     1.14678185    ER3/CD2
```

MEAN ELEMENTS OF MODIFIED BROUWER TYPE

```
EPOCH                                         YRMODYHRMMSS.SSSS
 CAL DAT                                      71 220 0 0 0.    0 UT2W
 J.D.S.                                         4903.         00  UT2W

A DOUBLE PRIME(SEMI-MAJOR AXIS CONSTANT)              0.12510845D 01   ER
E DOUBLE PRIME(ECCENTRICITY CONSTANT)                 0.11576170D 00
I DOUBLE PRIME(INCLINATION CONSTANT)                  0.14079379D 01   RAD
L ZERO DOUBLE PRIME(MEAN MEAN ANOMALY)                0.34870793D 00   RAD
G ZERO DOUBLE PRIME(MEAN ARG PERIGEE)                 0.17273379D 01   RAD
H ZERO DOUBLE PRIME(MEAN RT ASC ASC NODE)             0.60678070D 01   RAD
N (2,Q)                                               0.16039000D-08   RAD/CUT2
```

OSCULATING ELEMENTS OF MODIFIED BROUWER TYPE

```
EPOCH                                         YRMODYHRMMSS.SSSS
 CAL DAT                                      71 220 0 0 0.    0 UT2W
 J.D.S.                                         4903.         00  UT2W
```

POSITION VECTOR

UNITS	X COMPONENT	Y COMPONENT	Z COMPONENT
STATUTE MILES	-0.23059193D 04	0.11122772D 04	0.36105101D 04
KILOMETERS	-0.37110174D 04	0.17900367D 04	0.58105528D 04
NAUTICAL MILES	-0.20037891D 04	0.96654249D 03	0.31374475D 04
FEET	-0.12175254D 08	0.58728238D 07	0.19063494D 08

VELOCITY VECTOR

UNITS	X COMPONENT	Y COMPONENT	Z COMPONENT
SM/HOUR	-0.14962725D 05	0.17424079D 04	-0.91099711D 04
KM/HOUR	-0.24080171D 05	0.28041337D 04	-0.14661077D 05
KNOTS	-0.12988476D 05	0.15125068D 04	-0.79079610D 04
METERS/SECOND	-0.66889364D 04	0.77892602D 03	-0.40725215D 04
FEET/SECOND	-0.21945329D 05	0.25555315D 04	-0.13361291D 05

Figure 4c

GODDARD SPACE FLIGHT CENTER
SPACEL BULLETIN
MAR 3,1971
J.D.S. 4914


```
SATDESG NAME SL NRDN SBDAT  INJ.D.S. RVNEI OMAG KG/M2 RFDKCMPCW  CCNC
J.D.S. PERAN MOD   PER DERI PHTEQR APHTEQR INMOD RAANOD ARGPER MANOM C
UT2W   10,000 MIN MICROD/D KMX10  KMX10   100DG DEGRS  DEGRS  DEGRS S
X100   X1,000,000 X10,000  298.25 6378166 X1000 X1000  X1000  X1000 D

6806602 INJUN5 UW 3338  4914 3914 397 112921292
490600 0118288893-00000495 006701 0025327 80668 345393 092867 2075214
491300 0118288484-00000438 006703 0025325 80668 340103 078814 2850103
492000 0118298042-00000467 006709 0025318.80668 334814 064753 0026103
490600 0118161311-00000393 006618 0025348080665S345391C093127U2072374
```

Figure 4d

EQUATOR CROSSINGS

NORTHBOUND

EQUAT XING NO.	TIME UT2W HHMM	LONG W DEG	EQUAT XING NO.	TIME UT2W HHMM	LONG W DEG	EQUAT XING NO.	TIME UT2W HHMM	LONG W DEG
23 FEB 71								
11293	023.99	172.86	11294	222.34	202.59	11295	420.68	232.32
11296	619.02	262.05	11297	817.36	291.78	11298	1015.71	321.50
11299	1214.05	351.23	11300	1412.39	20.96	11301	1610.73	50.69
11302	18 9.08	80.42	11303	20 7.42	110.15	11304	22 5.76	139.88
24 FEB 71								
11305	0 4.10	169.60	11306	2 2.44	199.33	11307	4 0.79	229.06
11308	559.13	258.79	11309	757.47	288.52	11310	955.81	318.25
11311	1154.15	347.98	11312	1352.50	17.70	11313	1550.84	47.43
11314	1749.18	77.16	11315	1947.52	106.89	11316	2145.86	136.62
11317	2344.20	166.35						
25 FEB 71								
11318	142.55	196.08	11319	340.89	225.80	11320	539.23	255.53
11321	737.57	285.26	11322	935.91	314.99	11323	1134.25	344.72
11324	1332.60	14.45	11325	1530.94	44.18	11326	1729.28	73.90
11327	1927.62	103.63	11328	2125.96	133.36	11329	2324.30	163.09
26 FEB 71								
11330	122.64	192.82	11331	320.98	222.55	11332	519.32	252.27
11333	717.67	282.00	11334	916.01	311.73	11335	1114.35	341.46
11336	1312.69	11.19	11337	1511.03	40.92	11338	17 9.37	70.64
11339	19 7.71	100.37	11340	21 6.05	130.10	11341	23 4.39	159.83
27 FEB 71								
11342	1 2.73	189.56	11343	3 1.07	219.29	11344	459.41	249.01
11345	657.76	278.74	11346	856.10	308.47	11347	1054.44	338.20
11348	1252.78	7.93	11349	1451.12	37.65	11350	1649.46	67.38
11351	1847.80	97.11	11352	2046.14	126.84	11353	2244.48	156.57
28 FEB 71								
11354	042.82	186.30	11355	241.16	216.02	11356	439.50	245.75
11357	637.84	275.48	11358	836.18	305.21	11359	1034.52	334.94
11360	1232.86	4.66	11361	1431.20	34.39	11362	1629.54	64.12
11363	1827.88	93.85	11364	2026.22	123.58	11365	2224.56	153.30
1 MAR 71								
11366	022.90	183.03	11367	221.24	212.76	11368	419.58	242.49
11369	617.92	272.22	11370	816.26	301.94	11371	1014.60	331.67
11372	1212.94	1.40	11373	1411.27	31.13	11374	16 9.61	60.86
11375	18 7.95	90.58	11376	20 6.29	120.31	11377	22 4.63	150.04
2 MAR 71								
11378	0 2.97	179.77	11379	2 1.31	209.50	11380	359.65	239.22
11381	557.99	268.95	11382	756.33	298.68			

Figure 4e

ONE ORBIT EPHEMERIS

REVOLUTION NO. 11337

LAT N	MINUTES PLUS	LONG INCREM	HEIGHT KM	LAT S	MINUTES PLUS	LONG INCREM	HEIGHT KM
SN 00	0000.00	000.00	1427.8*	NS 00	50.43	192.68	1570.8
SN 10	3.12	359.13	1275.1*	NS-10	53.80	191.87	1736.8
SN 20	6.13	358.13	1135.5*	NS-20	57.32	191.00	1903.3
SN 30	9.04	356.86	1012.0*	NS-30	60.99	189.92	2064.4
SN 40	11.88	355.11	906.4*	NS-40	64.82	188.41	2213.6*
SN 50	14.67	352.46	820.4*	NS-50	68.81	186.07	2344.1*
SN 60	17.45	347.95	755.2*	NS-60	72.98	181.91	2449.3*
SN 70	20.30	338.44	711.7*	NS-70	77.42	172.79	2523.0*
SN 80	23.95	298.15	693.0*	NS-80	83.24	133.07	2556.4*
N PT	24.93	276.27	695.3*	S PT	84.80	111.31	2552.8*
NS 80	25.91	254.38	700.6*	SN-80	86.35	89.54	2544.1*
NS 70	29.59	214.10	747.3	SN-70	92.13	49.80	2466.4*
NS 60	32.47	204.60	812.0	SN-60	96.49	40.67	2362.3*
NS 50	35.30	200.10	896.7	SN-50	100.57	36.49	2232.8*
NS 40	38.16	197.47	1000.5	SN-40	104.45	34.12	2083.9*
NS 30	41.08	195.74	1122.2	SN-30	108.16	32.58	1922.5*
NS 20	44.08	194.49	1259.7	SN-20	111.70	31.47	1754.9*
NS 10	47.19	193.51	1410.3	SN-10	115.09	30.56	1587.4*
NS 00	50.43	192.68	1570.8	SN 00	118.34	29.73	1425.2*

Figure 4f

BROUWER DAF PARAMETERS
NO DAF PARAMETERS COMPUTED IN THIS RUN

Figure 4g

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