GODDARD BROUWER ORBIT BULLETIN

D. B. MORGAN  
R. A. GORDON

JULY 1971

GODDARD SPACE FLIGHT CENTER  
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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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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)
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

   $a_0 = a''$
   $e_0 = e''$
   $i = i''$
   $\lambda_0 = \lambda''$
   $g_0 = g''$
   $h_0 = h''$

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

   at $t = t_0$

2. With Pert tape

   a. For $\dot{\lambda}''$ 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 \( g'' \) and \( h'' \) calculation

\[ a'' = a_0 + \frac{\Delta a}{2}, \quad n_0 = \sqrt{\frac{\mu}{(a'')^3}} \]
\[ e'' = e_0 + \frac{\Delta e}{2} \]
\[ i''_0 = i_0 + \frac{\Delta i}{2} \]

c. Correction to \( \ell_0 \), \( g_0 \), and \( h_0 \) (epoch angular elements)

\[ \ell_0 + \Delta \ell \]
\[ g_0 + \Delta g \]
\[ h_0 + \Delta h \]
\[ \ell_0 = \ell'' \text{ at } (t = t_0) \]

II. Calculation of abbreviated notation to simplify formulas:

\[ \eta = \sqrt{1 - e''^2} \]
\[ \theta = \cos i'' \]
\[ \gamma_2 = \frac{k_2}{a''^2} \]
\[ \gamma_4 = \frac{k_4}{a''^4} \]
\[ \gamma_2' = \frac{\gamma_2}{\eta^4} \]
\[ \gamma_4' = \frac{\gamma_4}{\eta^8} \]
III. Compute the first time derivative of the secular terms:

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

\[ \dot{\gamma} = \frac{d\Gamma}{dt} - n_0 \cdot t = n_0 \gamma \left\{ \gamma_2' \left[ \frac{3}{2} (3\theta^2 - 1) + \frac{3}{32} \gamma_2' [25\eta^2 + 16\eta - 15 \right. \right. \]

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

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

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

2. **Mean Argument of Perigee** derivative;

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

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

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

3. **Mean longitude of ascending node** derivative;

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

\[ + \frac{5}{4} \gamma_4' (5 - 3\eta^2) \theta (3 - 7\theta^2) \}\]
IV. Compute constants for long-period terms;

\[ \gamma_3 = \frac{k}{a^3} \quad \gamma_5 = \frac{k_s}{a^5} \]

\[ \gamma_3' = \frac{\gamma_3}{\eta^6} \quad \gamma_5' = \frac{\gamma_5}{\eta^{10}} \]

\[(1 - \theta^2)^{-1}\]

Compute \( \ell P_1 - \ell P_{15} \)

\[ \ell P_1' = 40 \theta^4 (1 - \theta^2)^{-1} \]

\[ \ell P_1 = \frac{1}{8} \gamma_2' \gamma^2 (1 - 11 \theta^2 - \ell P_2') \]

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

\[ \ell P_3 = \frac{1}{4} \frac{\gamma_3'}{\gamma_2} \eta^2 \sin i'' \]

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

\[ \ell P_4 = \frac{5}{64} \frac{\gamma_4'}{\gamma_2} \eta^2 \ell P_4' \sin i'' \]

\[ \ell P_5' = 1 - 5 \theta^2 - 16 \theta^4 (1 - \theta^2)^{-1} \]

\[ \ell P_5 = \frac{35}{384} \frac{\gamma_5'}{\gamma_2} e'' \eta^2 \sin i'' \ell P_5 \]

\[ \ell P_6' = \ell P_1 (1 - \theta^2)^{-1} \]
\[ \begin{align*}
\mathcal{L}_P_6 &= 3 + 16\theta^2 (1 - 5\theta^2)^{-1} + \mathcal{L}_P_6' \\
\mathcal{L}_P_7 &= 4 + 3e''^2 \\
\mathcal{L}_P_8 &= \frac{35}{576} \gamma_5^i e''^3 \theta \sin i'' \left( 5 + 32\theta^2 (1 - 5\theta^2)^{-1} + 2\mathcal{L}_P_6' \right) \\
\mathcal{L}_P_9 &= \frac{e'' \theta}{\sin i''} \\
\mathcal{L}_P_{10} &= \frac{35}{1152} \frac{\gamma_5^i}{\gamma_2} e''^2 \mathcal{L}_9 \mathcal{L}_5' \\
\mathcal{L}_P_{11} &= \frac{\sin i''}{e''} \\
\mathcal{L}_P_{12} &= 2 + e''^2 \\
\mathcal{L}_P_{13} &= (2 + 3e''^2) \theta^2 \\
\mathcal{L}_P_{14} &= 8 (2 + 5e''^2) \theta^4 (1 - 5\theta^2)^{-1} \\
\mathcal{L}_P_{15} &= \frac{e''}{\eta^2 \tan i''} \\

\text{Compute } A_1 - A_{11} \\
A_1 &= e'' (\mathcal{L}_P_1 - \mathcal{L}_P_2) \\
A_2 &= \mathcal{L}_P_3 + (4 + 3e''^2) \mathcal{L}_P_4 \\
A_3 &= \eta (\mathcal{L}_P_1 - \mathcal{L}_P_2) \\
A_4 &= \frac{\eta}{e''} [\mathcal{L}_P_5 + (4 + 9e''^2) \mathcal{L}_P_4]
\end{align*} \]
\[ A_5 = \frac{\eta}{e''} \ell P_5 \]

\[ A_6 = \frac{1}{16} \gamma_2' (\ell P_{12} - 11 \ell P_{13} - 5 \ell P_{14} - 10 e''^2 \theta^2 \ell P_6') + \frac{5}{24} \frac{\gamma_4'}{\gamma_2'} (\ell P_{12} - 3 \ell P_{13} - \ell P_{14} - 2 e''^2 \theta^2 \ell P_6') \]

\[ A_7 = \frac{1}{4} \frac{\gamma_3'}{\gamma_2'} (\ell P_{11} - \theta \ell P_9) + \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} [(\eta^2 \ell P_{11} - \theta \ell P_9) \ell P_7 + e'' \sin i'' (26 + 9 e''^2)] \ell P_4' - \frac{15}{32} \frac{\gamma_3'}{\gamma_2'} e'' \theta^2 \sin i \ell P_7 \ell P_6 \]

\[ A_8 = -\frac{35}{1152} \frac{\gamma_5'}{\gamma_2'} [e'' \sin i'' (3 + 2 e''^2) - e''^2 \theta \ell P_9] \ell P_4' + \theta \ell P_8 \]

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

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

\[ A_{11} = \ell P_{10} + \ell P_8 \]

V. Compute constants for short-period terms included:

Compute \( SP_1 - SP_6 \)

\[ SP_1 = \frac{\eta^2}{2e''} \]

\[ SP_2 = \gamma_2' (1 - \theta^2) \]

\[ SP_3 = \frac{1}{2} \gamma_2' \]

\[ SP_4 = 2 (-1 + 3 \theta^2) \]
\[ \text{SP}_5 = 6(-1 + 5\theta^2) \quad \text{SP}_6 = \theta \text{SP}_3 (1 - \theta^2)^{\frac{1}{3}} \]

VI. Call DRAG Subroutine to compute \( \Delta l_{\text{drag}} \) at Observation time \( t \).

\[ \Delta l_{\text{drag}} = \sum_{q=0}^{m} \sum_{p=2}^{3} N_{p,q} (t - t_q)^p \]

where

\[ m = 0, 1, 2, \ldots, 19 \]

VII. Compute Secular Terms:

1. \( \ell'' = \text{mean mean anomaly}; \)

\[ \ell_0 \text{d}t = (\ell_0 + \Delta \ell_{\text{drag}}) \quad \ell_0 \text{d}t = \text{mod} (\ell_0 \text{d}t + \Delta \ell_{\text{drag}}, 2\pi) \]

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

2. \( g'' = \text{mean argument of Perigee}; \)

\[ g'' = \text{mod} (\dot{g} t + g_0, 2\pi) \]

3. \( h'' = \text{mean longitude of Ascending node}; \)

\[ h'' = \text{mod} (\dot{h} t + h_0, 2\pi) \]

VIII. Test for Critical Inclination:

\[ \Delta i = |i'' - i_c| \]

where

\[ i_c = 63.43^\circ \]

if

\[ \Delta i < 1.5 \]
then
\[ \delta_1 e = \delta_1 I = 1' = g' = h' \]

IX. Compute Long-Period terms:

1. \( \ell' \) = mean anomaly;
   \[ \ell' = \ell'' + A_3 \sin 2\ell'' - A_4 \cos \ell'' + A_5 \cos 3\ell'' \mod (\ell', 2\pi) \]
   \[ \ell_1 = \ell' - \dot{\ell}_0 t + l_0 + \Delta \ell_{d r a g} \mod (\ell_1, 2\pi) \]

2. \( g' \) = Argument of Perigee;
   \[ g' = g'' + A_6 \sin 2g'' + A_7 \cos g'' + A_8 \cos 3g'' \mod (g', 2\pi) \]

3. \( h' \) = longitude of Ascending node;
   \[ h' = h'' + A_3 \sin 2\ell'' + A_{10} \cos g'' - A_{11} \cos 3g'' \mod (h', 2\pi) \]

4. Call KEPLR1 Subroutine to determine \( E' \) and compute \( f' \) from
   \[ f' = \tan^{-1} \left( \frac{\sqrt{1 - e''^2 \sin (E')}}{\cos E' - e''} \right) \]
   \[ \frac{a''}{r'} = \frac{1}{1 - e'' \cos E'} \]

X. Compute Short-Period terms included:

Compute \( B_1 - B_6 \)

\[ B_1 = \gamma_2 \left[ (-1 + 3\theta^2) \left( \frac{a''^3}{r'} - \eta ^3 \right) + 3 (1 - \theta^2) \frac{a''^3}{r'} \cos (2g' + 2f') \right] \]
\[ B_2 = 3e'' \cos (2g' + f') + e'' \cos (2g' + 3f') \]
\[
B_3 = \frac{a''^2}{r^2} \eta^2 + \frac{a''}{r'}
\]

\[
B_4 = SP_4 (B_3 + 1) \sin f'
\]

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

\[
B_5 = f' - 1' + e'' \sin f'
\]

\[
B_6 = 3 \sin (2g' + 2f') + 3 e'' \sin (2g' + 2f')
\]

\[
+ 3 e'' \sin (2g' + f') + e'' \sin (2g' + 3f')
\]

XI. Compute Osculating Elements:

1. Compute a (semi-major axis)

\[
a = a'' (1 + B_1)
\]

2. Compute e (eccentricity)

\[
e = e'' + \delta_1 e + SP_1 \left( B_1 - \gamma_2 \eta^{-4} \cos (2g' + 2f') \right) + \left( B_3 + \frac{1}{3} \right) \sin (2g' + 3f')
\]

3. Compute i (inclination)

\[
i = i'' + \delta_1 i + SP_6 \left[ 3 \cos (2g' + 2f') + B_2 \right] \mod (i, 2\pi)
\]

4. Compute g (argument of Perigee)

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

5. Compute h (longitude of ascending node)

\[
h = h' - \theta SP_3 \left( 6B_5 - B_6 \right) \mod (h, 2\pi)
\]
6. Compute \( \ell \) (mean anomaly)

\[
\ell = \ell' - \eta SP_1 SP_3 B_4 \mod (\ell, 2\pi)
\]

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

8. Compute \( f \) (true anomaly)

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

XII. Compute Position and Velocity Vectors:

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

\[ a, e, i, g, h, \ell - x, y, z, \dot{x}, \dot{y}, \dot{z} \]

CALLING SEQUENCE

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

INPUT/OUTPUT

Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>T0</td>
<td>Epoch time and date</td>
</tr>
<tr>
<td>I</td>
<td>T</td>
<td>Observation time</td>
</tr>
<tr>
<td>I</td>
<td>DRG(60)</td>
<td>[ \left{ \begin{array}{l} t_0, t_1, \ldots, t_{19} \ N_2, 0, N_2, 1, \ldots, N_2, 19 \end{array} \right. ]</td>
</tr>
</tbody>
</table>
Arguments (continued)

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>NQ</td>
<td>Number of drag inputs</td>
</tr>
<tr>
<td>O</td>
<td>F</td>
<td>True Anomaly</td>
</tr>
<tr>
<td>O</td>
<td>EA</td>
<td>Eccentric Anomaly</td>
</tr>
<tr>
<td>O</td>
<td>R(3)</td>
<td>x, y, z Satellite Position Vector</td>
</tr>
<tr>
<td>O</td>
<td>DR(3)</td>
<td>(\dot{x}, \dot{y}, \dot{z}) Satellite Velocity Vector</td>
</tr>
<tr>
<td>O</td>
<td>RMAG</td>
<td>r – magnitude of Position Vector</td>
</tr>
<tr>
<td>O</td>
<td>DRMAG</td>
<td>v – magnitude of Velocity Vector</td>
</tr>
<tr>
<td>O</td>
<td>N</td>
<td>Anomalistic mean motion</td>
</tr>
<tr>
<td>O</td>
<td>PD</td>
<td>Anomalistic Period</td>
</tr>
</tbody>
</table>
| 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 = \(\sqrt{\frac{GM}{3}}\) | Gravitational Constant (length\(^{3/2}\)/time) |
| I   | SATID(11) | SATID(1) = Satellite identification number  
          SATID(2) = reference year  
          SATID(11) = day count of reference date |

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
</table>
| 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) = \(\mu\)  
          TABLE(61) - TABLE(64) = \(K_2, K_3, K_4, K_5\)  
          DPELE(6) = \(a'', e'', i'', g'', h'', l''\)  
          L0DOT = \(\dot{\lambda}_0\)  
          LDOT = \(\dot{\lambda}\)  
          GDOT = \(\dot{g}\)  
          HDOT = \(\dot{h}\) |
| O   | SECPRM | |
| O   | DOTELE | |
### Common

<table>
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<tr>
<th>I/O</th>
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<tr>
<td>O</td>
<td>LPPRM</td>
<td>DEL1E = $\delta_1e$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DEL1I = $\delta_1i$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L1 = $\xi_1$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LP = $\xi$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GP = $g'$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HP = $h'$</td>
</tr>
<tr>
<td>O</td>
<td>OSCELE</td>
<td>ORBPRM(6) = a, e, i, g, h, $\ell$</td>
</tr>
<tr>
<td>O</td>
<td>ETAP</td>
<td>$\eta^3$, $\eta^6$, $\eta^4$</td>
</tr>
<tr>
<td>O</td>
<td>THETA</td>
<td>M1P3T2 = $3\theta^2 - 1$, THETA = $\theta = \cos i$</td>
</tr>
<tr>
<td>O</td>
<td>GMPR</td>
<td>$\gamma_2$</td>
</tr>
<tr>
<td>O</td>
<td>UVPQ</td>
<td>U, V, P, Q</td>
</tr>
<tr>
<td>O</td>
<td>DGPRM</td>
<td>L0DGL = $\xi_0 + \Delta\xi_{drag}$</td>
</tr>
<tr>
<td>O</td>
<td>DAFPRM</td>
<td>LDAF(1) = $A_1$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDAF(2) = $A_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDAF(3) = $-\xi P_5$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDAF(4) = $A_3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDAF(5) = $-A_4$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDAF(6) = $A_5$</td>
</tr>
<tr>
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<td></td>
<td>LDAF(7) = $A_6$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDAF(8) = $A_7$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDAF(9) = $A_8$</td>
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<tr>
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<td></td>
<td>LDAF(10) = $A_9$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDAF(11) = $A_{10}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDAF(12) = $-A_{11}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LDAF(13) = $\xi P_{15}$</td>
</tr>
<tr>
<td>I</td>
<td>PIND</td>
<td>NPT</td>
</tr>
<tr>
<td>O</td>
<td>PERTL</td>
<td>L0DGPT = $\xi_0 + \Delta\xi + \Delta\xi_{drag}$</td>
</tr>
<tr>
<td>O</td>
<td>DELKEP</td>
<td>DKEP(6) = $\Delta a$, $\Delta e$, $\Delta i$, $\Delta g$, $\Delta h$, $\Delta \ell$</td>
</tr>
<tr>
<td>O</td>
<td>PRTKEP</td>
<td>PKEP(3) = $g_0 + \Delta g$, $h_0 + \Delta h$, $\xi_0 + \Delta \xi$</td>
</tr>
<tr>
<td>O</td>
<td>NOD</td>
<td>L0D = $\xi_0 D$</td>
</tr>
</tbody>
</table>

**CALLED BY**

- DAF
- ELEMLD
- PREDS
- SPACEL
- GTRACE
- NODALX
- NSPT

**CALLS**

- PQ
- PERTF0
- DRAG
- KEPLR1
- REDUCE
- UVJLK

17
BRWORB Flowchart
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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I/O</td>
<td>BPOOL</td>
<td>TABLE(80)</td>
<td>Frequently used constants that are previously set in the program but may be changed by the change of constants cards.</td>
</tr>
</tbody>
</table>

CALLED BY

MAIN
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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>NCK(10)</td>
<td>Array of ten numbers from a line of data</td>
</tr>
<tr>
<td>O</td>
<td>NX</td>
<td>Sum of all digits from NCK modulo ten</td>
</tr>
</tbody>
</table>

CALLED BY

SPACEL
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.

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

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

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

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

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

\[
+ \frac{5}{16} \gamma_4' [21 - 9\eta^2 + (-270 + 126\eta^2) \theta^2 + (385 - 189\eta^2) \theta^4]
\right\}
\]
\[ \text{HDOT} = \left\{ -3 \gamma_2 \delta + \frac{3}{8} \gamma_2^2 \left[ \left( -5 + 12 \eta + 9 \eta^2 \right) \delta + \left( -35 - 36 \eta - 5 \eta^2 \right) \delta^3 \right] + \frac{5}{4} \gamma_4^4 \left( 5 - 3 \eta^2 \right) \delta \left( 3 - 7 \delta^2 \right) \right\} \]

\[ \text{LDAF}_1 = \left\{ \frac{1}{8} \gamma_2^i e^\eta \eta^2 \left[ 1 - 11 \delta^2 - 40 \delta^4 \left( 1 - 5 \delta^2 \right)^{-1} \right] - \frac{5}{12} \frac{\gamma_4^4}{\gamma_2^2} e^\eta \eta^2 \left[ 1 - 3 \delta^2 - 8 \delta^4 \left( 1 - 5 \delta^2 \right)^{-1} \right] \right\} \]

\[ \text{LDAF}_2 = \left\{ \frac{1}{4} \frac{\gamma_3^i}{\gamma_2^i} \eta^2 \sin I^" + \frac{5}{64} \gamma_4^i \gamma_2^i \eta^2 \sin I^" \left( 4 + 3 e^\eta^2 \right) \left[ 1 - 9 \delta^2 - 24 \delta^4 \left( 1 - 5 \delta^2 \right)^{-1} \right] \right\} \]

\[ \text{LDAF}_3 = - \frac{35}{384} \frac{\gamma_5^i}{\gamma_2^i} e^2 \eta^2 \sin I^" \left[ 1 - 5 \delta^2 - 16 \delta^4 \left( 1 - 5 \delta^2 \right)^{-1} \right] \]

\[ \text{LDAF}_4 = \left\{ \frac{1}{8} \gamma_2^i \eta^3 \left[ 1 - 11 \delta^2 - 40 \delta^4 \left( 1 - 5 \delta^2 \right)^{-1} \right] - \frac{5}{12} \frac{\gamma_4^i}{\gamma_2^i} \eta^3 \left[ 1 - 3 \delta^2 - 8 \delta^4 \left( 1 - 5 \delta^2 \right)^{-1} \right] \right\} \]
\[\text{LDAF}_5 = \left\{ -\frac{1}{4} \frac{\gamma_3'}{\gamma_2'} \eta^3 \sin I'' \quad \right. \\
\left. \quad - \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} \eta^3 \sin I'' \left(4 + 9 \eta^2 \right) \left[1 - 9 \theta^2 - 24 \theta^4 \left(1 - 5 \theta^2 \right)^{-1}\right] \right\} \]

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

\[\text{LDAF}_7 = \left\{ -\frac{1}{16} \gamma_2' \left[+ \left(2 + \eta^2 \right) - 11 \left(2 + 3 \eta^2 \right) \theta^2 - 40 \left(2 + 5 \eta^2 \right) \theta^4 \left(1 - 5 \theta^2 \right)^{-1} \right. \\
\left. - 400 \eta^2 \theta^6 \left(1 - 5 \theta^2 \right)^{-2} \right] + \frac{5}{24} \frac{\gamma_4'}{\gamma_2'} \left[2 + \eta^2 - 3 \left(2 + 3 \eta^2 \right) \theta^2 \right. \\
\left. - 8 \left(1 + 5 \eta^2 \right) \theta^4 \left(1 - 5 \theta^2 \right)^{-1} - 80 \eta^2 \theta^6 \left(1 - 5 \theta^2 \right)^{-2} \right]\right\} \]

\[\text{LDAF}_8 = \left\{ \frac{1}{4} \frac{\gamma_3'}{\gamma_2'} \left(\frac{\sin I''}{e''} - \frac{e'' \theta^2}{\sin I''} \right) + \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} \right. \\
\left. \times \left[\left(\frac{\eta^2 \sin I''}{e''} - \frac{e'' \theta^2}{\sin I''} \right) \left(4 + 3 \eta^2 \right) + e'' \sin I'' \left(26 + 9 \eta^2 \right) \right] \left[1 - 9 \theta^2 \left. \\
\right. \right. \\
\left. - 24 \theta^4 \left(1 - 5 \theta^2 \right)^{-1} \right] - \frac{15}{32} \frac{\gamma_5'}{\gamma_2'} e'' \theta^2 \sin I'' \left(4 + 3 \eta^2 \right) \right. \\
\left. \left[3 + 16 \theta^2 \left(1 - 5 \theta^2 \right)^{-1} + 40 \theta^4 \left(1 - 5 \theta^2 \right)^{-2} \right]\right\} \]
\[ \text{LDAF}_9 = \left\{ - \frac{35}{1152} \frac{\gamma^i_5}{\gamma_2} \left[ e'' \sin I'' \left( 3 + 2e''^2 \right) - \frac{e''^3 \theta^2}{\sin I''} \right] [1 - 5\theta^2] \\
+ 16\theta^4 (1 - 5\theta^2)^{-1} \right\} + \frac{35}{576} \frac{\gamma^i_5}{\gamma_2} e''^3 \theta^2 \sin I'' \left[ 5 + 32\theta^2 (1 - 5\theta^2)^{-1} \right] \\
+ 80\theta^4 (1 - 5\theta^2)^{-2} \right\} \]

\[ \text{LDAF}_{10} = \left\{ - \frac{1}{8} \frac{\gamma^i_2}{\gamma_2} e''^2 \theta \left[ 11 + 80\theta^2 (1 - 5\theta^2)^{-1} + 200\theta^4 (1 - 5\theta^2)^{-2} \right] \\
+ \frac{5}{12} \frac{\gamma^i_4}{\gamma_2} e''^2 \theta \left[ 3 + 16\theta^2 (1 - 5\theta^2)^{-1} + 40\theta^4 (1 - 5\theta^2)^{-2} \right] \right\} \]

\[ \text{LDAF}_{11} = \left\{ \frac{1}{4} \frac{\gamma^i_3}{\gamma_2} \frac{e''}{\sin I''} + \frac{5}{64} \frac{\gamma^i_5}{\gamma_2} \frac{e''}{\sin I''} (4 + 3e''^2) \left[ 1 - 9\theta^2 \\
- 24\theta^4 (1 - 5\theta^2)^{-1} \right] + \frac{15}{32} \frac{\gamma^i_5}{\gamma_2} e'' \theta \sin I'' (4 + 3e''^2) \right\} \]

\[ [3 + 16\theta^2 (1 - 5\theta^2)^{-1} + 40\theta^4 (1 - 5\theta^2)^{-2}] \right\} \]
\[
LDAF_{12} = \left\{-\frac{35}{1152} \frac{\gamma_5^\prime}{\gamma_2^\prime} e^3 \frac{\theta}{\sin I^\prime} \left[1 - 5\theta^2 - 16\theta^4 \left(1 - 5\theta^2\right)^{-1}\right]
\right.
\]
\[
- \frac{35}{576} \frac{\gamma_5^\prime}{\gamma_2^\prime} e^3 \frac{\theta}{\sin I^\prime} \left[5 + 32\theta^2 \left(1 - 5\theta^2\right)^{-1} + 80\theta^4 \left(1 - 5\theta^2\right)^{-2}\right]\right\}
\]

\[
LDAF_{13} = \frac{e^\prime}{\eta^2 \tan I^\prime}
\]

where

\(e^\prime\) = eccentricity

\(I^\prime\) = inclination

\(\theta = \cos i_0\)

\(i_0\) = inclination at epoch

\(\eta = \sqrt{1 - e^\prime^2}\)

\(\gamma_n^\prime = \gamma_n / \eta^{2n}\)

\(\gamma_n = K_n / a^n\)

\(a\) = 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

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

### Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
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</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(2) = KMCUL</td>
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<tr>
<td>I</td>
<td></td>
<td>TABLE(24) = BK</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(35) = MINDAY</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(41) = MU</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(49) = ( \omega_e )</td>
</tr>
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<td>I</td>
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<td>TABLE(59) = MNCUT</td>
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<tr>
<td>I</td>
<td></td>
<td>TABLE(61) = K2</td>
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<td>DAFPRM</td>
<td>LDAF(13)</td>
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<td>DOTELE</td>
<td>LDOT</td>
</tr>
<tr>
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</tr>
<tr>
<td>I</td>
<td>THETAP</td>
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</tr>
<tr>
<td>I</td>
<td>RADIAN</td>
<td>AMBDA</td>
</tr>
</tbody>
</table>
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**

<table>
<thead>
<tr>
<th>Col. No.</th>
<th>Format</th>
<th>Description</th>
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<tbody>
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<tr>
<td>10-11</td>
<td>XX</td>
<td>Year</td>
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<tr>
<td>12</td>
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<td>Blank</td>
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<tr>
<td>13-14</td>
<td>XX</td>
<td>Month</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>Date predictions begin</td>
</tr>
<tr>
<td>16-17</td>
<td>XX</td>
<td>Day</td>
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<td>19-20</td>
<td>XX</td>
<td>Hour</td>
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<td></td>
<td>Blank</td>
</tr>
<tr>
<td>22-23</td>
<td>XX</td>
<td>Minutes</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Col. No.</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-15</td>
<td>SXXXXXXXXXXDSXX</td>
</tr>
<tr>
<td>16</td>
<td>Blank</td>
</tr>
<tr>
<td>17-31</td>
<td>SXXXXXXXXXXDSXX</td>
</tr>
<tr>
<td>32</td>
<td>Blank</td>
</tr>
<tr>
<td>33-47</td>
<td>SXXXXXXXXXXDSXX</td>
</tr>
<tr>
<td>48</td>
<td>Blank</td>
</tr>
<tr>
<td>Col. No.</td>
<td>Format</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>49-63</td>
<td>SXXXXXXXXXXXXXDSXX</td>
</tr>
<tr>
<td>64</td>
<td>Blank</td>
</tr>
<tr>
<td>65-79</td>
<td>SXXXXXXXXXXXXXDSXX</td>
</tr>
<tr>
<td>80</td>
<td>Blank</td>
</tr>
<tr>
<td>81-95</td>
<td>SXXXXXXXXXXXXXDSXX</td>
</tr>
<tr>
<td>96</td>
<td>Blank</td>
</tr>
<tr>
<td>97-111</td>
<td>SXXXXXXXXXXXXXDSXX</td>
</tr>
</tbody>
</table>

The order of the parameters is as follows:

**Line 3**
- \( \text{LDAF}_4/2\pi \)
- \( \text{LDAF}_5/2\pi \)
- \( \text{LDAF}_6/2\pi \)
- \( \text{LDAF}_7 \)
- \( \text{LDAF}_8 \)
- \( \text{LDAF}_9 \)
- \( \text{LDAF}_{10} \)

**Line 4**
- \( \text{LDAF}_{11} \)
- \( \text{LDAF}_{12} \)
- \( \text{LDAF}_1 \)
- \( \text{LDAF}_2 \)
- \( \text{LDAF}_3 \)
- \( \cos I'' \)
- \( e'' \)

**Line 5**
- \( \text{GDOT}/13.4472 \)
- \( \text{HDOT}/13.4472 \)
- \( \tilde{g}_0'' \)
- \( \tilde{h}_0'' \)
- \( \tilde{I}_0''/2\pi \)
- \( I''/2\pi \)
- \( \lambda_g(t_p)/2\pi \)
Line 6 — \(-\text{LDAF}_{13}/2\pi\)
\(d\)
\(h\)
\(m\)
\(a\)
\(N_2/2\pi (13.4472)^2\)
\(n_0 + S_1/2\pi (13.4472)\)

Line 7 — \(K_2\)
\(K_3\)
\(-K_8\)
\(1/4\gamma_2\)
\(K_9/2\pi\)
\(K_1\)
\(K_4\)

Line 8 — \(-K_5\)
\(-K_6\)
\(\eta/4 e^\gamma_2\)
\(t_{p_1} - t_0\)

CALLED BY

MAIN

CALLS

DREFOD
JDSCUT
BRWORB
REDUCE
DAYCT
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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>IYR</td>
<td>Year</td>
</tr>
<tr>
<td>I</td>
<td>IDY</td>
<td>Number of days from January 0 of year IYR</td>
</tr>
<tr>
<td>O</td>
<td>IY</td>
<td>Year</td>
</tr>
<tr>
<td>O</td>
<td>IM</td>
<td>Month</td>
</tr>
<tr>
<td>O</td>
<td>ID</td>
<td>Day</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>IY</td>
<td>Year</td>
</tr>
<tr>
<td>I</td>
<td>IM</td>
<td>Month</td>
</tr>
<tr>
<td>I</td>
<td>ID</td>
<td>Day</td>
</tr>
<tr>
<td>O</td>
<td>IDAYS</td>
<td>Number of days from January 0 of given year to given date</td>
</tr>
</tbody>
</table>

CALLED BY

MAIN
DAF
DREFOD
DAYCT Flowchart

1. ENTER DAYCT

2. Initialize
   - I(1) = 0  I(7) = 181
   - I(2) = 31  I(8) = 212
   - I(3) = 59  I(9) = 243
   - I(4) = 90  I(10) = 273
   - I(5) = 120  I(11) = 304
   - I(6) = 151  I(12) = 334

3. Set L = 1

4. DAYS = I(L)

5. Is Month > L?
   - NO: DAYS = DAYS + 1
   - YES: L = L + 1

6. Is Month > 2?
   - YES: L = 60
   - NO: RETURN

7. Does Y = L?
   - YES: DAYS = DAYS + 1
   - NO: L = L + 4

8. RETURN
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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>DEG</td>
<td>Degrees</td>
</tr>
<tr>
<td>I</td>
<td>FM</td>
<td>Minutes</td>
</tr>
<tr>
<td>I</td>
<td>SS</td>
<td>Seconds</td>
</tr>
<tr>
<td>O</td>
<td>RAD</td>
<td>Radians</td>
</tr>
</tbody>
</table>

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(16) = DEGRAD (deg/rad)</td>
</tr>
</tbody>
</table>

CALLED BY

MAIN
POOL
DMSTOR Flowchart

ENTER DMSTOR

A = 1
C = 1/60

Is
DEG
Negative?

YES

A = -1
DEG = DEG

NO

RAD =
((SS*C + FM)*C + DEG)*A/DEGRAD

RETURN
DRAG
Compute Drag

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

METHOD

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

where

- $m = 0, 1, 2, 3, \ldots, 19$
- $t$ = 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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>DRG(60)</td>
<td>$\text{DRG}(1)$ [\text{DRG}(20)] [t_0, t_1, \ldots, t_{19}]</td>
</tr>
</tbody>
</table>
Arguments (continued)

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>DRG(60)</td>
<td>( \text{DRG(21)} ) ( N_{2,0}, N_{2,1}, \ldots, N_{2,19} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \text{DRG(40)} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \text{DRG(41)} ) ( N_{3,0}, N_{3,1}, \ldots, N_{3,19} )</td>
</tr>
<tr>
<td>I</td>
<td>PI2</td>
<td>( 2\pi ) radians</td>
</tr>
<tr>
<td>O</td>
<td>DRAGL</td>
<td>( \Delta L )</td>
</tr>
<tr>
<td>I</td>
<td>T0</td>
<td>Epoch time</td>
</tr>
<tr>
<td>I</td>
<td>T</td>
<td>Observation time - T0</td>
</tr>
<tr>
<td>I</td>
<td>KMULT</td>
<td>K multiplier</td>
</tr>
<tr>
<td>I</td>
<td>NQ</td>
<td>Number of drag inputs</td>
</tr>
</tbody>
</table>

CALLED BY

BRWORB

CALLS

REDUCE
DRAG Flowchart
DRAGLD
Drag Load

PURPOSE

To load $N_{(p, q)}$ data for the computation of $\Delta L$ drag.

CALLING SEQUENCE

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

INPUT/OUTPUT

Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>SATID(11)</td>
<td>SATID(1) = reference satellite ID number</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SATID(2) = reference year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SATID(11) = day count of reference date</td>
</tr>
<tr>
<td>O</td>
<td>DRAGDT(40)</td>
<td>DRAGDT(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRAGDT(3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>packed drag date</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRAGDT(30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRAGDT(2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>packed drag time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRAGDT(4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRAGDT(40)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRG(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$t_0, t_1, \ldots, t_{19}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRG(20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRG(21)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$N_{2,0}, N_{2,1}, \ldots, N_{2,19}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRG(40)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DRG(41)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$N_{3,0}, N_{3,1}, \ldots, N_{3,19}$</td>
</tr>
<tr>
<td>O</td>
<td>NQ</td>
<td>Number of drag inputs</td>
</tr>
</tbody>
</table>
Arguments (continued)

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>NERROR</td>
<td>Error indicator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 0    no error</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= -1   wrong Sat. ID number on drag card</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>IYREF</td>
<td>Year of reference date</td>
</tr>
<tr>
<td>I</td>
<td>IDC</td>
<td>Number of days from January 0 of the year to the day of reference</td>
</tr>
<tr>
<td>I</td>
<td>IOY</td>
<td>Year of observation date</td>
</tr>
<tr>
<td>I</td>
<td>IOM</td>
<td>Month of observation date</td>
</tr>
<tr>
<td>I</td>
<td>IOD</td>
<td>Day of observation date</td>
</tr>
<tr>
<td>O</td>
<td>IDAYS</td>
<td>Number of days from the reference date to the observation date</td>
</tr>
</tbody>
</table>

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

Compute

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

Compute the semi-major axis of the orbit:

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

Compute the inclination angle:

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

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:

\[ \omega = u - \nu, \text{ for } e \neq 0, \]

where:

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

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

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

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

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, \( \nu \):

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

Compute the position magnitude, \( r \):

\[ r = a (1 - e \cos E). \]
Compute the radial and horizontal components of $r$, $V_r$ 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, $r = (x, y, z)$ and $\dot{r} = (\dot{x}, \dot{y}, \dot{z})$, respectively:

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

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

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

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

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

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

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 $(x, y, z, \dot{x}, \dot{y}, \dot{z})$. 

55
INPUT/OUTPUT

Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>INPUT(6)</td>
<td>Position and velocity vectors (x, y, z, ( \dot{x}, \dot{y}, \dot{z} ))</td>
</tr>
<tr>
<td>O</td>
<td>OUTPUT(6)</td>
<td>Osculating elements (a, e, i, ( \omega ), ( \Omega ), M)</td>
</tr>
</tbody>
</table>

From entry point ELOSC

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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(34) = PI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(4) = MU</td>
</tr>
</tbody>
</table>

CALLED BY

ELEMLD

CALLS

VECTOR
VMAG
VCROSS
VDOT
KEPLR1
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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
</table>
| 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)

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

Common

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

CALLED BY

MAIN
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: \( \phi_S \) (geodetic latitude)

Compute geocentric latitude from

\[
\phi'_S = \tan^{-1} \left[ (1 - f)^2 \tan \phi_S \right]
\]

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

Compute the height above the reference ellipsoid,

\[
H_s = \left[ r^2 - r_s^2 \sin^2 (\phi_s - \phi'_s) \right]^{\frac{1}{2}} - r_c \cos (\phi_s - \phi'_s)
\]

\[
\Delta \phi'_s = \sin^{-1} \left[ \frac{H_s}{r} \sin (\phi_s - \phi'_s) \right], \quad -\frac{\pi}{2} \leq \Delta \phi'_s \leq \frac{\pi}{2}
\]

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;

\[ |g_{i+1} - g_i| \leq \varepsilon \]

where \( \varepsilon \) 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**

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>TAO</td>
<td>T_{\Omega} — start time of reference ellipsoid</td>
</tr>
<tr>
<td>I</td>
<td>T0</td>
<td>t_0 — epoch time</td>
</tr>
<tr>
<td>I</td>
<td>REV</td>
<td>Number of orbital revolutions</td>
</tr>
<tr>
<td>O</td>
<td>GDL(360)</td>
<td>Geodetic latitudes (( \phi ))</td>
</tr>
<tr>
<td>O</td>
<td>DLONG(360)</td>
<td>Longitude of geodetic meridian east of ascending nodal meridian (( \lambda_{\phi} ))</td>
</tr>
<tr>
<td>O</td>
<td>HT(360)</td>
<td>Height above meridian of satellites geodetic meridian (Ht_{\phi})</td>
</tr>
<tr>
<td>O</td>
<td>TGDL(360)</td>
<td>Time of geodetic latitude (t_{\phi})</td>
</tr>
<tr>
<td>I</td>
<td>DGDL</td>
<td>Increment in geodetic latitude by degrees (( \Delta \phi ))</td>
</tr>
<tr>
<td>O</td>
<td>KGDL</td>
<td>Number of GDL's in the interval ascending node to north point</td>
</tr>
<tr>
<td>O</td>
<td>ADGDL(6)</td>
<td>ADGDL(1-3) — t_{U}, \lambda_{U}, ht_{U}, ADGDL(4-6) — t, \lambda, ht</td>
</tr>
</tbody>
</table>
Arguments (continued)

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>NSGDL(6)</td>
<td>NSGDL(1-3) = ( t_N, \lambda_N, h_N ), ( t_s, \lambda_s, h_s )</td>
</tr>
<tr>
<td>I</td>
<td>DRG(1)</td>
<td>( t_0, t_1, \ldots, t_{19} )</td>
</tr>
<tr>
<td></td>
<td>DRG(20)</td>
<td>( N_{2,0}, N_{2,1}, \ldots, N_{2,19} )</td>
</tr>
<tr>
<td></td>
<td>DRG(21)</td>
<td>( N_{3,0}, N_{3,1}, \ldots, N_{3,19} )</td>
</tr>
<tr>
<td>I</td>
<td>SATID(11)</td>
<td>Number of drag inputs</td>
</tr>
<tr>
<td>I</td>
<td>STAR(300)</td>
<td>'*' indicates satellites in sunlight, ' ' not in sunlight</td>
</tr>
<tr>
<td>O</td>
<td>TAR(6)</td>
<td>TAR = BLANK, or TAR = *, indicates if ascending, descending nodal crossings, or north and south points are in or out of shadow</td>
</tr>
</tbody>
</table>

Data Statements

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT</td>
<td>IT /10/ max. no. of iterations</td>
</tr>
<tr>
<td>TG</td>
<td>tg /0.0/ Greenwich epoch time</td>
</tr>
<tr>
<td>ASTRX</td>
<td>'*'</td>
</tr>
<tr>
<td>BLANK</td>
<td>'/'</td>
</tr>
</tbody>
</table>
Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>POOL</td>
<td>TABLE(9) = 1/f, TABLE(24) = 2, TABLE(31) = t_0 l</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(69) = \omega, TABLE(59) = min/cut</td>
</tr>
<tr>
<td>I</td>
<td>OSCELE</td>
<td>ORB(6) = a, e, i, g, h, l</td>
</tr>
<tr>
<td>I</td>
<td>SECPRM</td>
<td>DPELE(6) = a', e', i', g', h', l'</td>
</tr>
<tr>
<td>I</td>
<td>PERTL</td>
<td>LDGPT = 1dgPt, E_0, t_0</td>
</tr>
<tr>
<td>I</td>
<td>NSMAP</td>
<td>T_{minN}, \lambda_N, \lambda_{EN}, \phi_N, Ht_N, t_{minS}, \lambda_S, \lambda_{ES}, \phi_S, Ht_S</td>
</tr>
<tr>
<td>I</td>
<td>DHMNS</td>
<td>min_N, min_S, hr_N, hr_S, Dy_N, Dy_S</td>
</tr>
<tr>
<td>I</td>
<td>DOTELE</td>
<td>I_0dot</td>
</tr>
<tr>
<td>I</td>
<td>NOD</td>
<td>LOD = 1_0D</td>
</tr>
<tr>
<td>I</td>
<td>NODMAP</td>
<td>t_{min\Omega}, \lambda_{\Omega}, \lambda_{E\Omega}, ht_{\Omega}, t_{min\Omega}, \lambda_{\Omega}, \lambda_{E\Omega}, ht_{\Omega}, E_{\Omega}</td>
</tr>
<tr>
<td>I</td>
<td>DHMNSD</td>
<td>min_{\Omega}, min_{\Omega}, hr_{\Omega}, hr_{\Omega}, Dy_{\Omega}, Dy_{\Omega}</td>
</tr>
</tbody>
</table>

CALLED BY

MAIN

CALLS

CALL BRWORB
CALL SSPTHT
CALL SDFWOE
GTRACE Flowchart

GTRACE

1. Compute Ground Trace of Ascending Node, Descending Node, North and South Point
2. Determine if Nodal Crossings and North, South Points Are In, or Out of Shadow
3. Increment Ground Trace by Geodetic Latitude
4. Compute Geodetic Latitude (\( \phi \)) and Approximate Declination (\( \delta \))

C-1

1. Compute Argument of Latitude \( \upsilon_{G} \)
2. Compute True Anomaly \( \nu \)
3. Compute Eccentric Anomaly \( E_{G} \)
4. Compute Time \( t_{G} \)
5. Update Kepler Elements

C-2

1. Compute Vectors
2. Call BWRORB, Call SSPTHT
3. Compute Longitude \( \lambda_{G} \) and Height \( (H_{G}) \)
4. Determine if Satellite Is in Shadow Call SDFHOE

RETURN
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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>HH</td>
<td>Hours</td>
</tr>
<tr>
<td>I</td>
<td>FM</td>
<td>Minutes</td>
</tr>
<tr>
<td>I</td>
<td>SS</td>
<td>Seconds</td>
</tr>
<tr>
<td>O</td>
<td>RAD</td>
<td>Radians</td>
</tr>
</tbody>
</table>

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(65) = RADPHR (rad/hr)</td>
</tr>
</tbody>
</table>

CALLED BY
MAIN
HMSTOR Flowchart

ENTER HMSTOR

C = \frac{1}{60}

RAD = [(SS \times C + FM) \times C + HH] \times \text{rad/hr}

RETURN
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

\[
\begin{align*}
  t_6 & \quad \text{times from the perturbation tape} \\
  t_5 & \\
  t_4 & \\
  t_3 & \\
  t_2 & \\
  t_1 & \\
  f(t_6) & \\
  f(t_5) & \\
  f(t_4) & \\
  f(t_3) & \\
  f(t_2) & \\
  f(t_1) & \\
\end{align*}
\]

\[t = \text{observation or request time}\]

\[\Delta t = \text{time increment from perturbation tape}\]

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

\[\Delta^{K-1} f(t_{i+1}) - \Delta^{K-1} f(t_i)\]
where

\[ \Delta^0 f(t_i) = f(t_i) \]

**Difference Table**

<table>
<thead>
<tr>
<th>(t_6)</th>
<th>(f(t_6))</th>
<th>(\Delta f(t_5))</th>
<th>(\Delta^2 f(t_4))</th>
<th>(\Delta^3 f(t_3))</th>
<th>(\Delta^4 f(t_2))</th>
<th>(\Delta^5 f(t_1))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(t_5)</td>
<td>(f(t_5))</td>
<td>(\Delta f(t_4))</td>
<td>(\Delta^2 f(t_3))</td>
<td>(\Delta^3 f(t_2))</td>
<td>(\Delta^4 f(t_1))</td>
<td>(\Delta^5 f(t_1))</td>
</tr>
<tr>
<td>(t_4)</td>
<td>(f(t_4))</td>
<td>(\Delta f(t_3))</td>
<td>(\Delta^2 f(t_2))</td>
<td>(\Delta^3 f(t_1))</td>
<td>(\Delta^4 f(t_1))</td>
<td>(\Delta^5 f(t_1))</td>
</tr>
<tr>
<td>(t_3)</td>
<td>(f(t_3))</td>
<td>(\Delta f(t_2))</td>
<td>(\Delta^2 f(t_1))</td>
<td>(\Delta^3 f(t_1))</td>
<td>(\Delta^4 f(t_1))</td>
<td>(\Delta^5 f(t_1))</td>
</tr>
<tr>
<td>(t_2)</td>
<td>(f(t_2))</td>
<td>(\Delta f(t_1))</td>
<td>(\Delta^2 f(t_1))</td>
<td>(\Delta^3 f(t_1))</td>
<td>(\Delta^4 f(t_1))</td>
<td>(\Delta^5 f(t_1))</td>
</tr>
<tr>
<td>(t_1)</td>
<td>(f(t_1))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[(\text{elements}) \phi = f(t_6) + \Delta f(t_5) (tt0) + \Delta^2 f(t_4) \left[ \frac{(tt0)(tt1)}{2} \right] + \Delta^3 f(t_3) \left[ \frac{(tt0)(tt1)(tt2)}{6} \right] + \Delta^4 f(t_2) \left[ \frac{(tt0)(tt1)(tt2)(tt3)}{24} \right] + \Delta^5 f(t_1) \left[ \frac{(tt0)(tt1)(tt2)(tt3)(tt4)}{120} \right] \]

where

\[ tt0 = t - t_6 \]
\[ tt1 = \Delta t + tt0 \]
\[ tt2 = \Delta t + tt1 \]
\[ tt3 = \Delta t + tt2 \]
\[ tt4 = \Delta t + tt3 \]
CALLING SEQUENCE

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

INPUT/OUTPUT

Arguments

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

Definition of Array A (I, J)

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

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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>DAYJ</td>
<td>Julian days</td>
</tr>
<tr>
<td>I</td>
<td>SS</td>
<td>Seconds</td>
</tr>
<tr>
<td>O</td>
<td>CUT</td>
<td>Julian days and seconds in canonical units of time</td>
</tr>
</tbody>
</table>

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(5) = SECCUT</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(30) = SECDAY</td>
</tr>
</tbody>
</table>

CALLED BY

DRAGLD
TIMETB
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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>DAYJ</td>
<td>Julian days</td>
</tr>
<tr>
<td>I</td>
<td>SEC</td>
<td>Seconds</td>
</tr>
<tr>
<td>I</td>
<td>RF</td>
<td>Rounding factor (added to SEC)</td>
</tr>
<tr>
<td>O</td>
<td>DAY</td>
<td>Julian days</td>
</tr>
<tr>
<td>O</td>
<td>HH</td>
<td>Hours</td>
</tr>
<tr>
<td>O</td>
<td>FM</td>
<td>Minutes</td>
</tr>
<tr>
<td>O</td>
<td>SS</td>
<td>Seconds</td>
</tr>
</tbody>
</table>

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, \( \text{MAX} = 10 \)

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 \(|E_0 - E| - \text{TOL} \leq 0\), go to Step 13; otherwise continue to Step 8

8. Add 1 to number of iterations

9. If (number of iterations - \( \text{MAX} \)) \leq 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 ±.05 × 10⁻¹⁰.

CALLING SEQUENCE

CALL KEPLRI (MA, ECC, ERRC, E2)

INPUT/OUTPUT

Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>MA</td>
<td>Mean anomaly</td>
</tr>
<tr>
<td>I</td>
<td>ECC</td>
<td>Eccentricity</td>
</tr>
<tr>
<td>O</td>
<td>ERRC</td>
<td>Error code</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 0, convergence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≠ 0, no convergence</td>
</tr>
<tr>
<td>O</td>
<td>E2</td>
<td>Eccentric anomaly</td>
</tr>
</tbody>
</table>

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 \ast \frac{(X - X1) \ast (X - X2)}{(X0 - X1) \ast (X0 - X2)}
Term 2 = Y1 \ast \frac{(X - X0) \ast (X - X2)}{(X1 - X0) \ast (X1 - X2)}
Term 3 = Y2 \ast \frac{(X - X0) \ast (X - X1)}{(X2 - X0) \ast (X2 - X1)}

Y = Term 1 + Term 2 + Term 3

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

INPUT/OUTPUT
Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>X</td>
<td>Input request variable</td>
</tr>
<tr>
<td>O</td>
<td>Y</td>
<td>Computed F(X) for output</td>
</tr>
<tr>
<td>I</td>
<td>X0</td>
<td>First input variable</td>
</tr>
<tr>
<td>I</td>
<td>Y0</td>
<td>F(X0)</td>
</tr>
<tr>
<td>I</td>
<td>X1</td>
<td>Second input variable</td>
</tr>
<tr>
<td>I</td>
<td>Y1</td>
<td>F(X1)</td>
</tr>
<tr>
<td>I</td>
<td>X2</td>
<td>Third input variable</td>
</tr>
<tr>
<td>I</td>
<td>Y2</td>
<td>F(X2)</td>
</tr>
</tbody>
</table>

CALLED BY
SATOR

83
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:

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

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

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

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:

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

where $\epsilon$ is some preassigned, small positive number.
CALLING SEQUENCE

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

INPUT/OUTPUT

Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>REV</td>
<td>Number of orbital revolutions from epoch</td>
</tr>
<tr>
<td>I</td>
<td>DRG(1)</td>
<td>(t_0, t_1, \ldots, t_{19})</td>
</tr>
<tr>
<td></td>
<td>DRG(20)</td>
<td>(N_2, 0, N_2, 1, \ldots, N_{2, 19})</td>
</tr>
<tr>
<td></td>
<td>DRG(21)</td>
<td>(N_3, 0, N_3, 1, \ldots, N_{3, 19})</td>
</tr>
<tr>
<td>I</td>
<td>NQ</td>
<td>Number of drag inputs</td>
</tr>
<tr>
<td>O</td>
<td>TACUT</td>
<td>Time of ascending nodal crossing from epoch</td>
</tr>
<tr>
<td>I</td>
<td>SATID(11)</td>
<td>SATID(1) = Satellite identification number</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SATID(2) = reference year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SATID(11) = day count of reference date</td>
</tr>
<tr>
<td>I</td>
<td>T0</td>
<td>Epoch time</td>
</tr>
<tr>
<td>I</td>
<td>IDAD</td>
<td>= 0, time of ascending and descending nodal crossing determined</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 1, time of ascending node determined</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 2, time of descending node determined</td>
</tr>
</tbody>
</table>

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(16) = deg/rad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(23) = (2 \pi)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(34) = (\pi)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(31) = TOL</td>
</tr>
</tbody>
</table>

86
Common (continued)

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(69) = $\omega_e$</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(59) = min/cut</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(24) = $\mu^2$</td>
</tr>
<tr>
<td>I</td>
<td>OSCELE</td>
<td>ORB(6) = a, e, i, g, h, l</td>
</tr>
<tr>
<td>I</td>
<td>SECPRM</td>
<td>DPELE(6) = $a''$, $e''$, $i''$, $g''$, $h''$, $l''$</td>
</tr>
<tr>
<td>I</td>
<td>N0D</td>
<td>L0D = 10 D</td>
</tr>
<tr>
<td>I</td>
<td>PERTL</td>
<td>LDGPT = 1dgPt</td>
</tr>
<tr>
<td>O</td>
<td>NODMAP</td>
<td>$T_{\min\Omega}$, $\lambda_\Omega$, $\lambda_{E\Omega}$, $ht_\Omega$, $t_{\min\Omega}$, $\lambda_\Sigma$, $\lambda_{E\Sigma}$, $ht_\Sigma$, $E_\Omega$</td>
</tr>
<tr>
<td>O</td>
<td>DHMNOD</td>
<td>min$<em>\Omega$, min$</em>\Sigma$, hr$<em>\Omega$, hr$</em>\Sigma$, Dy$<em>\Omega$, Dy$</em>\Sigma$</td>
</tr>
<tr>
<td></td>
<td>DATA</td>
<td>IT = 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tg = 0.0D0</td>
</tr>
</tbody>
</table>

CALLED BY

    MAIN
    GTRACE

CALLS

    CALL BRWORB
    CALL SSPTHT
NODALX

\[ n = \lfloor GM_{\text{loD}} \rfloor \]

\[ E_{rev} = (\lambda_c - 1) \frac{2n}{\lambda_c} \]

IA = 1
IB = 2

IDAD

IB = 1
Compute Ascending Node

Compute Ascending and Descending

IA = 2
Compute Descending Node

Compute Time of Nodal Crossing's

C.1

Call BRWORB

Compute Map of Nodal Crossings

Call SSPTHT

RETURN

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

\[
fi = \begin{cases} 
\frac{\pi}{2} - g_i & \text{at the North point} \\
\frac{3\pi}{2} - g_i & \text{at the South point}
\end{cases}
\]  

(1)

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

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

(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 \(\epsilon\) is some preassigned, small positive number.
CALLING SEQUENCE

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

INPUT/OUTPUT

Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>REV</td>
<td>Number of orbital revolutions</td>
</tr>
<tr>
<td>I</td>
<td>DRG(1)</td>
<td>$t_0, t_1, \ldots, t_{19}$</td>
</tr>
<tr>
<td></td>
<td>DRG(20)</td>
<td>$N_2,0, N_2,1, \ldots, N_2,19$</td>
</tr>
<tr>
<td></td>
<td>DRG(21)</td>
<td>$N_3,0, N_3,1, \ldots, N_3,19$</td>
</tr>
<tr>
<td>I</td>
<td>NQ</td>
<td>Number of drag inputs</td>
</tr>
<tr>
<td>I</td>
<td>SATID(11)</td>
<td>SATID(1) = Satellite identification number</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SATID(2) = reference year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SATID(11) = day count of reference date</td>
</tr>
<tr>
<td>I</td>
<td>TO</td>
<td>Epoch time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 0, time of north point and south point determined</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 1, time of north point determined</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 2, time of south point determined</td>
</tr>
<tr>
<td>I</td>
<td>IDNS</td>
<td></td>
</tr>
</tbody>
</table>

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(31) = TOL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(69) = $\omega_e$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(59) = min/cut</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(24) = $\mu^2$</td>
</tr>
<tr>
<td>I</td>
<td>OSCELE</td>
<td>ORB(6) = a, e, i, g, h, l</td>
</tr>
</tbody>
</table>
| I   | SECPRM| DPELE(6) = a", e", i", g", h", l"
| I   | PERTL | LDGPT = $l_{dPt}, E_0, l_0$ |
| O   | NSMAP | $T_{minN}, \lambda_N, \lambda_{EN}, \phi_N, Ht_N, t_{minS}, \lambda_S, \lambda_{ES}, \phi_S, Ht_S$ |
Common (continued)

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>DHMNS DATA</td>
<td>min$_N$, min$_S$, hr$_N$, hr$_S$, Dy$_N$, Dy$_S$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IT = 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tg = 0.0D0</td>
</tr>
</tbody>
</table>

**CALLED BY**

- MAIN
- GTRACE

**CALLS**

- CALL BRWORB
- CALL SSPTHT
NSPT Flowchart
### 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

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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(22) = RAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(41) = Mu</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(42) = FLAT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(49) = ROT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(58) = J</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(61) = K2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(62) = K3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(63) = K4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(64) = K5</td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>PLN</td>
<td>Perturbation tape logical input unit</td>
</tr>
<tr>
<td>I</td>
<td>SATID(11)</td>
<td>SATID(1) = reference satellite ID</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SATID(2) = year of reference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SATID(3) = day count of reference date</td>
</tr>
<tr>
<td>I</td>
<td>TIME</td>
<td>Observation time</td>
</tr>
<tr>
<td>I/O</td>
<td>KMULT</td>
<td>K multiplier for ΔL drag computation</td>
</tr>
<tr>
<td>O</td>
<td>B(6)</td>
<td>Array of elements from perturbation tape for observation time - aₚ, eₚ, iₚ, lₚ, gₚ, hₚ</td>
</tr>
<tr>
<td>O</td>
<td>IERR</td>
<td>Error</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 0 no error</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 37 error in reading pert tape</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 38 wrong satellite ID on pert tape</td>
</tr>
</tbody>
</table>
Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(5) = SECCUT</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(45) = CUTDAY</td>
</tr>
</tbody>
</table>

CALLED BY

BRWORB

CALLS

DREFOD
JDSCUT
INTPL0
PERTF0 Flowchart
PERTF0 Flowchart (continued)
POOL

Constants Pool

PURPOSE

To compute frequently used constants.

CALLING SEQUENCE

CALL POOL

INPUT/OUTPUT

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(1) = meters/ft</td>
</tr>
<tr>
<td></td>
<td>(BLOCK</td>
<td>TABLE(2) = km/CUL</td>
</tr>
<tr>
<td></td>
<td>DATA)</td>
<td>TABLE(4) = km/A.U.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(5) = sec/CUT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(9) = 1/flattening coefficient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(11) = $\omega_e$ (earth rotation in rad/sec)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(12) = $J_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(13) = $J_3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(14) = $J_4$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(15) = $J_5$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(16) = deg/rad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(17) = deg of obliquity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(18) = min of elliptic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(19) = sec of elliptic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(21) = km/mi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(22) = radius of earth in CUL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(24) = GM = $\mu^2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(30) = sec/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(32) = sec/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(33) = deg/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(41) = $\mu$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(42) = Flattening coefficient</td>
</tr>
<tr>
<td>O</td>
<td>BPOOL</td>
<td></td>
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</tbody>
</table>

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<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
</table>
| 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) = \(\omega_e\) (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 \(\tau\).  
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) = \(\omega_0\) (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.  
TABLE(74) = \(\epsilon\) (earth rotation) in deg/min  
TABLE(75) = 102...
Common (continued)

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
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<tbody>
<tr>
<td>O</td>
<td>BPOOL</td>
<td>TABLE(74) = Tolerance for $R^* \cdot U$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(75) = Tolerance for magnitude of RXU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(76)-(80) = Not used</td>
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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 $\Omega$, $i$, $\omega$, yields the direction cosines of $P,Q$; substitution of $u$ for $\omega$ yields the direction cosines for the set $U,V$.

FORMULATION

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

$$\begin{align*}
P_1 &= \cos \omega \cos \Omega - \sin \omega \sin \Omega \cos i, \\
P_2 &= \cos \omega \sin \Omega + \sin \omega \cos \Omega \cos i, \\
P_3 &= \sin \omega \sin i,
\end{align*}$$

$$\begin{align*}
Q_1 &= -\sin \omega \cos \Omega - \cos \omega \sin \Omega \cos i, \\
Q_2 &= -\sin \omega \sin \Omega + \cos \omega \cos \Omega \cos i, \\
Q_3 &= \cos \omega \sin i,
\end{align*}$$

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

CALLING SEQUENCE

```fortran
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

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

Common

<table>
<thead>
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<tr>
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<td>BPOOL</td>
<td>TABLE(31) = ε = .1 x 10^-11</td>
</tr>
</tbody>
</table>

CALLED BY

BRWORB

CALLS

VDOT
PQUV → ENTRY UV

P₀ = P
Q₀ = Q

i = 1
ω₀ = ω
ω = ω + f

ENTRY PQ

J = 0

P₁ = \cos(\omega) \cos(Ω) - \sin(\omega) \sin(Ω) \cos(i)
P₂ = \cos(\omega) \sin(Ω) + \sin(\omega) \cos(Ω) \cos(i)
P₃ = \sin(\omega) \sin(i)
Q₁ = \sin(\omega) \cos(Ω) - \cos(\omega) \sin(Ω) \cos(i)
Q₂ = \sin(\omega) \sin(Ω) + \cos(\omega) \cos(Ω) \cos(i)
Q₃ = \cos(\omega) \sin(i)

1 → J = 0

C-1

U = P
V = Q
ω = ω₀

Print errors if any

RETURN

C-1 → ENTRY PQ

1 → J = 0

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 $\Delta t$, and corresponding $(N_{2,1})'$s whose value may be zero or a non-zero quantity. Other associated parameters at epoch time are computed.

For $i = 0$, compute

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

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

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

$$M(t_0) = L_0 + l_1(t_0)$$

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

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

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For \( i > 0 \), compute

\[
\begin{align*}
\tau_{1,i} &= t_{i+1} - t_i \\
\tau_{2,i} &= \frac{\tau_{1,i}}{2}
\end{align*}
\]

\[
\begin{align*}
C_1 &= \ell_1(t_{i+1}) - \ell_1(t_i) \\
C_2 &= \ell_1(t_i + \tau_{2,i}) - \ell_1(t_i)
\end{align*}
\]

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

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

\[
M_{0,i} = \ell''_i + \ell_1(t_i); \quad \text{for } i = 0 \quad M(t_i) = M_{0,i}
\]

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

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

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

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

\[
g(t_{i+1}) = g'(t_{i+1})
\]

\[
h(t_{i+1}) = h'(t_{i+1})
\]

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

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

- Period, anomalistic \((ti) = \frac{2\pi}{M_{1,i}}\)

\[ \dot{p}_{a,i} = \frac{-M_{2,i} p_{a,i}^2}{\pi} \]

Height of perigee = \(a(1 - e) - 1\)

Height of apogee = \(a(1 + e) - 1\)

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

Velocity of apogee = \(\frac{\mu}{\sqrt{a}} \sqrt{\frac{1 + e}{1 - e}} \)

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

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, ELEMO, NQ, SATID)

INPUT/OUTPUT

Arguments

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

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<td>TABLE(41) = μ</td>
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<td></td>
<td>ETAP</td>
<td>ETA3 - (\eta^3)</td>
</tr>
<tr>
<td></td>
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<td>ETA4 - (\eta^4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ETA6 - (\eta^6)</td>
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<td>GM2 - (\gamma_2)</td>
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<td>DEL1E - (\delta_1 e)</td>
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<td>DEL1I - (\delta_1 i)</td>
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<tr>
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<td>(L_1 - L_1)</td>
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<td></td>
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<td>GP - (g^\prime)</td>
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<td>HP - (h^\prime)</td>
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<td>DPELE(6) - Brouwer mean elements</td>
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<td>I</td>
<td>DOTELE</td>
<td>L0DOT - (\dot{L}_0)</td>
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<tr>
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<td>THEETAP</td>
<td>M1P3T2 - 3 (\theta^2) - 1</td>
</tr>
<tr>
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<td>DELKEP</td>
<td>DKEP(1) - (\Delta a_{pert})</td>
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<tr>
<td>I</td>
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<td>DKEP(2) - (\Delta e_{pert})</td>
</tr>
<tr>
<td>I</td>
<td>PRTKEP</td>
<td>PKEP(3) - (k_0 + \Delta \ell)</td>
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**TAPE OUTPUT**

Prediction Space Elements

**Epoch:** Calendar Date

**Epoch:** Julian Date for Space

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<th>(t'_1)</th>
<th>(t_2)</th>
<th>(t_3)</th>
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<td>(P_2)</td>
<td>(P_3)</td>
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<td><strong>Period derivative</strong></td>
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<td>(\dot{P}_2)</td>
<td>(\dot{P}_3)</td>
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<td><strong>Eccentricity</strong></td>
<td>(e_1)</td>
<td>(e_2)</td>
<td>(e_3)</td>
</tr>
<tr>
<td><strong>Inclination</strong></td>
<td>(i_1)</td>
<td>(i_2)</td>
<td>(i_3)</td>
</tr>
<tr>
<td><strong>Right ascension of ascending node</strong></td>
<td>(\Omega_1)</td>
<td>(\Omega_2)</td>
<td>(\Omega_3)</td>
</tr>
<tr>
<td><strong>Argument of perigee</strong></td>
<td>(\omega_1)</td>
<td>(\omega_2)</td>
<td>(\omega_3)</td>
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<tr>
<td><strong>Mean anomaly</strong></td>
<td>(M_1)</td>
<td>(M_2)</td>
<td>(M_3)</td>
</tr>
<tr>
<td><strong>Semi-major axis</strong></td>
<td>(a_1)</td>
<td>(a_2)</td>
<td>(a_3)</td>
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</table>
CALLED BY

MAIN

CALLS

BRWORB
REDUCE
PRED 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

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<th>I/O</th>
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<td>Epoch time and information</td>
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<td>ETIME</td>
<td>Epoch hours, minutes, seconds in seconds</td>
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<tr>
<td>I</td>
<td>NN</td>
<td>Index for column times</td>
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<tr>
<td>I</td>
<td>MI</td>
<td>Index for column prediction elements</td>
</tr>
<tr>
<td>I</td>
<td>PA(56)</td>
<td>Array of anomalistic periods</td>
</tr>
<tr>
<td>I</td>
<td>PADOT(56)</td>
<td>Array of anomalistic period derivatives</td>
</tr>
<tr>
<td>I</td>
<td>EL(8, 56)</td>
<td>Array of Bulletin prediction elements — $a_i$, $e_i$, $I_i$, $\Omega_i$, $\omega_i$, $M_{0,i}$, $M_{1,i}$, $M_{2,i}$ where $i = 1, 56$</td>
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## Arguments (continued)

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<th>Variable</th>
<th>Description</th>
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<td>SATID(2) = year of reference</td>
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<tr>
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<td>SATID(11)</td>
<td>SATID(11) = day count of reference date</td>
</tr>
<tr>
<td>I</td>
<td>SECDRG(112)</td>
<td>SECDRG(1), (3), ..., (111) = seconds from columns time</td>
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<tr>
<td>I</td>
<td>SECDRG(2)</td>
<td>SECDRG(2), (4), ..., (112) = total column time (hours, minutes, seconds)</td>
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<tr>
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<td>DRG(60)</td>
<td>Drag time and parameters table</td>
</tr>
<tr>
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<td>OSCO(6)</td>
<td>Epoch Brouwer osculating elements</td>
</tr>
<tr>
<td>I</td>
<td>PV(6)</td>
<td>Epoch Brouwer position and velocity vectors</td>
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<td>I</td>
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<td>Epoch in Canonical Unit of Time</td>
</tr>
<tr>
<td>I</td>
<td>ELEM0(6)</td>
<td>Epoch elements — a, e, i, g, h, m</td>
</tr>
</tbody>
</table>

## Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(1) = meters/ft</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(2) = km/CUL</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(5) = sec/CUT</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(16) = deg/rad</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(23) = (2\pi)</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(25) = knots/mi/hr</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(26) = km/N.M.</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(28) = GM (km(^3)/sec(^2))</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(30) = sec/day</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(34) = (\pi)</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(35) = min/day</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(41) = (\mu)</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(45) = cut/day</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(49) = (\omega_e) (earth rotation) in rad/CUT</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(50) = mi/CUL</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(51) = CUL/CUT to mi/hr</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(57) = TAUDOT</td>
</tr>
</tbody>
</table>

115
Common (continued)

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(59) = min/CUT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(60) = CUL/CUT to m/sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(65) = rad/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(66) = km/ft</td>
</tr>
<tr>
<td>I</td>
<td>RADIUS</td>
<td>TABLE(67) = obliquity of ecliptic in rad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TAU = τ, satellite degrees, minutes, seconds in rad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AMBDA = λ, satellite.hour, minutes, seconds in rad</td>
</tr>
</tbody>
</table>

CALLED BY

MAIN

CALLS

DREFOD
REDUCE
DATAN0
SPACEL
REDUCE
Reduce Angle

PURPOSE
To reduce an angle between 0 and $2\pi$.

CALLING SEQUENCE

REDUCE (Z, PI2)

Note that REDUCE is a function.

INPUT/OUTPUT

Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Z</td>
<td>Angle to be reduced</td>
</tr>
<tr>
<td>I</td>
<td>PI2</td>
<td>$2\pi - 360^\circ$ in radians</td>
</tr>
<tr>
<td>O</td>
<td>REDUCE</td>
<td>Reduced-angle Z</td>
</tr>
</tbody>
</table>

CALLED BY

BRWORB
DAF
DRAG
PREDs
PRINT
SATOR
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:

\[ \mathbf{r} \] = the position vector of the satellite in the inertial coordinate system, measured in CUL, and having components \( X, Y, \) and \( Z. \)

\( \tau \) = the longitude of the sun on reference date, in radians.

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

\( \text{T IME} \) = \( t - t_0 \) = 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 \( \tau \) (\( U_1 = 1, 0, 0; U_2 = 0, \cos \epsilon, \sin \epsilon \) where \( \epsilon \) = obliquity of ecliptic).

\( f \) = the flattening coefficient of the ellipsoid of reference.

Compute:

\[ \mathbf{r}^* = \text{the unit satellite position vector} \]

\[ T = \tau + \dot{\tau} (t - t_0) \]

\[ U = U_1 \cos T + U_2 \sin T, \text{ having coordinates } u, v, w \]
If |\(r \times u| < T_1\), where \(T_1 = 1 - f(Z + W \sqrt{r^2 - 1})^2\), or a constant, and if \(r^* \cdot u < T_2\), then the satellite is in darkness. Otherwise, it is in sunlight.

CALLING SEQUENCE

CALL SDFWOE (TIME, R, IX, RMAG)

INPUT/OUTPUT

Arguments

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

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(42) = F</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(54) = X component of (U_2)</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(55) = Y component of (U_2)</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(56) = Z component of (U_2)</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(57) = TAUDOT ((\dot{\tau}))</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(71) = X component of (U_1)</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(72) = Y component of (U_1)</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(73) = Z component of (U_1)</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>TABLE(74) = T2 (tolerance for (R^* \cdot U))</td>
</tr>
<tr>
<td>I/O</td>
<td></td>
<td>TABLE(75) = T1 (tolerance for magnitude of RXU)</td>
</tr>
<tr>
<td>I</td>
<td>RADIAN</td>
<td>TAU ((\tau))</td>
</tr>
</tbody>
</table>
CALLED BY

GTRACE

CALLS

VECTOR
VADD
VDOT
VMAG
VPROD
VUNIT
VCROSS
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

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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>SATID(11)</td>
<td>SATID(1) - satellite ID number</td>
</tr>
<tr>
<td></td>
<td>SATID(1)</td>
<td>SATID(2) - year of reference</td>
</tr>
<tr>
<td></td>
<td>SATID(11)</td>
<td>SATID(11) - day count of reference date</td>
</tr>
</tbody>
</table>

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>OSCELE</td>
<td>OS(6) = Brouwer osculating elements</td>
</tr>
<tr>
<td>I</td>
<td>TABLE</td>
<td>TABLE(2) = Km/CUL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(16) = deg/rad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(23) = $2\pi$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(24) = BK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(34) = $\pi$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(40) = NSPAC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 0, no spacel osculating epoch elements output</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 1, spacel osculating epoch elements output</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(41) = $\mu$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(59) = min/CUT</td>
</tr>
</tbody>
</table>

TAPE OUTPUT

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

SATCESC NAME SL NRDN SBDAT INJ.D.S. RVNEI GMAG KG/K2 RFDO CK MWC CCNC
J.D.S. PERAN MOD PER CERI PHTEQR APHTEQR INMCD RAANCD AKGPER MAANCM C
UTN 16.000 MIN MICRODY/D KMX10 KMX10 1000D DEGRS DEGRS DEGRS SERI S
X100 X1ccc ccc ccc ccc 258.25 6378166 X1000 X1000 X1000 J X1000 C

X806602 INJUNE UH 3338 4914 3514 357 112921292
490640 011E2FBE8553-CCCOG4C5 CC67C1 C025327 8C668 345393 092857 2075214
491360 011E2FBE8484-CCCOG4G5 CC6103 CC25325 8C668 340103 076814 2850103
4S7CC0 C11E2FBE42-C McL4E7 CC67C9 CC2531E 8C668 334814 367753 0026103
490600 C11E161311-C McL4353 CC6618 0025348EC8665 345391C093272 2072374

125
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, \( \times 10^6 \)
3. Period derivative, microdays/day, \( \times 10^4 \)
4. Perigee height relative to equatorial radius, kilometers, \( \times 10 \).
   Flattening = \( \frac{1}{298.25} \)
5. Apogee height relative to equatorial radius, kilometers, \( \times 10 \).
   Equatorial radius = 6378.166
6. Inclination in degrees, modulo 100, \( \times 1000 \)
7. Right ascension of ascending node in degrees, \( \times 1000 \)
8. Argument of perigee in degrees, \( \times 1000 \)
9. Mean anomaly in degrees, \( \times 1000 \)
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
SPACECL 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

\[
\sin \delta = \frac{Z}{r}, \quad -\frac{\pi}{2} \leq \delta \leq \frac{\pi}{2}
\]

\[
\lambda' = a - \theta g - \omega t, \quad \lambda = \text{mod} (\lambda', 2\pi), \quad 0 \leq \lambda \leq 2\pi
\]

Set \( \phi_S' = \delta \), where \( \delta \) has already been determined, and continue calculating with

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

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

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

\[
\Delta \phi_S' = \sin^{-1} \left[ \frac{H_S}{r} \sin (\phi_S - \phi_S') \right], \quad -\frac{\pi}{2} \leq \Delta \phi_S' \leq \frac{\pi}{2}
\]
Recalculate $\phi_s' = \delta - \Delta \phi_s'$ and return to Eq. (1). Repeat this loop until $\phi_s'$ no longer varies. This process is exact and rapidly convergent, and at the same time yields the ground trace geodetic latitude, $\phi$.

**CALLING SEQUENCE**

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

**INPUT/OUTPUT**

**Arguments**

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

**Common**

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>SDT</td>
<td>GST — Greenwich Sidereal Time</td>
</tr>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(31) = $\epsilon = .1 \times 10^{-11}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(9) = 1/f</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(2) = km/E.R.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(42) = f</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TABLE(52) = 2f - f²</td>
</tr>
</tbody>
</table>
CALLED BY

GTRACE
NODALX
NSPT

CALLS

None
SSPTHT

\[ \delta = \sin^{-1}\left(\frac{v}{r}\right) \]
\[ 0^\circ \leq \delta \leq 90^\circ \]
\[ a = \tan^{-1}\left(\frac{v}{r}\right) \]
\[ 0^\circ \leq a \leq 360^\circ \]

\[ \lambda_C = a - \delta - \omega_{et} \mod (360^\circ) \]
Compute \( \lambda \)
\[ -180^\circ \leq \lambda \leq 180^\circ \]

\[ \phi' = 5 \]
\[ i = 1 \]

\[ \phi_{old} = \phi' \]

\[ \epsilon = \alpha \left[ 1 - \frac{1}{2} (2f - f^2) \right] \]

\[ \phi' = \delta - \Delta \phi' \]
\[ \Delta \leq \frac{\Delta}{\phi_{old}} \]

C.1

\[ \phi = \tan^{-1}\left[\frac{\tan^{-1} \phi''}{(1 - f)^2}\right] \]
\[ -\pi/2 \leq \phi \leq \pi/2 \]

\[ H = [e^2 - e^2 \sin^2 (\phi - \phi'')] \]
\[ -e \cos (\phi - \phi'') \]

\[ \Delta \phi' = \sin^{-1}[H/e \sin (\phi - \phi'')] \]
\[ -\pi/2 \leq \Delta \phi' \leq \pi/2 \]

C.2

\[ \phi' = \delta - \Delta \phi' \]
\[ \phi_{old} = \phi' \]

RETURN

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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
</table>
| 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 x 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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(5) = sec/CUT&lt;br&gt;TABLE(30) = sec/day</td>
</tr>
</tbody>
</table>

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 $0^\text{hr}$ U.T. of Date and add the amount of rotation in the hours, minutes, and seconds elapsed since $0^\text{hr}$ U.T. of Date.

FORMULATION

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

$$\theta g_0 = 99^\circ 6909833 + 36000^\circ 7689 T_u + 0^\circ 00038708 T_u^2$$

where the time is measured in centurie as

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

and we have for the Greenwich sidereal time

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

where $\omega_e$ is the earth's rotation in deg/min

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

CALLING SEQUENCE

CALL UTGST (YY, MM, DY, HR, MIN, SEC)
**INPUT/OUTPUT**

Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>YY</td>
<td>Year</td>
</tr>
<tr>
<td>I</td>
<td>MM</td>
<td>Month</td>
</tr>
<tr>
<td>I</td>
<td>DY</td>
<td>Day</td>
</tr>
<tr>
<td>I</td>
<td>HR</td>
<td>Hour</td>
</tr>
<tr>
<td>I</td>
<td>MIN</td>
<td>Minute</td>
</tr>
<tr>
<td>I</td>
<td>SEC</td>
<td>Second</td>
</tr>
</tbody>
</table>

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>SDT</td>
<td>GST, GST0 - (θ₉, θ₀₉)</td>
</tr>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(69) - ωₖ</td>
</tr>
</tbody>
</table>

**CALLED BY**

MAIN

**CALLS**

None
UTGST

Compute Julian Date (J.D.) at \( \theta^h \text{ U.T.} \)

Compute \( \theta^h \), \( \theta^h \text{ U.T.} \)

Compute \( \theta \)

RETURN

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

\[ r = ru, r = a(1 - e \cos E) \]
\[ v_r = \sqrt{\mu a / r} \cdot e \cdot \sin E, \quad v_T = \sqrt{\mu a(1 - e^2)} / r \]
\[ \dot{r} = v_r u + v_T v \]

CALLING SEQUENCE


INPUT/OUTPUT

Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>A</td>
<td>Semimajor axis (e.r.)</td>
</tr>
<tr>
<td>I</td>
<td>ECC</td>
<td>Eccentricity</td>
</tr>
<tr>
<td>I</td>
<td>I</td>
<td>Orbital inclination</td>
</tr>
<tr>
<td>I</td>
<td>G</td>
<td>Argument of perigee</td>
</tr>
<tr>
<td>I</td>
<td>H</td>
<td>Longitude of the ascending node</td>
</tr>
<tr>
<td>I</td>
<td>F</td>
<td>True anomaly</td>
</tr>
<tr>
<td>I</td>
<td>E</td>
<td>Eccentric anomaly</td>
</tr>
</tbody>
</table>
Arguments (continued)

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>R</td>
<td>Sat. radial vector</td>
</tr>
<tr>
<td>O</td>
<td>DR</td>
<td>Sat. vel. vector</td>
</tr>
<tr>
<td>O</td>
<td>U</td>
<td>P(I, G &amp; F, H) ≡ r/r</td>
</tr>
<tr>
<td>O</td>
<td>V</td>
<td>Q(I, G &amp; F, H)</td>
</tr>
<tr>
<td>O</td>
<td>RMAG</td>
<td>r magnitude of radial vector</td>
</tr>
<tr>
<td>O</td>
<td>DRMAG</td>
<td>v magnitude of vel. vector</td>
</tr>
</tbody>
</table>

Common

<table>
<thead>
<tr>
<th>I/O</th>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(31) = ε ≡ .1 x 10^{-11}</td>
</tr>
<tr>
<td>I</td>
<td>BPOOL</td>
<td>TABLE(41) ≡ μ</td>
</tr>
<tr>
<td>O</td>
<td>VTVR</td>
<td>VT(3) Transverse velocity component vector</td>
</tr>
<tr>
<td>O</td>
<td>VTVR</td>
<td>VR(3) Radial velocity component vector</td>
</tr>
</tbody>
</table>

CALLED BY

BRWORB

CALLS

VDOT
START
CALL UV
(U, G, H, F, U, V)

\[ r = a \left(1 - e \cos E\right) \]
\[ v_1 = \frac{\sqrt{u a}}{r} \]
\[ v_T = \frac{\sqrt{u a} \left(1 - e^2\right)}{r} \]

COMPUTE POSITION AND VELOCITY IN THE INERTIA SYSTEM.

\[ \dot{r} = ru \]
\[ \dot{v}_T = v_1 u + v_T v \]

CALL VDOT (r, r, DP)

UVIJK Flowchart

CALL VDOT (r, i, DP)

\[ \text{DP} - r^2/\text{TOL} \leq \]

/DP - r^2/\text{TOL} \leq \]

RETURN

WRITE CK. r CALCULATION

WRITE CK. \dot{r} CALCULATION
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, $S = (S_1, S_2, S_3)$, of the two given vectors, $A = (A_1, A_2, A_3)$ and $B = (B_1, B_2, B_3)$, 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, $C = (C_1, C_2, C_3)$, of the two given vectors, $A = (A_1, A_2, A_3)$ and $B = (B_1, B_2, B_3)$, 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, \( \mathbf{A} \cdot \mathbf{B} \), of the two given vectors, \( \mathbf{A} = (A_1, A_2, A_3) \) and \( \mathbf{B} = (B_1, B_2, B_3) \), is given by:

\[ \mathbf{A} \cdot \mathbf{B} = A_1 B_1 + A_2 B_2 + A_3 B_3 \]

**VMAG** — Computes the magnitude of a vector.

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

\[ A = (A_1^2 + A_2^2 + A_3^2)^{\frac{1}{2}} \]

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

The product vector, \( \mathbf{P} = (P_1, P_2, P_3) \), of the scalar, \( a \), and the vector, \( \mathbf{A} = (A_1, A_2, A_3) \), 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, \( \mathbf{D} = (D_1, D_2, D_3) \), of the two given vectors, \( \mathbf{A} = (A_1, A_2, A_3) \) and \( \mathbf{B} = (B_1, B_2, B_3) \), 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 \( A^* = (A_1^*, A_2^*, A_3^*) \) along the vector \( A = (A_1, A_2, A_3) \) is given by:

\[ A_1^* = \frac{A_1}{|A|} \]
\[ A_2^* = \frac{A_2}{|A|} \]
\[ A_3^* = \frac{A_3}{|A|} \]

where

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

**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

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

CALLED BY

ELCON0
PQLJK
PQUV
SDFWOE
UVLJK
VECTOR Flowchart

ENTER VADD

Perform Vector Addition of Input Vectors $\mathbf{A}$ and $\mathbf{B}$

ENTER VCROSS

Compute Cross Product $\mathbf{C}$ of Input Vectors $\mathbf{A}$ and $\mathbf{B}$

ENTER VDOT

Compute Dot Product $\mathbf{A} \cdot \mathbf{B}$ of Input Vectors $\mathbf{A}$ and $\mathbf{B}$

ENTER VMAG

Compute Magnitude $|\mathbf{A}|$ of Input Vector $\mathbf{A}$

ENTER VPROD

Compute Product of a Scalar and a Vector $\mathbf{A}$

ENTER VSUB

Perform Vector Subtraction of $\mathbf{D}$ of Input Vectors $\mathbf{A}$ and $\mathbf{B}$

ENTER VUNIT

Compute Magnitude $|\mathbf{A}|$ of Input Vector $\mathbf{A}$

Compute Unit Vector $\mathbf{A}$ from $|\mathbf{A}|$ and $\mathbf{B}$

RETURN
WMAPLD
World Map Request Load

PURPOSE

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

CALLING SEQUENCE

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

INPUT/OUTPUT

Arguments

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
</table>
| O   | REQUEST(15) | REQUEST(1) = Year  
|     |           | REQUEST(2) = Month  
|     |           | REQUEST(3) = Day    
|     |           | REQUEST(4) = Hour   
|     |           | REQUEST(5) = Minutes 
|     |           | REQUEST(6) = Seconds |
|     |           | REQUEST(7) = Year   
|     |           | REQUEST(8) = Month   
|     |           | REQUEST(9) = Day     
|     |           | REQUEST(10) = Hour   
|     |           | REQUEST(11) = Minutes 
|     |           | REQUEST(12) = Seconds |
|     |           | REQUEST(13) = Latitude increment |
|     |           | REQUEST(14) = Inclination |
|     |           | REQUEST(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

<table>
<thead>
<tr>
<th>I/O</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>N</td>
<td>Number of output digits (including the sign) that is desired – maximum is 8</td>
</tr>
<tr>
<td>I</td>
<td>IIN</td>
<td>Input number</td>
</tr>
<tr>
<td>O</td>
<td>AREA(8)</td>
<td>AREA(1) = Sign of the output number</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AREA(2)-(8) = digits of output number including leading zeroes.</td>
</tr>
</tbody>
</table>

CALLED BY

SPACEL
BLOCK DATA

PURPOSE

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

OUTPUT

Common

<table>
<thead>
<tr>
<th>Block</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPOOL</td>
<td>TABLE(1) ( \frac{\text{meter}}{\text{ft}} )</td>
</tr>
<tr>
<td></td>
<td>TABLE(2) = ( \text{km/CUL} )</td>
</tr>
<tr>
<td></td>
<td>TABLE(3) = ( \text{mile/nautical mile} )</td>
</tr>
<tr>
<td></td>
<td>TABLE(4) = ( \text{km/A.U.} )</td>
</tr>
<tr>
<td></td>
<td>TABLE(5) = ( \text{sec/CUT} )</td>
</tr>
<tr>
<td></td>
<td>TABLE(6) = velocity of light (km/sec)</td>
</tr>
<tr>
<td></td>
<td>TABLE(7) = sun mass/earth mass</td>
</tr>
<tr>
<td></td>
<td>TABLE(8) = earth mass/moon mass</td>
</tr>
<tr>
<td></td>
<td>TABLE(9) = ( \frac{1}{f} ) (flattening coefficient)</td>
</tr>
<tr>
<td></td>
<td>TABLE(10) = Pressure of sunlight</td>
</tr>
<tr>
<td></td>
<td>TABLE(11) = ( \omega_e ) - earth rotation (rad/sec)</td>
</tr>
<tr>
<td></td>
<td>TABLE(12) = ( J_2 )</td>
</tr>
<tr>
<td></td>
<td>TABLE(13) = ( J_3 )</td>
</tr>
<tr>
<td></td>
<td>TABLE(14) = ( J_4 )</td>
</tr>
<tr>
<td></td>
<td>TABLE(15) = ( J_5 )</td>
</tr>
<tr>
<td></td>
<td>TABLE(16) = ( \frac{\text{deg}}{\text{rad}} )</td>
</tr>
<tr>
<td></td>
<td>TABLE(17) = Deg</td>
</tr>
<tr>
<td></td>
<td>TABLE(18) = Min Obliquity of Ecliptic</td>
</tr>
<tr>
<td></td>
<td>TABLE(19) = Sec</td>
</tr>
<tr>
<td></td>
<td>TABLE(20) = Mean long. of sun (deg/day)</td>
</tr>
<tr>
<td></td>
<td>TABLE(21) = km/mile</td>
</tr>
<tr>
<td></td>
<td>TABLE(22) = Radius of earth in CUL</td>
</tr>
<tr>
<td></td>
<td>TABLE(23) = ( 2\pi )</td>
</tr>
<tr>
<td></td>
<td>TABLE(24) = GM = ( \mu^2 )</td>
</tr>
<tr>
<td></td>
<td>TABLE(25) = knots/mi/hr</td>
</tr>
<tr>
<td></td>
<td>TABLE(26) = km/n.m.</td>
</tr>
<tr>
<td></td>
<td>TABLE(27) = Lunar distance (CUL)</td>
</tr>
<tr>
<td></td>
<td>TABLE(28) = GM (km(^3)/sec(^2))</td>
</tr>
</tbody>
</table>
### Common (continued)

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Description</th>
<th>Program Where Defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE</td>
<td></td>
<td>Table of Constants</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(1)</td>
<td>.30480</td>
<td>meters/foot</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(2)</td>
<td>.6378.1660</td>
<td>kilometers/Canonical Unit of Length</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(3)</td>
<td>1652.0</td>
<td>meters/nautical mile</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(4)</td>
<td>149598600.0</td>
<td>kilometers/astronomical unit</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(5)</td>
<td>806.812418099482</td>
<td>seconds/Canonical Unit of Time</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(6)</td>
<td>299792.5</td>
<td>velocity of light in km/sec</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(7)</td>
<td>332948.55</td>
<td>ratio of sun mass/earth mass</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(8)</td>
<td>81.3</td>
<td>ratio of earth mass/moon mass</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(9)</td>
<td>298.250</td>
<td>1/flattening coefficient (f)</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(10)</td>
<td>.000045</td>
<td>pressure of sunlight</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(11)</td>
<td>.0000729211510</td>
<td>ω_e - earth rotation in rad/sec</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(12)</td>
<td>.001082480</td>
<td>J_2</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(13)</td>
<td>-.00000256</td>
<td>J_3</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(14)</td>
<td>-.00000184</td>
<td>J_4</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(15)</td>
<td>-.00000006</td>
<td>J_5</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(16)</td>
<td>57.29577951308232</td>
<td>degrees/radian</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(17)</td>
<td>23.0</td>
<td>degrees</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(18)</td>
<td>26.0</td>
<td>minutes/seconds</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(19)</td>
<td>34.795</td>
<td>Obliquity of Ecliptic</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(20)</td>
<td>.9856470</td>
<td>mean longitude of sun in deg/day</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(21)</td>
<td>1.609344</td>
<td>kilometers/mile</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(22)</td>
<td>1.0</td>
<td>R - radius of the earth in CUL (e.r.)</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(23)</td>
<td>6.283185307179586</td>
<td>2π (360° in radians)</td>
<td>BLOCK DATA</td>
</tr>
</tbody>
</table>
### Table 1: Variables and Values

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Description</th>
<th>Where Defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE(24)</td>
<td>1.0</td>
<td>$GM = \mu^2$ (Gaussian constant)</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(25)</td>
<td>1.152</td>
<td>knots/mile/hr</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(26)</td>
<td>1.852</td>
<td>kilometers/nautical mile</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(27)</td>
<td>60.266011</td>
<td>lunar distance in CUL</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(28)</td>
<td>398603.2</td>
<td>$GM^* (km^3/sec^2)$</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(29)</td>
<td>234658.04</td>
<td>solar distance in CUL</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(30)</td>
<td>86400.0</td>
<td>seconds/day</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(31)</td>
<td>.000000000001</td>
<td>tolerance</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(32)</td>
<td>3600.0</td>
<td>seconds/hour</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(33)</td>
<td>15.0</td>
<td>degrees/hour</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(34)</td>
<td>3.141592653589793</td>
<td>$n$ (180° in radians)</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(35)</td>
<td>1440.0</td>
<td>minutes/day</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(36)</td>
<td>0.0</td>
<td>indicator for satel code</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td></td>
<td>.0</td>
<td>= 0 compute satel code</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td></td>
<td>&gt; 0 no satel code</td>
<td></td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(37)</td>
<td>0.0</td>
<td>radio frequency</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(38)</td>
<td>0.0</td>
<td>radio frequency</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(39)</td>
<td>0.0</td>
<td>radio frequency</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td>TABLE(40)</td>
<td>1.0</td>
<td>indicator for SPACEL osculating elements</td>
<td>BLOCK DATA</td>
</tr>
<tr>
<td></td>
<td>= 1 compute osculating elements</td>
<td>BLOCK DATA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>= 0 no SPACEL osculating elements</td>
<td>BLOCK DATA</td>
<td></td>
</tr>
<tr>
<td>TABLE(41)</td>
<td>1.0</td>
<td>$\mu$</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(42)</td>
<td>f</td>
<td>flattening coefficient</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(43)</td>
<td>$(1 - f) \times R$</td>
<td>$B$ - polar radius of the earth</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(44)</td>
<td>(km/A.U.)/(km/CUL)</td>
<td>CUL/astronomical unit</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(45)</td>
<td>(sec/day)/(sec/CUT)</td>
<td>CUT/day</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(46)</td>
<td>(sec/hr)/(sec/CUT)</td>
<td>CUT/hr</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(47)</td>
<td>(km/CUL)/(sec/CUT)</td>
<td>Convert CUL/CUT to kilometers/second</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(48)</td>
<td>(km/CUL)/(sec/CUT) * (sec/hr)</td>
<td>Convert CUL/CUT to kilometers/hour</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(49)</td>
<td>$\omega_0$ in rad/sec * (sec/CUT)</td>
<td>earth rotation in rad/CUT</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(50)</td>
<td>(km/CUL)/(km/mi)</td>
<td>miles/CUL</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(51)</td>
<td>(mi/CUL) * (CUT/hr)</td>
<td>Convert CUL/CUT to miles/hour</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(52)</td>
<td>$2f - f^2$</td>
<td>$e^2$ - eccentricity of the earth squared</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(53)</td>
<td>e</td>
<td>$e$ - eccentricity of the earth</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(54)</td>
<td>0.0</td>
<td>X component of U2</td>
<td>POOL</td>
</tr>
<tr>
<td>TABLE(55)</td>
<td>cos $\epsilon$</td>
<td>Y component of U2</td>
<td>POOL</td>
</tr>
</tbody>
</table>
### TABLE(56) sin c
Z component of U2 POOL

### TABLE(57)
rate of change of the mean longitude of sun in rad/CUT

### TABLE(58)
J2 * R2 * 3/2

### TABLE(59)
(sec/CUT)*60

### TABLE(60)
(km/CUL)/(sec/CUT) * 1000

### TABLE(61)
J2 * R2 /2

### TABLE(62)
-J3 * R3

### TABLE(63)
-J4 * R4 * (3/8)

### TABLE(64)
-J5 * R5

### TABLE(65)
(deg/hr)/(deg/rad)

### TABLE(66)
(meters/ft) * 1000

### TABLE(67)
.40915751

### TABLE(68)
1.0

### TABLE(69)
ν in rad/sec * (deg/rad) * 60

### TABLE(70)
1/(min/CUT)

### TABLE(71)
1.0

### TABLE(72)
0.0

### TABLE(73)
0.0

### TABLE(74)
0.0

### TABLE(75)
1.0

### TABLE(76)-(80)
0.0

### COMMON/DAFPRM/LDAF(13)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Program Where Defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDAF(13)</td>
<td>Intermediate values from BRWORB used in computing the Data Acquisition Facility Parameters</td>
<td>BRWORB</td>
</tr>
</tbody>
</table>
\[ \text{LDAF}_1 = \left\{ \frac{1}{8} \gamma_2' \sin^2 \eta \left[ 1 - 11 \theta^2 - 40 \theta^4 (1 - 5 \theta^2)^{-1} \right] \right. \]
\[ \left. \left. - \frac{5}{12} \frac{\gamma_4'}{\gamma_2'} \sin^2 \eta \left[ 1 - 3 \theta^2 - 8 \theta^4 (1 - 5 \theta^2)^{-1} \right] \right\} \]
\[ \text{LDAF}_2 = \left\{ \frac{1}{4} \frac{\gamma_3'}{\gamma_2'} \eta^2 \sin \eta'' \right. \]
\[ \left. + \frac{5}{64} \frac{\gamma_5'}{\gamma_2' \eta^2} \sin \eta'' (4 + 3 \sin^2) \left[ 1 - 9 \theta^2 - 24 \theta^4 (1 - 5 \theta^2)^{-1} \right] \right\} \]
\[ \text{LDAF}_3 = -\frac{35}{384} \frac{\gamma_5'}{\gamma_2'} \sin^2 \eta'' \left[ 1 - 5 \theta^2 - 16 \theta^4 (1 - 5 \theta^2)^{-1} \right] \]
\[ \text{LDAF}_4 = \left\{ \frac{1}{8} \frac{\gamma_3'}{\gamma_2'} \eta^3 \left[ 1 - 11 \theta^2 - 40 \theta^4 (1 - 5 \theta^2)^{-1} \right] \right. \]
\[ \left. \left. - \frac{5}{12} \frac{\gamma_4'}{\gamma_2'} \eta^3 \left[ 1 - 3 \theta^2 - 8 \theta^4 (1 - 5 \theta^2)^{-1} \right] \right\} \]
\[ \text{LDAF}_5 = \left\{ -\frac{1}{4} \frac{\gamma_3'}{\gamma_2'} \frac{\eta^3}{\sin \eta''} \right. \]
\[ \left. - \frac{5}{64} \frac{\gamma_5'}{\gamma_2'} \frac{\eta^3}{\sin \eta''} (4 + 9 \sin^2) \left[ 1 - 9 \theta^2 - 24 \theta^4 (1 - 5 \theta^2)^{-1} \right] \right\} \]
\[ \text{LDAF}_6 = \frac{35}{384} \frac{\gamma_5'}{\gamma_2'} \eta^3 \sin \eta'' \left[ 1 - 5 \theta^2 - 16 \theta^4 (1 - 5 \theta^2)^{-1} \right] \]
$$\text{LDAF}_7 = \left\{ -\frac{1}{16} \gamma_2' \left[ + (2 + e''^2) - 11 (2 + 3 e''^2) \theta^2 - 40 (2 + 5 e''^2) \theta^4 (1 - 5 \theta^2)^{-1} \right. \right.$$ 

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

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

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

\[\times \left[ \left( \frac{\gamma_2 \sin I''}{e''} - \frac{e'' \theta^2}{\sin I''} \right) (4 + 3 e''^2) + e'' \sin I'' (26 + 9 e''^2) \right] \left[ 1 - 9 \theta^2 \right.$$ 

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

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

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

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

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

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LDAF_{10} = \left\{ -\frac{1}{8} \gamma_2^' \ e'' \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'' \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 + 3 e''^2) \left[ 1 - 9 \theta^2 \\
- 24 \theta^4 (1 - 5 \theta^2)^{-1} + \frac{15}{32} \frac{\gamma_5^'}{\gamma_2^'} \ e'' \theta \sin I^'' (4 + 3 e''^2) \left[ 3 + 16 \theta^2 (1 - 5 \theta^2)^{-1} + 40 \theta^4 (1 - 5 \theta^2)^{-2} \right] \right\}

LDAF_{12} = \left\{ - \frac{35}{1152} \frac{\gamma_5^'}{\gamma_2^'} \ \frac{e'' \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'' \theta \sin I^'' \left[ 5 + 32 \theta^2 (1 - 5 \theta^2)^{-1} + 80 \theta^4 (1 - 5 \theta^2)^{-2} \right] \right\}

LDAF_{13} = \frac{e''}{\eta^2 \tan I^''}
### /DELKEP/

**COMMON/DELKEP/DKEP(6)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Program Where Defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>DKEP(6)</td>
<td>Perturbation ( \Delta a, \Delta e, \Delta i, \Delta g, \Delta h, \Delta l )</td>
<td>BRWORB</td>
</tr>
</tbody>
</table>

\[
\Delta X = X_{t0} - X_{obs}
\]

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**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Program Where Defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPT</td>
<td>Perturbation tape logical number</td>
<td>MAIN - Initializes</td>
</tr>
</tbody>
</table>

- \( > 0 \) read pert tape
- \( < 0 \) do not read pert tape
- \( = 0 \) error
### /PRTKEP/

**COMMON/PRTKEP/PKEP(3)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Program Where Defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>PKEP(1)</td>
<td>$g_0 + \Delta g$</td>
<td>BRWORB</td>
</tr>
<tr>
<td>PKEP(2)</td>
<td>$h_0 + \Delta h$</td>
<td></td>
</tr>
<tr>
<td>PKEP(3)</td>
<td>$l_0 + \Delta l$</td>
<td></td>
</tr>
</tbody>
</table>

where

\[
X_0 = \text{value of } X \text{ at epoch} \\
\Delta X = X_{t0} - X_{obs} \\
X_{t0} = \text{value of } X \text{ on the pert tape at epoch} \\
X_{obs} = \text{value of } X \text{ on the pert tape at the requested time}
\]

### /RADIUS/

**COMMON/RADIUS/TAU, AMBDA**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Program Where Defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAU</td>
<td>$\tau$ - longitude (in radians) of the sun on reference date</td>
<td>MAIN</td>
</tr>
<tr>
<td>AMBDA</td>
<td>$\lambda$ - hour angle (in radians) of the first point of Aries on reference date</td>
<td>MAIN</td>
</tr>
</tbody>
</table>

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

| Block | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
|       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

| Subroutine | 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 | X | X | X | X | X |

### Common Blocks

| Block | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
|       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

| Common Block | 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 | X | X | X | X | X |

---

### Note

The table above represents a cross-reference for common blocks and subroutines used in a specific bulletin. Each cell indicates the presence of a block or subroutine, with a 'X' signifying presence and a blank indicating absence.
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
- **Δℓ**: 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
- **P_a**: Derivative of Anomalistic Period
- **r**: Satellite Position Vector
- **r^\ast**: Unit Satellite Position Vector
- **T_0**: Epoch — Time of Elements
- **T(P,Q)**: Time of Drags
- **X**
- **Y**
- **Z**: Satellite Position Vectors
\[ \begin{align*}
\dot{X} & \quad \text{Satellite Velocity Vectors} \\
\dot{Y} & \quad \text{Right Ascension of Ascending Node} \\
\dot{Z} & \quad \text{Derivative of Right Ascension of Ascending Node} \\
\Omega & \quad \text{Argument of Perigee} \\
\dot{\Omega} & \quad \text{Derivative of Argument of Perigee} \\
\omega & \quad \text{Rotation of Earth} \\
\nu & \quad \text{True Anomaly} \\
\lambda & \quad \text{Hour Angle (in radians)} \\
\tau & \quad \text{Longitude (in radians) of Sun on Reference Date} \\
\dot{\tau} & \quad \text{Motion of } \tau \\
\theta & \quad \text{Elevation} \\
\pi & \quad 180^\circ \text{ in radians} \\
\mu & \quad \text{Gravitational Constant } \times \text{ Mass of Earth (Usually } = 1) \\
\end{align*} \]
E. REFERENCES


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

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**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 or digits right justified in a field of n columns with an exponent of the form $D \pm XX$, 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

<table>
<thead>
<tr>
<th>Card Col.</th>
<th>Format</th>
<th>Field Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-8</td>
<td>bbb ... b</td>
<td>Leave blank</td>
</tr>
<tr>
<td>9-40</td>
<td>A40</td>
<td>First line of run identification</td>
</tr>
<tr>
<td>41-70</td>
<td>A40</td>
<td>Second line of run identification</td>
</tr>
<tr>
<td>71-80</td>
<td></td>
<td>Not used</td>
</tr>
</tbody>
</table>
b and e. Change of Constant Card

<table>
<thead>
<tr>
<th>Card Col.</th>
<th>Format</th>
<th>Field Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>I2</td>
<td>Table location to be changed</td>
</tr>
<tr>
<td>3-25</td>
<td>D23.16</td>
<td>Constant to be inserted in above location</td>
</tr>
<tr>
<td>26-27</td>
<td>I2</td>
<td>Table location to be changed</td>
</tr>
<tr>
<td>28-50</td>
<td>D23.16</td>
<td>Constant to be inserted in above location</td>
</tr>
<tr>
<td>51-52</td>
<td>I2</td>
<td>Table location to be changed</td>
</tr>
<tr>
<td>58-75</td>
<td>D23.16</td>
<td>Constant to be inserted in above location</td>
</tr>
<tr>
<td>76-80</td>
<td></td>
<td>Not used</td>
</tr>
</tbody>
</table>
c. Satellite Identification Card

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

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

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

173
g. Elements Card 1

<table>
<thead>
<tr>
<th>Card Col.</th>
<th>Format</th>
<th>Field Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-23</td>
<td>D23.16</td>
<td>X (CUL or km)</td>
</tr>
<tr>
<td>24</td>
<td>b</td>
<td>a (CUL or km)</td>
</tr>
<tr>
<td>25-47</td>
<td>D23.16</td>
<td>Y (CUL or km)</td>
</tr>
<tr>
<td>48</td>
<td>b</td>
<td>e</td>
</tr>
<tr>
<td>49-71</td>
<td>D23.16</td>
<td>Z (CUL or km)</td>
</tr>
<tr>
<td>72-80</td>
<td></td>
<td>i (radians or degrees)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not used</td>
</tr>
</tbody>
</table>
g. Element Card 2

<table>
<thead>
<tr>
<th>Card Col.</th>
<th>Format</th>
<th>Field Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-23</td>
<td>D23.16</td>
<td>( \dot{X} ) (CUL/CUT or km/sec)</td>
</tr>
<tr>
<td>24</td>
<td>b</td>
<td>( M ) (radians or degrees)</td>
</tr>
<tr>
<td>25-47</td>
<td>D23.16</td>
<td>( \dot{Y} ) (CUL/CUT or km/sec)</td>
</tr>
<tr>
<td>48</td>
<td>b</td>
<td>( \omega ) (radians or degrees)</td>
</tr>
<tr>
<td>49-71</td>
<td>D23.16</td>
<td>( \dot{Z} ) (CUL/CUT or km/sec)</td>
</tr>
<tr>
<td>72-80</td>
<td></td>
<td>( \Omega ) (radians or degrees)</td>
</tr>
</tbody>
</table>

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

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

Note: For spaced 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

<table>
<thead>
<tr>
<th>Card Col.</th>
<th>Format</th>
<th>Field Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-6</td>
<td>I6</td>
<td>Issue Date of Bulletin: year, month, day</td>
</tr>
<tr>
<td>7-80</td>
<td></td>
<td>Not used</td>
</tr>
</tbody>
</table>

j. Bulletin Remarks Card

<table>
<thead>
<tr>
<th>Card Col.</th>
<th>Format</th>
<th>Field Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-8</td>
<td>bbb ... b</td>
<td>Leave blank</td>
</tr>
<tr>
<td>9-40</td>
<td>A40</td>
<td>Line 1 of Remarks</td>
</tr>
<tr>
<td>41-72</td>
<td>A40</td>
<td>Line 2 of Remarks</td>
</tr>
<tr>
<td>73-80</td>
<td></td>
<td>Not used</td>
</tr>
</tbody>
</table>
### Bulletin Request Card

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

**Card Col.**: Column number of the field in the request card. **Format**: Character(s) to be entered in the field. **Field Description**: Description of the field's purpose.
1. Spacel Bulletin

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

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

**Date Record**

<table>
<thead>
<tr>
<th>Word Number</th>
<th>Word Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Fortran word count</td>
</tr>
<tr>
<td>1</td>
<td>Time in seconds from epoch</td>
</tr>
<tr>
<td>2</td>
<td>a (semi-major axis) – e.r.</td>
</tr>
<tr>
<td>3</td>
<td>e (eccentricity)</td>
</tr>
<tr>
<td>4</td>
<td>i (inclination)</td>
</tr>
<tr>
<td>5</td>
<td>$\Delta M$ (delta mean anomaly change from $T_0$)</td>
</tr>
<tr>
<td>6</td>
<td>$\omega$ (argument of perigee)</td>
</tr>
<tr>
<td>7</td>
<td>$\Omega$ (right ascension of the ascending node)</td>
</tr>
</tbody>
</table>

- $\pi/2 \leq i \leq \pi/2$
- $\phi \leq \Delta M \leq 2\pi$
- $\phi \leq \omega \leq 2\pi$
- $\phi \leq \Omega \leq 2\pi$

**Sentinel Record**

<table>
<thead>
<tr>
<th>Word Number</th>
<th>Word Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Fortran word count</td>
</tr>
<tr>
<td>1</td>
<td>$0.9999999999999999 \times 10^{30}$</td>
</tr>
<tr>
<td>2-8</td>
<td>Irrelevant</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Tape Function</th>
<th>Tape</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read Only Tapes</td>
<td>9T</td>
<td>Program Tape*</td>
</tr>
<tr>
<td></td>
<td>9T</td>
<td>Unit 4 Perturbation Tape (Optional)</td>
</tr>
<tr>
<td>Generated Tape to be Saved</td>
<td>7T or 9T</td>
<td>Unit 9 Bulletin Output Tape</td>
</tr>
</tbody>
</table>

*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

//G50BMBUL 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.FTO4F001 DD UNIT=2400-9,DISP=(OLD,PASS),LABEL=(,BLP),
// DCR=(RECFM=VS,BLKSIZE=128,LRECL=124,DEN=2,
// VOLUME=SER=XXXXX
// GO.FTO9F001 DD UNIT=2400-7,DISP=(NEW,PASS),LABEL=(,BLP),
// DCR=(RECFM=FA,BLKSIZE=120,TRTCH=ET,DEN=1),
// VOLUME=SER=*
// GO.SYSUDUMP DD SYSOUT=A
// GO.DA5 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**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>No DAF Parameters Computed</td>
<td>User does not desire to print DAF parameters and has blank input DAF card.</td>
</tr>
<tr>
<td>In This Run</td>
<td></td>
</tr>
<tr>
<td>TABLE(XX) = YYYY</td>
<td>Specified location XX of TABLE now equals indicated value YYYY.</td>
</tr>
<tr>
<td>End Bulletin Run</td>
<td>Program has followed normal path.</td>
</tr>
</tbody>
</table>
**TABLE(5)**  =  0.5661242000000000 C3

<table>
<thead>
<tr>
<th>ID.NO.</th>
<th>REF.DATE</th>
<th>LAMBDA</th>
<th>TAU</th>
<th>IMS</th>
<th>SATELLITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6806602</td>
<td>71 2 1 42 116</td>
<td>31 28</td>
<td>26600</td>
<td>INJUN-5</td>
<td>BROUWER BULLETIN</td>
</tr>
</tbody>
</table>

**INPUT QUANTITIES FROM CARDS**

<table>
<thead>
<tr>
<th>EPOCH</th>
<th>71 2 20 0 0 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>E</td>
</tr>
<tr>
<td>S CMEGA</td>
<td>C OMEGA</td>
</tr>
<tr>
<td>0.28557510 00 0.91205554D 00 0.84603385C 00 0.98460400D-01 0.51502780D 00</td>
<td></td>
</tr>
</tbody>
</table>

**CONVERTED QUANTITIES**

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>XDOT</th>
<th>YDOT</th>
<th>ZDOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.581111420 00 0.28057510 00 0.91205554D 00 0.84603385C 00 0.98460400D-01 0.51502780D 00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DRAG EFFECTS**

<table>
<thead>
<tr>
<th>T(P,0)</th>
<th>h(2,0)</th>
<th>N(3,0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>710220</td>
<td>0 0.16039000D-08 0.0</td>
<td></td>
</tr>
</tbody>
</table>

**COLUMN TABLE**

<table>
<thead>
<tr>
<th>T(P,0)</th>
<th>h(2,0)</th>
<th>N(3,0)</th>
<th>K(I)</th>
<th>MIN=100</th>
</tr>
</thead>
<tbody>
<tr>
<td>710223</td>
<td>C 0.16039000D-08 0.0 3 1008000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**EARTH CONSTANTS**

<table>
<thead>
<tr>
<th>HARMONICS</th>
<th>ML</th>
<th>ROTATION</th>
<th>FACIUS</th>
<th>FLATNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>K2</td>
<td>0.5412400000D-03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K3</td>
<td>0.266030000D-05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K4</td>
<td>0.690000000D-06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K5</td>
<td>0.600000000D-07</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>J</th>
<th>K</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16237200D-02</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

**INPUT UNITS -- CUL AND RADIANS**

<table>
<thead>
<tr>
<th>A</th>
<th>E</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1251046119400000 01 0.11571700 00 0.1407937930540000D 01 0.172733790 01 0.606780790 01 0.348709393 00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S CMEGA</td>
<td>C OMEGA</td>
<td>M</td>
</tr>
<tr>
<td>0.1727337861800000D 01 0.6678070415200000D 01 0.3487073290330000C 00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CONVERTED QUANTITIES -- KM AND DEGREES**

<table>
<thead>
<tr>
<th>A</th>
<th>E</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70756246971823000D 04 0.11571700 00 0.80668901236325240 02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S CMEGA</td>
<td>C OMEGA</td>
<td>M</td>
</tr>
<tr>
<td>0.996916967134700 02 0.34765734378885820 03 0.19970492662174980 02</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**BROUWER DAF PARAMETERS**

No DAF parameters completed in this run.

**END BULLETIN RUN**

Figure 3. Sample On-Line Printout
### Table 4

**Error Statements**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect Elements SAT. ID.</td>
<td>Input satellite ID does not agree with elements time satellite ID.*</td>
</tr>
<tr>
<td>Wrong SAT. ID. on Drag Card Drag Load Unsuccessful</td>
<td>Input satellite ID does not agree with drag satellite ID.</td>
</tr>
<tr>
<td>Error in Column Elements Request Card</td>
<td>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.</td>
</tr>
<tr>
<td>Column Time Table Load Unsuccessful</td>
<td></td>
</tr>
<tr>
<td>Wrong SAT. ID. on Column Elements Card</td>
<td>Input satellite ID does not agree with column elements time satellite ID.</td>
</tr>
<tr>
<td>Column Time Table Load Unsuccessful</td>
<td></td>
</tr>
<tr>
<td>Elements Type Equals Zero</td>
<td>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.</td>
</tr>
<tr>
<td>Latitude Increment Exceeds Inclination</td>
<td>The latitude increment can not exceed the inclination on the Bulletin request card.</td>
</tr>
<tr>
<td>Tape Check on Perturbation Tape</td>
<td>An uncorrectable error occurred when reading the perturbation tape. If tape is the correct tape to be used, rerun job.</td>
</tr>
<tr>
<td>Perturbation SAT. ID.</td>
<td>Input satellite ID does not agree with pert tape satellite ID.</td>
</tr>
<tr>
<td>Incorrect Data to CHANPL</td>
<td>The location of the constant to be changed is not in the range of the Table (0 thru 80).</td>
</tr>
<tr>
<td>Error in DAF SAT. ID.</td>
<td>Input satellite ID does not agree with DAF satellite ID.</td>
</tr>
</tbody>
</table>
Table 4 (Continued)

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

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.
**R183 D.P. BROUWER BULLETIN**

**INJUN-5**

FROM 710223  0  
TO  710302  81500

**INJUN-5 BROUWER BULLETIN**

Figure 4. Listing of Sample Output Tape

---

**INJUN-5 BROUWER BULLETIN**

<table>
<thead>
<tr>
<th>ID.NO.</th>
<th>REF.DATE</th>
<th>LAMBDA</th>
<th>HMS</th>
<th>TAU</th>
<th>DMS</th>
<th>SATELLITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6806602</td>
<td>71 2 1 8</td>
<td>42 11663 311 28 26600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**INPUT QUANTITIES FROM CARDS**

| EPOCH | 71 2 20 0 0 0 |

**CONVERTED QUANTITIES**

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>XDOT</th>
<th>YDOT</th>
<th>ZDOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.58119192D</td>
<td>0.28055751D</td>
<td>0.91206554D</td>
<td>0.34633388D</td>
<td>0.98469400D-01</td>
<td>0.51502878D</td>
</tr>
</tbody>
</table>

**DRAG EFFECTS**

<table>
<thead>
<tr>
<th>T(P,Q)</th>
<th>N(2,Q)</th>
<th>N(3,Q)</th>
<th>K11</th>
<th>MIN*100</th>
</tr>
</thead>
<tbody>
<tr>
<td>710220</td>
<td>0.16039000D-08 0.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**COLUMN TABLE**

<table>
<thead>
<tr>
<th>T(P,Q)</th>
<th>N(2,Q)</th>
<th>N(3,Q)</th>
<th>K11</th>
<th>MIN*100</th>
</tr>
</thead>
<tbody>
<tr>
<td>710223</td>
<td>0.16039000D-08 0.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**EARTH CONSTANTS**

<table>
<thead>
<tr>
<th>MU</th>
<th>ROTATION</th>
<th>RADIUS</th>
<th>FLATNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.100000030</td>
<td>0.588336900</td>
<td>0.13003300D</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>K</th>
<th>MIN*100</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>10*8000</td>
</tr>
</tbody>
</table>

**HARMONICS**

| K2 | 0.54124000D-03 | K3 | 0.256000000E05 | K4 | 0.690000000E06 | K5 | 0.600000000E07 |
| J | 0.16272000D-02 | H | 0.0 | K | 0.0 | L | 0.0 |

**INPUT UNITS -- CUL AND RADIANS**

<table>
<thead>
<tr>
<th>A</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.125104511947123</td>
<td>0.115761702235674D</td>
<td>0.14793793564D</td>
<td>0.14179379354D</td>
<td>0.14179379354D</td>
<td>0.14179379354D</td>
</tr>
<tr>
<td>S</td>
<td>OMEGA</td>
<td>C</td>
<td>OMEGA</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>0.172737869199000</td>
<td>0.6067800000000</td>
<td>0.3487079293300D</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CONVERTED QUANTITIES -- KM AND DEGREES**

<table>
<thead>
<tr>
<th>A</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.797962497182301D</td>
<td>0.115761702230000</td>
<td>0.805689012363252</td>
<td>0.2</td>
<td>S</td>
<td>OMEGA</td>
</tr>
<tr>
<td>0.989969169671747D</td>
<td>0.3476597343708582D</td>
<td>0.0</td>
<td>0.199794926627495D</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4a
### Space Elements

<table>
<thead>
<tr>
<th>EPOCH</th>
<th>YRMODYHRMMSS.SSSS</th>
<th>JULIAN DATE FOR SPACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALENDAR DATE</td>
<td>71 220 0 0 0. 0 UT2W</td>
<td>4903. 00 UT2W</td>
</tr>
</tbody>
</table>

| PERIOD, ANOMALISTIC       | 118.289055         | MIN                    |
| PERIOD DERIVATIVE         | -0.03807           | MICRODAYS/DAY          |
| ECCENTRICITY              | 0.11669938         |                       |
| INCLINATION               | 80.66793           | DEG                    |
| RIGHT ASCENSION OF ASCENDING NODE | 347.65948          | DEG                    |
| RT. ASC. OF ASC. NODE DERIVATIVE | -0.25198           | DEG/DAY                |
| ARGUMENT OF PERIGEE       | 98.88999           | DEG                    |
| ARGUMENT OF PERIGEE DERIVATIVE | -0.28681           | DEGDAY                 |
| MEAN ANOMALY              | 20.95734           | DEG                    |
| SEMI MAJOR AXIS           | 1.2510762 ER       |                        |

### Descriptive Space Elements

<table>
<thead>
<tr>
<th>EPOCH</th>
<th>YRMODYHRMMSS.SSSS</th>
<th>JULIAN DATE FOR SPACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAL DAT</td>
<td>71 220 0 0 0. 0 UT2W</td>
<td>4903. 00 UT2W</td>
</tr>
</tbody>
</table>

| 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 | 15.37797 | 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         | 6.28590C KM/SC     | 14061.159 ST MI/HR     |

### Prediction Space Elements

<table>
<thead>
<tr>
<th>EPOCH</th>
<th>YRMODYHRMMSS.SSSS</th>
<th>JULIAN DATE FOR SPACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAL DAT UT2W</td>
<td>717223 0 0 0 0 0</td>
<td>4906.000000000000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PERIOD</th>
<th></th>
<th>T-1</th>
<th>T-2</th>
<th>T-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN</td>
<td>118.288893</td>
<td>118.288484</td>
<td>118.288042</td>
<td></td>
</tr>
<tr>
<td>PERIOD DER MOD</td>
<td>-0.04053</td>
<td>-0.04385</td>
<td>-0.04674</td>
<td></td>
</tr>
<tr>
<td>ECCENTRICITY</td>
<td>0.11671034</td>
<td>0.11668890</td>
<td>0.11660359</td>
<td></td>
</tr>
<tr>
<td>INCLINATION</td>
<td>80.667821</td>
<td>80.667843</td>
<td>80.667935</td>
<td></td>
</tr>
<tr>
<td>RA ASC NODE DEG</td>
<td>345.392596</td>
<td>340.103199</td>
<td>334.813777</td>
<td></td>
</tr>
<tr>
<td>ARG PERIGEE DEG</td>
<td>92.867035</td>
<td>78.813560</td>
<td>64.752881</td>
<td></td>
</tr>
<tr>
<td>MEAN ANOM</td>
<td>207.520943</td>
<td>285.010408</td>
<td>2.610200</td>
<td></td>
</tr>
<tr>
<td>SEMIMAJ AXIS ER</td>
<td>1.2516750</td>
<td>1.2510722</td>
<td>1.2510694</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4b
### Osculating Space Elements

<table>
<thead>
<tr>
<th>EPOCH</th>
<th>YRMODYHRMSS.SSSS</th>
<th>J.D.S.</th>
<th>71 220 0 0 0 0 UT2W</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSCULATING SPACE ELEMENTS</td>
<td>PERIOD</td>
<td>118.11675</td>
<td>MIN</td>
</tr>
<tr>
<td></td>
<td>ECCENTRICITY</td>
<td>0.1159741</td>
<td>ER</td>
</tr>
<tr>
<td></td>
<td>INCLINATION</td>
<td>80.66564</td>
<td>DEG</td>
</tr>
<tr>
<td></td>
<td>ARGUMENT OF ASCENDING NODE</td>
<td>347.65290</td>
<td>DEG</td>
</tr>
<tr>
<td></td>
<td>MEAN ANOMALY</td>
<td>98.50309</td>
<td>DEG</td>
</tr>
</tbody>
</table>

### Osculating Cartesian Quantities

<table>
<thead>
<tr>
<th></th>
<th>X COMPONENT</th>
<th>Y COMPONENT</th>
<th>Z COMPONENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>-0.37110174D 0</td>
<td>0.17930367D 0</td>
<td>0.29755569D 0</td>
</tr>
<tr>
<td>Y</td>
<td>0.17930367D 0</td>
<td>0.28065969</td>
<td>0.910103684</td>
</tr>
<tr>
<td>Z</td>
<td>0.58105528D 0</td>
<td>0.4612362E -0</td>
<td>0.140793790 01</td>
</tr>
</tbody>
</table>

### Mean Elements of Modified Brouwer Type

<table>
<thead>
<tr>
<th></th>
<th>A DOUBLE PRIME(SEMI-MAJOR AXIS CONSTANT)</th>
<th>0.12510845D 01</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E DOUBLE PRIME(ECCENTRICITY CONSTANT)</td>
<td>0.1157617D 00</td>
</tr>
<tr>
<td></td>
<td>I DOUBLE PRIME(INCLINATION CONSTANT)</td>
<td>0.140793790 01</td>
</tr>
<tr>
<td></td>
<td>L ZERO DOUBLE PRIME(MEAN MEAN ANOMALY)</td>
<td>0.3487079300 01</td>
</tr>
<tr>
<td></td>
<td>G ZERO DOUBLE PRIME(MEAN ARG PERIGEE)</td>
<td>0.172733790 01</td>
</tr>
<tr>
<td></td>
<td>H ZERO DOUBLE PRIME(MEAN RT ASC ASC NODE)</td>
<td>0.606780700 01</td>
</tr>
<tr>
<td></td>
<td>N (2,Q)</td>
<td>0.160390000 08</td>
</tr>
</tbody>
</table>

### Osculating Elements of Modified Brouwer Type

<table>
<thead>
<tr>
<th>EPOCH</th>
<th>YRMODYHRMSS.SSSS</th>
<th>J.D.S.</th>
<th>71 220 0 0 0 0 UT2W</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSITION VECTOR</td>
<td>X COMPONENT</td>
<td>Y COMPONENT</td>
<td>Z COMPONENT</td>
</tr>
<tr>
<td>UNITS</td>
<td>STATUTE MILES</td>
<td>-0.23059193D 04</td>
<td>0.11122772D 04</td>
</tr>
<tr>
<td></td>
<td>KILOMETERS</td>
<td>-0.37110174D 04</td>
<td>0.17900367D 04</td>
</tr>
<tr>
<td></td>
<td>NAUTICAL MILES</td>
<td>-0.20037891D 04</td>
<td>0.96654249D 04</td>
</tr>
<tr>
<td></td>
<td>FEET</td>
<td>-0.12175254D 08</td>
<td>0.58728238D 07</td>
</tr>
</tbody>
</table>

| VELOCITY VECTOR       | X COMPONENT | Y COMPONENT | Z COMPONENT |
| UNITS       | SM/HOUR | -0.14962725D 05 | 0.17424079D 04 | 0.91099711D 04 |
|             | KN/HOUR | -0.240380171D 05 | 0.28041337D 04 | 0.16661077D 04 |
|             | KNOTS | -0.12988476D 05 | 0.15125068D 04 | 0.7907961D 00 |
|             | METERS/SECOND | -0.66893934D 04 | 0.77892602D 03 | 0.4072521D 04 |
|             | FEET/SECOND | -0.21945329D 05 | 0.2555315D 04 | 0.13361291D 05 |

Figure 4c
**Goddard Space Flight Center**  
**Space Flight Bulletin**  
**Mar 3, 1971**  
**J.D.S. 4914**

SAT DESG NAME SL NRDN SBUAT INJ.D.S. RVNEI OMAG KG/M2 RFDKCMPC W CCNC  
J.D.S. PERAN MUD PEK DEKE PHTEQUR APHEQUR INMOD RAANOD ARGPER MANAC C  
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**Figure 4d**  
**Figure 4e**

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192
### ONE ORBIT EPHEMERIS

**REVOLUTION NO. 11337**

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Figure 4f

### BROUWER CAFT PARAMETERS

**NO DAF PARAMETERS COMPUTED IN THIS RUN**

Figure 4g