SHUTTLE ON-ORBIT RENDEZVOUS TARGETING: CIRCULAR ORBITS

Prepared for:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Aero-Astrodynamics Laboratory

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by

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HUNTSVILLE, ALABAMA
FOREWORD

This memorandum presents the results of work performed by Northrop Services, Inc. while under contract to the Aero-Astrodynamics Laboratory of the Marshall Space Flight Center (NAS8-21810). This task was conducted in response to the requirements of Appendix E-1, Schedule Order No. 3, Technical Directive No. 1. Technical Coordination was provided by Mr. Wayne Deaton of the Guidance Applications Section (R-AERO-GG).
ABSTRACT

This memorandum presents a description of the strategy and logic used in a space shuttle on-orbit rendezvous targeting program. The program generates ascent targeting conditions for boost to insertion into an intermediate parking orbit, and generates on-orbit targeting and timeline bases for each maneuver to effect rendezvous with a space station. Time of launch is determined so as to eliminate any plane change, and all work was performed for a near-circular space station orbit.
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KEY WORDS

Orbiter - chaser or pursuit vehicle

Space Station - any target vehicle, satellite

Shuttle Launch Vehicle - booster plus orbiter configuration

Intermediate Orbit - a phasing orbit for the orbiter on-orbit used to alleviate large phasing differences between vehicles. (= 100 n mi Parking orbit for this analysis)

Constant Delta Height (CDH) - a height differential existing between the orbiter and the space station (an orbit approximately 10 n mi below or above the space station). Same as coelliptic orbit.

Transfer Phase Initiation (TPI) - A point on the CDH orbit when gross rendezvous conditions have been met in order to make the final transfer to the rendezvous point.

On-Orbit - the pursuit vehicle after insertion and before rendezvous during all of its intermediate phasing orbits.
SYMBOLS

$\Delta i$  Wedge angle between planes at TPI
$\Delta \phi$  Range angle difference at TPI after isolation
$\Delta \theta_N$  Nodal difference at TPI
$\Delta T_{L\phi}$  Lift-off time correction to compensate for nodal regression
$\Delta \phi_{TB}$  First pass Range angle difference using first guess two-body targeting
$X_S', Y_S', Z_S'$  Space fixed launch coordinate system
$A_z$  Launch aximuth
$\phi_L$  Geodetic latitude of launch site (28.608°)
$\phi_{SV}$  Sun vector right ascension
$\alpha_{SV}$  Sun vector declination
$U.T.$  Universal Time measured from midnight Greenwich to launch meridian
$\lambda_L$  Longitude of launch site
$\Delta \phi$  Difference in range angles of orbiter and space station at time of orbiter insertion
$\psi$  Insertion latitude, a function of inclination of the space station
$I_D$  Desired inclination for targeting purposes
$P_S$  Semi-latus rectum of CDH orbit
$e_S$  Eccentricity of CDH orbit
$\bar{\omega}, |\omega|$  Earth's rotational velocity
$P_P$  Semi-latus rectum of orbiter on-orbit during Hohmann transfer
$e_P$  Eccentricity of orbiter on-orbit during Hohmann transfer
$TULO$  Universal time of lift-off
$\phi_T$  Range angle
$\phi$  True anomaly
$\alpha_{PL}$  Argument of perigee
### SYMBOLS (Continued)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Semi-major axis</td>
</tr>
<tr>
<td>e</td>
<td>eccentricity</td>
</tr>
<tr>
<td>$\psi_{\text{DS}}$</td>
<td>desired insertion latitude for southerly launch</td>
</tr>
<tr>
<td>$\psi_{\text{DN}}$</td>
<td>desired insertion latitude for northerly launch</td>
</tr>
<tr>
<td>$\phi_{\text{LS}}$</td>
<td>Range angle at the desired latitude</td>
</tr>
<tr>
<td>$\vec{x}_p, \dot{\vec{x}}_p$</td>
<td>State vector position and velocity of orbiter</td>
</tr>
<tr>
<td>$\vec{x}_T, \dot{\vec{x}}_T$</td>
<td>State vector position and velocity of space station</td>
</tr>
<tr>
<td>$T_1$</td>
<td>Time of orbit insertion</td>
</tr>
<tr>
<td>$\beta_{\text{SVPT}}$</td>
<td>instantaneous angle from the sun's projection vector on orbital plane to the TPI point</td>
</tr>
<tr>
<td>$\beta_{\text{SVPD}}$</td>
<td>same as above but is the desired input value</td>
</tr>
<tr>
<td>$\hat{E}_{\text{RA}}$</td>
<td>Unit vector in the equatorial plane and through the launch longitude</td>
</tr>
<tr>
<td>$\theta_{\text{NT}}$</td>
<td>descending node of space station referenced from space-fixed shuttle launch meridian in the equatorial plane</td>
</tr>
<tr>
<td>$\theta_{\text{NP}}$</td>
<td>descending node of the orbiter referenced from space-fixed shuttle launch meridian in the equatorial plane</td>
</tr>
<tr>
<td>$\Delta \phi_R$</td>
<td>desired range angle difference between vehicles at TPI</td>
</tr>
<tr>
<td>$\Delta \phi_E$</td>
<td>difference between actual and desired range angle difference, this value to be driven &lt; .05 in the isolation logic</td>
</tr>
<tr>
<td>$\phi_T$</td>
<td>Range angle of space station measured from the descending node w.r.t. equatorial plane</td>
</tr>
<tr>
<td>$\phi_P$</td>
<td>Range angle of orbiter measured from descending node w.r.t. equatorial plane</td>
</tr>
<tr>
<td>$\phi_{\text{NT}}$</td>
<td>Range angle of the space station measured from the common (ascending) node of the space station and the orbiter planes</td>
</tr>
<tr>
<td>$\phi_{\text{NP}}$</td>
<td>Range angle of the orbiter measured from the common (ascending) node of the space station and the orbiter planes</td>
</tr>
<tr>
<td>$\Delta \phi$</td>
<td>difference in the range angles of the space station and the orbiter</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>WATP</td>
<td>Wedge angle between the space station and the orbiters plane</td>
</tr>
<tr>
<td>WATOL</td>
<td>Tolerance to select which $\Delta \phi$ to use (for example, $WATOL &lt; .1 : : \Delta \phi = \phi_T - \phi_P$ or $\Delta \phi = \phi_{NT} - \phi_{NT}$)</td>
</tr>
<tr>
<td>TSTI</td>
<td>Time of Circularization</td>
</tr>
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Section I

INTRODUCTION

This memorandum is primarily an equation defining document containing the basic targeting equations in flowchart form to create targeting conditions at lift-off for the shuttle launch vehicle. This also includes the method of determining the on-orbit timeline of thrusting events* during orbital maneuvers and also determines the Universal Time of lift-off.

The basic mission profile considered for this targeting procedure includes boost to insertion and three impulsive maneuvers, as listed below, to establish a constant delta height position (Figure 1-1).

- Insertion (50 x 100 n mi)
- Circularization at apogee (100 n mi)
- Perigee impulse (≥ 100 x 265 n mi)
- Coelliptic impulse (≥ 260 n mi)

The launch azimuth (A Z), inclination (i) and node (θ N) for the launch phase are generated to achieve orbiter/satellite rendezvous. These are generated in such a manner as to achieve orbiter/satellite rendezvous with coplanar conditions near rendezvous and with the proper phase and coelliptic height differential at TPI.

The given task assignment was to build a space shuttle on-orbit rendezvous targeting computer program that would depend only upon a target satellite ephemeris and the initial in-plane orbital conditions of the space shuttle (50 x 100 n mi). The computer program was to establish lift-off time for the space shuttle so as to require no plane change in the ascent portion of flight, or on-orbit portion of the rendezvous mission. The computer program establishes a timeline of the thrusting events and guidance targeting requirements.

*This targeting procedure is developed with impulsive maneuver simulations. Using these targeting values on-orbit will result in ignition time deviations for each maneuver. This could be alleviated by simulating finite burns with the targeting deck itself.
Figure 1-1. COPLANAR PROFILE DEPICTING TIME BASES FOR NEAR-CIRCULAR RENDEZVOUS
Care was to be taken to minimize the number of instructions and storage requirements of the program so that it would be possible to have an on-board shuttle rendezvous capability. The Coordinators flowcharts were to be used, and deviations were to be made whenever necessary and storage instruction could be reduced.
Section II
DISCUSSION

The shuttle, being a performance critical vehicle, should be targeted to a zero plane change, on-time ascent to orbit (50 x 100 n mi) flight profile (as well as to basic satellite delivery missions). The shuttle should not be burdened with a requirement for a rendezvous launch window since this would degrade the payload delivery capability. The procedure presented here will allow launches to be achieved at each in-plane point. One in-plane point will occur for a northerly launch opportunity and the other for a southerly launch opportunity. These conditions occur twice per day, 365 days/year. These two launch opportunities that occur each day are only restricted if the launch site is too close to the in-plane point to allow pre-flight analysis to be performed before the launch. With more restrictive launch vehicles (short systems lifetimes), the correct in-phase and in-plane condition (rendezvous compatible) has to exist to achieve a rendezvous; but, this is not a requirement for the targeting technique presented in this memorandum. An intermediate near-circular phasing orbit at the apogee of the shuttle launch vehicle 50 x 100 n mi insertion orbit will eliminate the space station in-phase requirement at orbital insertion. (If the relative catch-up rate between the 100 n mi intermediate phasing orbit and the space station is not sufficient to null out phase differences, the use of an intermediate stay orbit at a higher altitude will be necessary.) An intermediate phasing orbit exists so that phase angle differences between the two vehicles can be eliminated by exploiting the difference in their respective orbital periods.

Other advantages of this targeting technique include:

- Launch vehicle performance variations will merely change the range correction of the terminal rendezvous maneuvers without causing unacceptable performance losses.
- Eliminates high closing rates of the orbiter w.r.t. the space station, which might be encountered when using direct rendezvous techniques and their resulting performance losses.
This technique allows launch opportunities to occur on a daily basis without degrading the payload delivery capabilities. This is important, for example, when considering the shuttle launch vehicle configuration which requires many launches each year for economical reasons.

If count-down is delayed the next opportunity can be utilized.

The targeting program generates complete targeting based upon space station ephemeris data. This is accomplished by assuming that the Manned Space Flight Tracking Network (MSFN) has made available the epoch (Universal) time when the launch site will be contained in the space station plane, based upon spherical trigonometry and also the ephemeris at this time. The orbital elements (node, inclination, eccentricity, etc.) describing the position of the space station at the in-plane time (U.T.) are presented in Section V.

The periodic perturbations of the space stations' inclination were determined and accounted for in the targeting procedure by using a rapid integration algorithm to advance the space station to the insertion latitude of the shuttle (at present a variable step size Runge Kutta numerical integration scheme is utilized).

The effects of orbital nodal regression are corrected by adjusting the shuttle launch vehicle lift-off time while maintaining the same ascent targeting parameters. The amount of nodal regression depends on the transfer orbits necessary to satisfy phasing requirements, navigation update requirements and lighting requirements.

The ascent trajectory was programmed as a functional representation of an ascent profile. This is presently a sixth order curve fit polynomial as shown in the flowchart on page D-6. Future work in this area includes curve fit techniques using exponential curves and other types of fits which will improve curve-fit accuracy and reduce ephemerical curve-fit coefficients.
Section III
RENDZVOUS TARGETING TECHNIQUES

The procedures for effecting rendezvous include integration of the space station to the insertion latitude (\(\psi\)) to determine the desired inclination (I\(_D\)) for the orbiter insertion. This causes the orbiter to have the same mean inclination as the space station at insertion. This procedure is necessary to account for periodic variations in the inclination of the space station orbit about the oblate earth. The variation of inclination versus time from insertion and time after circularization for both vehicles is presented in Figures 3-1 and 3-2. These figures depict variations with approximately the same mean inclination. Similar results, at a point on-orbit after the apsidal rotation maneuver where the orbiter is phasing 10 n mi below the space station, are presented in Figure 3-3. As can be observed at this point, the variations in inclinations are almost in-phase and thus nearly synchronized. This is desirable for rendezvous targeting to alleviate unnecessary plane change during coelliptic coast.

The desired inclination (I\(_D\)) for targeting purposes dictates the ascent targeting parameters for the shuttle booster/orbiter launch configuration. As shown on page D-6 of the flowchart the insertion conditions for the southerly and northerly launches are a function of the desired inclination. The launch azimuth, descending node, insertion time, and range angle are presently least square curve fit functions of the desired inclination (I\(_D\)).

A quick-look two-body analysis of the on-orbit phasing is executed after orbit insertion. Many of the two-body parameters (page D-8) are used for the initialization of the isolation technique for its "first guess".

The time bases for each on-orbit maneuver are given in Table 3-1. These time bases occur approximately 200 seconds prior to the actual maneuver. The actual times will be presented in Section IV. This timeline includes the insertion time, the time of circularization, time of perigee burn out of the
Figure 3-1. ORBITER AFTER INSERTION WITH APPROXIMATE SAME MEAN INCLINATION
Figure 3-2. ORBITER AFTER CIRCULARIZATION WITH APPROXIMATE SAME MEAN INCLINATION
Figure 3-3. SHUTTLE RENDEZVOUS INPLANE LAUNCH GEOMETRY
100 n mi intermediate orbit, time of coelliptic maneuver, and the time of Transfer Phase Initiation (TPI).

Table 3-1. TIME BASES FOR PREPARATION OF MANEUVERS

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>DEFINITION</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁</td>
<td>Insertion time of orbiter</td>
<td>sec</td>
</tr>
<tr>
<td>TTEST 1</td>
<td>Preparation for the circularization maneuver begins at this time (approximately 200 seconds before apogee of initial insertion orbit of the orbiter)</td>
<td>sec</td>
</tr>
<tr>
<td>TTEST 2</td>
<td>Preparation for perigee maneuver out of the near-circular phasing orbit begins at this time</td>
<td>sec</td>
</tr>
<tr>
<td>TTEST 3</td>
<td>Preparation for the coelliptic maneuver begins at this time</td>
<td>sec</td>
</tr>
<tr>
<td>TSBST</td>
<td>Time for the transfer phase initiation (TPI)</td>
<td>sec</td>
</tr>
</tbody>
</table>

The mission time of insertion and time of circularization will not be changed during the isolation loop. This is a constraint which must be met to maintain the same ascent targeting parameters.

The time of perigee burn out of the 100 n mi intermediate orbit is a variable and depends on the desired value of the phase angle difference (ΔΦ₃) at TPI. It also depends on the oblate earth effects on the "first guess" two-body timing.

The effects of orbital nodal regression are corrected by adjusting the shuttle lift-off time. Once the desired phase angle (ΔΦ₃) at TPI is isolated, then the existing nodal error is mapped into a Universal Time correction at lift-off. This is demonstrated on page D-18 of the flowchart.
The manner in which the sun's declination and right ascension are evaluated is illustrated in Figure 3-4, and the sun's position in the launch coordinate system is depicted in Figure 3-5. Knowledge of the sun's position is necessary in the targeting procedures when proper lighting is considered.

A general flowchart of the rendezvous targeting technique is presented in Figure 3-6. Detailed flow of this targeting procedure is included on pages D-2 through D-20.

A typical mission profile is illustrated in Figure 1-1. The orbiter is inserted into a 50 x 100 n mi orbit. A coast to apogee occurs where an apogee burn is made to circularize into the 100 n mi circular orbit (TEST1). After circularization a coast of at least a half-orbit is necessary (and is handled by the scale factor input SFN01). A value of SFN01=0.5 insures at least a half-orbit before the perigee burn onto a Hohmann transfer at time TTEST2. This scale factor can be initialized to any desired value. More stay time would be desired if phasing or lighting constraint is to be satisfied. The purpose of extra stay time would be to insure time needed for real time preparations. The scale factor for the Hohmann phasing (SFN02) and the coelliptic phasing, 10 n mi below or above target, (SFN03) will insure extra stay time in all phasing orbits until rendezvous is accomplished. This extra stay time will enforce adequate time for crew and orbiter check-out, orbit evaluation and system checkout, propulsion checkout, tracking acquisition, and navigation update. Any realistic targeting technique has to provide this extra controlled stay time for real time targeting.

After the perigee maneuver at time base TTEST2, a coast of approximately a half an orbit brings the vehicle to an intersection with the coelliptic orbit. The derivation of the equations for determining the intersection of the near-Hohmann transfer with the Constant Delta Height (CDH) orbit at time base TTEST3 is presented in Appendix A. The equations necessary for determining the desired values for the differential height are included in Appendix 3-6.
\[ \phi_{SV} = \pi + \lambda_L - \text{U.T.}|\bar{\omega}| \]

\[ \alpha_{SV} = a \cos(b + c \cdot T_Y) \]

Figure 3-4. RIGHT ASCENTION AND DECLINATION OF SUN WITH RESPECT TO LAUNCH MERIDIAN
Figure 3-5. ROTATIONS FROM LAUNCH COORDINATE SYSTEM TO SUN VECTOR

\[ x_N = [\phi_L]_3 [A_{\omega} - \frac{\pi}{2}]_1 \bar{x}_S \]

\[ \bar{x}_{SV} = [-\alpha_{SV}]_3 [-\phi_{SV}]_2 \bar{x}_N \]
Figure 3-6. GENERAL FLOWCHART TO CORRECT LIFT-OFF TIME FOR NO PLANE CHANGE ON-TIME SHUTTLE ASCENT TARGETING
B. These equations have been presented in a earlier publication (ref. 1), but in a different manner.

A pictorial illustration of the position of the orbiter and space station at insertion ($T_N + T_1$) and at lift-off ($T_N$) for the tracking network is given in Figure 3-7. The $\Delta\phi$ angle represents the range angle difference between the space station and the orbiter at insertion time $T_1$. It is reasoned that the tracking network will supply the ephemeris of the target when it is in-plane at U.T. of $T_N$ or $T_5$, and not the ephemeris that the target vehicle has at any acquisition time $T$. The ephemeris will be used to determine the time deviation ($\Delta T_{LO}$) for lift-off from this in-plane time ($T_N$) which will result in coplanar on-orbit phasing near the rendezvous point. It is not a necessary criterion, as stated earlier, that this be a rendezvous compatible orbit, so any $\Delta\phi$ relation may exist at lift-off/insertion and rendezvous can be accomplished through proper on-orbit phasing.

Figure 3-7. SPACE STATION AT ACQUISITION TIME \( (T_N) \) AND AT INSERTION \( (T_N + T_1) \)
Section IV

RESULTS AND CONCLUSIONS

The rendezvous targeting program was developed to generate targeting conditions for the shuttle launch vehicle at launch. The desired inclination ($I_D$) and launch azimuth ($A_Z$) at lift-off can be determined to achieve rendezvous with near-circular target satellites at various inclinations and various altitudes. Also, the time of launch (Universal Time, U.T.) and the timeline bases from lift-off have been determined for the orbital maneuver to accomplish rendezvous.

Verification of the targeting scheme included a total of 30 cases being run with varying phase relationships of the space station ($0 < \Delta \phi < 2\pi$) at the time of orbiter insertion (Figure 4-1). Included were cases with lighting constraints, northerly and southerly launch opportunities, and different phase relationships at transfer phase initiation.

Several cases were run for a northerly launch, without a lighting constraint. The phase relation of the orbiter at TPI is below and behind the space station by a 10 n mi height differential (the orbiter lags the space station by a desired $\Delta \phi = -0.29$ degree). Isolated phase angles at TPI of 0.29, 0.32, 0.28, and 0.24 degree were obtained (as shown in Table 4-1), which are all within the desired tolerance of 0.05 degree. Also, the inplane conditions at TPI are within acceptable limits as can be observed from the values of $\Delta i$ and $\Delta \phi_N$. These inplane conditions could be improved, if desired, by decreasing the tolerance (of 0.02 degree) on pages D-18 through D-20 of the flowchart. Also, the timeline for the on-orbit maneuvers is listed in Table 4-1 for different range angles of the space station at the time of orbiter insertion (255, 345, 75, and 165 degrees). The adjustment required in the lift-off time is listed as $\Delta T_{LO}$, with the negative values representing launch before the spherical in-plane point.

Similar results for a southerly launch with a lighting constraint are presented in Table 4-2. The desired sun angle input was 110.0 degrees.
$3.3^\circ < \Delta \phi < 4.8^\circ$

$\Delta \phi = \phi_T - \phi_P$
Table 4-1. LIFT-OFF TIME CORRECTION FOR NEAR-CIRCULAR TARGET ORBITS FOR NORtherLY LAUNCH WITH NO LIGHTING CONSTRAINT

<table>
<thead>
<tr>
<th>TRUE ANOMALY</th>
<th>45°</th>
<th>135°</th>
<th>255°</th>
<th>315°</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABOVE AND AHEAD RANGE ANGLE</td>
<td>255°</td>
<td>345°</td>
<td>75°</td>
<td>165°</td>
</tr>
<tr>
<td>Insertion</td>
<td>0 hr. 6 m. 11 s.</td>
<td>0 hr. 6 m. 11 s.</td>
<td>0 hr. 6 m. 11 s.</td>
<td>0 hr. 6 m. 11 s.</td>
</tr>
<tr>
<td>Circularization</td>
<td>0 hr. 48 m. 27 s.</td>
<td>0 hr. 48 m. 27 s.</td>
<td>0 hr. 48 m. .27 s.</td>
<td>0 hr. 48 m. 27 s.</td>
</tr>
<tr>
<td>Perigee</td>
<td>1 hr. 26 m. 7 s.</td>
<td>7 hr. 14 m. 41 s.</td>
<td>12 hr. 23 m. 5 s.</td>
<td>18 hr. 36 m. 11 s.</td>
</tr>
<tr>
<td>Constant Delta Height</td>
<td>2 hr. 14 m. 33 s.</td>
<td>8 hr. 4 m. 42 s.</td>
<td>13 hr. 13 m. 17 s.</td>
<td>19 hrs. 27 m. 3 s.</td>
</tr>
<tr>
<td>Transfer Phase Initiation</td>
<td>5 hr. 48 m. 19 s.</td>
<td>11 hr. 10 m. 59 s.</td>
<td>16 hr. 37 m. 46 s.</td>
<td>21 hr. 58 m. 17 s.</td>
</tr>
<tr>
<td>Sun Angle (deg)</td>
<td>N. A.</td>
<td>N. A.</td>
<td>N. A.</td>
<td>N. A.</td>
</tr>
<tr>
<td>$\delta_t$ (deg)</td>
<td>$5.3 \times 10^{-4}$</td>
<td>$1.1 \times 10^{-2}$</td>
<td>$6.9 \times 10^{-4}$</td>
<td>$4.4 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\Delta \psi$ (deg)</td>
<td>0.29</td>
<td>0.32</td>
<td>0.28</td>
<td>0.24</td>
</tr>
<tr>
<td>$\Delta \theta_N$ (deg)</td>
<td>$-4.0 \times 10^{-4}$</td>
<td>$-1.3 \times 10^{-2}$</td>
<td>$-2.8 \times 10^{-4}$</td>
<td>$4.6 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\Delta T_L0$ (sec)</td>
<td>-284.7</td>
<td>-226.4</td>
<td>-199.06</td>
<td>-143.6</td>
</tr>
<tr>
<td>$\Delta \phi_T$ (deg)</td>
<td>-.81</td>
<td>-2.21</td>
<td>-4.43</td>
<td>5.94</td>
</tr>
<tr>
<td>SFN03 (unitless)</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Table 4-2. LIFT-OFF TIME CORRECTION FOR NEAR-CIRCULAR TARGET ORBITS FOR SOUTHERLY LAUNCH WITH LIGHTING CONSTRAINT

<table>
<thead>
<tr>
<th>TRUE ANOMALY</th>
<th>RANGE ANGLE</th>
<th>45°</th>
<th>135°</th>
<th>225°</th>
<th>315°</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABove AND AHEAD</td>
<td>255°</td>
<td>345°</td>
<td>75°</td>
<td>165°</td>
<td></td>
</tr>
<tr>
<td>Insertion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 hr. 6 m. 11 s.</td>
<td>1111 s.</td>
<td>0 hr. 6 m. 11 s.</td>
<td>0 hr. 6 m. 11 s.</td>
<td>0 hr. 6 m. 11 s.</td>
<td></td>
</tr>
<tr>
<td>Circularization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 hr. 50 m. 48 s.</td>
<td>4 48 s.</td>
<td>0 hr. 60 m. 48 s.</td>
<td>0 hr. 50 m. 48 s.</td>
<td>0 hr. 50 m. 48 s.</td>
<td></td>
</tr>
<tr>
<td>Perigee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 hr. 27 m. 36 s.</td>
<td>29 s.</td>
<td>7 hr. 51 m. 52 s.</td>
<td>13 hr. 30 m. 17 s.</td>
<td>14 hr. 19 m. 59 s.</td>
<td></td>
</tr>
<tr>
<td>Constant Delta Height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19 hr. 16 m. 59 s.</td>
<td>3 s.</td>
<td>8 hr. 42 m. 23 s.</td>
<td>14 hr. 19 m. 59 s.</td>
<td>18 hr. 50 m. 34 s.</td>
<td></td>
</tr>
<tr>
<td>Transfer Phase Initiation</td>
<td>26 hr. 22 m. 50 s.</td>
<td>8 hr. 37 m. 27 s.</td>
<td>14 hr. 33 m. 22 s.</td>
<td>18 hr. 50 m. 34 s.</td>
<td></td>
</tr>
<tr>
<td>Sun Angle (deg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>109.91</td>
<td>109.88</td>
<td>109.92</td>
<td>109.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δi (deg)</td>
<td>8.17 x 10^-4</td>
<td>2.8 x 10^-3</td>
<td>7.9 x 10^-3</td>
<td>1.27 x 10^-3</td>
<td></td>
</tr>
<tr>
<td>Δφ (deg)</td>
<td>-.332</td>
<td>-.256</td>
<td>-.317</td>
<td>-.278</td>
<td></td>
</tr>
<tr>
<td>ΔθN (deg)</td>
<td>-1.87 x 10^-4</td>
<td>-2.53 x 10^-3</td>
<td>-9.3 x 10^-3</td>
<td>5.2 x 10^-4</td>
<td></td>
</tr>
<tr>
<td>ΔTLO (sec)</td>
<td>319.65</td>
<td>190.1</td>
<td>235.9</td>
<td>275.42</td>
<td></td>
</tr>
<tr>
<td>ΔφTB (deg)</td>
<td>35.5</td>
<td>13.36</td>
<td>22.7</td>
<td>16.11</td>
<td></td>
</tr>
<tr>
<td>SFN03 (unitless)</td>
<td>4.0</td>
<td>3.0</td>
<td>3.5</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>
The results presented in Tables 4-1 and 4-2 are for effecting rendezvous with the baseline target in a 270 n mi orbit with an approximate 55 degree inclination. Rendezvous targeting was accomplished in all cases considered, with a time constraint of approximately 24 hours to the TPI point.

It should be noted that rendezvous with satellites at altitudes other than 270 will result in violation of a 24 hour time constraint, but targeting is still possible. This violation will most likely happen when the target satellite has a lower altitude and thus additional phasing in the 100 n mi phasing orbit will be required to alleviate large phase differences which may exist.

The executed listing presented as an example in Appendix C gives the eccentricity vector $\vec{e}$, angular momentum ($\vec{h}$) and delta velocity required ($\Delta V_R$) at each maneuver time to effect each burn. These on-orbit targeting conditions at each maneuver time can be used as inputs for any guidance package to simulate that particular orbital maneuver.

Results to date show that the present rendezvous targeting deck will establish lift-off time and on-orbit targeting parameters to effect gross rendezvous at TPI.
Section V
PROGRAM INPUTS AND OUTPUTS

5.1 INPUT

The rendezvous targeting deck was programmed in Fortran IV language for use on the CDC-3200 computer. Inputs to the program are described in the following text, and are listed in Table 5-1.

Table 5-1. INPUTS FOR NEAR-CIRCULAR RENDEZVOUS

<table>
<thead>
<tr>
<th>MATH SYMBOL</th>
<th>FORTRAN ALFA-NUMERIC NAME</th>
<th>DEFINITION OF SYMBOL; SCALE FACTOR, FLAG, VARIABLE, ETC.</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISURF</td>
<td>ISURF</td>
<td>=1, Boost cut-off surface =0, Steady state trajectory comp. (see page D-6 of flowchart)</td>
<td>Unitless</td>
</tr>
<tr>
<td>ILIG</td>
<td>ILIG</td>
<td>=1, Lighting constraint considered =0, No lighting considered (see page D-10 of flowchart)</td>
<td>Unitless</td>
</tr>
<tr>
<td>A0→A6</td>
<td>A(7)</td>
<td>Polynomial coefficients as a function of inclination to determine latitude of insertion for northerly launch.</td>
<td>Deg</td>
</tr>
<tr>
<td>B0→B6</td>
<td>B(7)</td>
<td>(Same as above for southerly launch).</td>
<td>Deg</td>
</tr>
<tr>
<td>C0→C6</td>
<td>C(7)</td>
<td>Polynomial coefficients as a function of inclination to determine azimuth of insertion for northerly launch.</td>
<td>Deg</td>
</tr>
<tr>
<td>D0→D6</td>
<td>D(7)</td>
<td>(Same as above for northerly node).</td>
<td>Deg</td>
</tr>
<tr>
<td>E0→E6</td>
<td>E(7)</td>
<td>(Same as above for northerly time-of-insertion).</td>
<td>Deg</td>
</tr>
<tr>
<td>F0→F6</td>
<td>F(7)</td>
<td>Polynomial coefficients as a function of inclination to determine azimuth of insertion for southerly launch.</td>
<td>Deg</td>
</tr>
<tr>
<td>G0→G6</td>
<td>G(7)</td>
<td>(Same as above for southerly node)</td>
<td>Deg</td>
</tr>
<tr>
<td>H0→H6</td>
<td>H(7)</td>
<td>(Same as above for southerly time-of-insertion).</td>
<td>Deg</td>
</tr>
<tr>
<td>Q0→Q6</td>
<td>Q(7)</td>
<td>Range angle of insertion (northerly).</td>
<td>Deg</td>
</tr>
<tr>
<td>S0→S6</td>
<td>S(7)</td>
<td>Range angle of insertion (southerly).</td>
<td>Deg</td>
</tr>
<tr>
<td>T</td>
<td>T</td>
<td>The universal time ephemeris data received from tracking station.</td>
<td>Sec</td>
</tr>
</tbody>
</table>
### Table 5-1. INPUTS FOR NEAR-CIRCULAR RENDEZVOUS (Continued)

<table>
<thead>
<tr>
<th>MATH SYMBOL</th>
<th>FORTRAN ALFA-NUMERIC NAME</th>
<th>DEFINITION OF SYMBOL; SCALE FACTOR, FLAG, VARIABLE, ETC.</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_N$</td>
<td>TN</td>
<td>The universal time of the in-plane opportunity for northerly launch.</td>
<td>Sec</td>
</tr>
<tr>
<td>$T_S$</td>
<td>TS</td>
<td>The universal time of the in-plane opportunity for southerly launch</td>
<td>Sec</td>
</tr>
<tr>
<td>TTOL</td>
<td>TTOL</td>
<td>Maximum time necessary to perform pre-flight analysis using this targeting deck.</td>
<td>Sec</td>
</tr>
<tr>
<td>HAP</td>
<td>HAP</td>
<td>Altitude of apogee of orbiter insertion ellipse</td>
<td>N MI</td>
</tr>
<tr>
<td>HPER</td>
<td>HPER</td>
<td>Altitude of perigee of orbiter insertion.</td>
<td>N MI</td>
</tr>
<tr>
<td>$A_N$</td>
<td>AN</td>
<td>Semi-major axis of space station received from tracking network for northerly opportunity ($T_N$).</td>
<td>M</td>
</tr>
<tr>
<td>$e_N$</td>
<td>EN</td>
<td>Eccentricity of space station received from tracking network for northerly opportunity ($T_N$).</td>
<td>Unitless</td>
</tr>
<tr>
<td>$i_N$</td>
<td>$\chi_{ENCN}$</td>
<td>Inclination of space station received from tracking network for northerly opportunity ($T_N$).</td>
<td>Deg</td>
</tr>
<tr>
<td>$\theta_{NN}$</td>
<td>TNNN</td>
<td>Descending node for northerly launch (TN).</td>
<td>Deg</td>
</tr>
<tr>
<td>$\alpha_{PLN}$</td>
<td>ALFAN</td>
<td>Argument of perigee for northerly launch (measured from descending node opposite direction of flight).</td>
<td>Deg</td>
</tr>
<tr>
<td>$\phi_N$</td>
<td>PNIN</td>
<td>True anomaly of space station for northerly launch.</td>
<td>Deg</td>
</tr>
<tr>
<td>$A_S$</td>
<td>AS</td>
<td>Semi-major axis for southerly launch.</td>
<td>M</td>
</tr>
<tr>
<td>$e_S$</td>
<td>ES</td>
<td>Eccentricity for southerly launch</td>
<td>Unitless</td>
</tr>
<tr>
<td>$i_S$</td>
<td>$\chi_{ENCSC}$</td>
<td>Inclination for southerly launch.</td>
<td>Deg</td>
</tr>
<tr>
<td>$\theta_{NS}$</td>
<td>THNS</td>
<td>Node for southerly launch.</td>
<td>Deg</td>
</tr>
<tr>
<td>$\alpha_{PLS}$</td>
<td>ALFAS</td>
<td>Argument of perigee for southerly launch.</td>
<td>Deg</td>
</tr>
<tr>
<td>$\phi_S$</td>
<td>PHIS</td>
<td>True anomaly for southerly launch.</td>
<td>Deg</td>
</tr>
<tr>
<td>$\phi_L$</td>
<td>PHI</td>
<td>Geodetic latitude of launch site measured from equatorial plane.</td>
<td>Deg</td>
</tr>
</tbody>
</table>
### Table 5-1. INPUTS FOR NEAR-CIRCULAR RENDEZVOUS (Concluded)

<table>
<thead>
<tr>
<th>MATH SYMBOL</th>
<th>FORTRAN NAME</th>
<th>DEFINITION OF SYMBOL; SCALE FACTOR, FLAG, VARIABLE, ETC.</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda_L )</td>
<td>XLAMAL</td>
<td>Longitude of launch site measured negative west of prime meridian.</td>
<td>Deg</td>
</tr>
<tr>
<td>( \beta_{SVD} )</td>
<td>BSVD</td>
<td>Desired sun angle, measured from sun projection on space-station plane in direction of flight to TPI.</td>
<td>Deg</td>
</tr>
<tr>
<td>( a, b, c )</td>
<td>A1, B1, C1</td>
<td>Coefficients for calculation of the declination angle of the sun W.R.T. in the equatorial plane. (see page D-10 of the flowchart)</td>
<td>Unitless</td>
</tr>
<tr>
<td>( e_{TOL} )</td>
<td>TOLE</td>
<td>When the space station gets within this tolerance, a simplified logic for the space station in a circular orbit will be inacted (eccentricity tolerance).</td>
<td>Unitless</td>
</tr>
<tr>
<td>( T_Y )</td>
<td>TY</td>
<td>Number of days past January 1 of launch year.</td>
<td>Days</td>
</tr>
<tr>
<td>( \Delta H_D )</td>
<td>DLHD</td>
<td>The desired differential height for the orbiter: &gt; 0 :: CHD below target; &lt;0 :: CDH above target.</td>
<td>N MI</td>
</tr>
<tr>
<td>( \Delta H_B )</td>
<td>DLHB</td>
<td>A bias used to insure that the transfer orbit will intersect the C.D.H. orbit.</td>
<td>N MI</td>
</tr>
<tr>
<td>SFNO1</td>
<td>SFNO1</td>
<td>Scale factor for the initial orbiter insertion orbit. (Generally = .5)</td>
<td>Unitless</td>
</tr>
<tr>
<td>SFNO2</td>
<td>SFNO2</td>
<td>Transfer orbit scale factor for intermediate phasing orbit (SFNO2 = .5 for second orbital intersection).</td>
<td>Unitless</td>
</tr>
<tr>
<td>SFNO3</td>
<td>SFNO3</td>
<td>Scale factor for phasing time in the coelliptic C.D.H orbit (normally = 1.5).</td>
<td>Unitless</td>
</tr>
<tr>
<td>SLM</td>
<td>SLM</td>
<td>Slope of the ( \Delta g = f(\Delta H) ) curve assumed to be linear.</td>
<td>Unitless</td>
</tr>
</tbody>
</table>

The first input card contains two fixed point options with a 2I2 format. Presently the first option ISURF is flaged as 1. This designates that a sixth order polynomial curve fit will be utilized for describing the Shuttles insertion surface (Figure 3-3). A future mode may be programmed to execute.
a steady state trajectory. When this mode is developed the user would read ISURF=0. The second option ILIG is for the lighting constraint. If ILIG=1, lighting is considered and future inputs will include $\beta_{SVD}$, $a$, $b$, $c$, $T_Y$ as described in the input nomenclature.

The format for the remaining inputs is $6E13.8$. $A_0$ through $S_6$ contain the coefficients for the curve fit surface of the orbiters cut-off. These are contained on the next 20 cards.

Input on card 22 are the universal times from the tracking station, along with the radius of apogee and perigee of the orbiter insertion orbit. Card 23 provides input for the ephemeris for the space station at the time (U.T.) the launch site is in-plane with the space station for a northerly launch opportunity. Similar values for the southerly launch opportunity are input on card 24. The latitude of the launch site $\phi_L$, longitude $\lambda_L$, desired sun angle $\beta_{SVD}$, and coefficients for calculation of the sun's declination $A_l$, $B_l$, $C_l$ are input on card 25. Cards 26 and 27 will be changed by the user as different mission profiles are desired. These cards contain the desired differential height ($\Delta H$) for the final phasing orbit (coelliptic) before TPI. The desired phase angle ($\Delta \phi$) at TPI is determined as a function of $\Delta H$ and is presently read in as a linear function with a slope SLM.

Three flags are input which represent whole or fractional stay time periods in each of the orbiters phasing orbits. SFN01 and SFN02 will be input and will stay fixed. SFN03 can and will be "bumped" if the isolation results in orbit coast periods in the coelliptic orbit is less than SFN03 times the orbital period. That is, when the stay time in final coelliptic orbit between the constant delta height maneuver and the TPI maneuver is less than SFN03 orbits (Note Page D-14 of the flowcharts), then SFN03 will be bumped by .5 and reinitialized.

A list of sample input data is presented in Table 5-2. It should be noted that only two coefficients are listed for each surface or polynomial curve fit variable.
Table 5-2. INPUT LISTING OF DATA

<table>
<thead>
<tr>
<th>CARD</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>27.785842</td>
<td>.15193435</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>16.249967</td>
<td>.069000928</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>106.6733904</td>
<td>-1.2483319</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>113.74390</td>
<td>.81471544</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>361.2315599</td>
<td>.19373362</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>71.972429</td>
<td>1.2579258</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>69.504248</td>
<td>-.842646</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>359.43239</td>
<td>.2231473</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>250.25958</td>
<td>-.43718955</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>309.06871</td>
<td>.47380784</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1000.0</td>
<td>2000.0</td>
<td>3000.</td>
<td>900.</td>
<td>100.</td>
<td>90.0</td>
</tr>
<tr>
<td>13</td>
<td>6678206.0</td>
<td>0.00001</td>
<td>55.0</td>
<td>157.3</td>
<td>150.0</td>
<td>135.0</td>
</tr>
<tr>
<td>14</td>
<td>6678206.0</td>
<td>0.00001</td>
<td>55.0</td>
<td>23.9</td>
<td>150.0</td>
<td>315.0</td>
</tr>
<tr>
<td>15</td>
<td>28.608</td>
<td>-80.0</td>
<td>110.</td>
<td>23.444</td>
<td>192.4205</td>
<td>.9703504</td>
</tr>
<tr>
<td>16</td>
<td>.0000074</td>
<td>300.</td>
<td>10.0</td>
<td>4.0</td>
<td>.5</td>
<td>.5</td>
</tr>
<tr>
<td>17</td>
<td>1.5</td>
<td>.029</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2 OUTPUT

The sample output (executed listing) presented in Appendix C is for a northerly launch opportunity with lighting considered. The first two pages yield the input values from the tracking station and the "first guess" two-body analysis of the total mission. The last variable printed on the second page, DVIT, gives the delta velocity budget requirement for all on-orbit maneuvers; but, does not include the values for TPI and TPF.

The listing has comment cards throughout, describing each maneuver, and gives on-orbit targeting requirements (e, h, Δv). Both Universal Time and mission time from lift-off for each maneuver is located at the top of the page, along with the state variables of the orbiter and space station.

The last two pages present the final isolated values at the TPI point; for example, sun angle, Δϕ, Δi, Δθ_N, and, also, the state vector of the space station in the updated coordinate system at the time of lift-off and orbit insertion. The very last print statement yields the updated time-of-launch.
INTERSECTION OF NEAR-HOHMANN TRANSFER WITH CDH ORBIT

A maneuver at the second orbital intersection of the transfer eclipse with the CDH orbit will place the orbiter coelliptic with the space station. Thus, a method had to be determined to compute the true anomaly of the orbiter at the desired second orbital intersection. A solution to this problem is possible if the two-body polar equations for position of each orbit are equated and then solved for the true anomaly of the intersection. The derivation for determining the intersection point follows.

Considering the equation

\[ \Delta a = \alpha_T - \alpha_p \]

where \( \alpha_T \) is the argument of perigee of the space station orbit and \( \alpha_p \) is the argument of perigee of the orbiter orbit, then

\[ \theta_S = \theta_p + \Delta a \]

where \( \theta_S \) is the true anomaly of the CDH orbit and \( \theta_p \) is the true anomaly of the orbiter at the intersection point.

Then, equating the position equations,

\[ \frac{P_p}{1 + e_p \cos \theta_p} = \frac{P_S}{1 + e_S \cos (\theta_p + \Delta a)} \]

or,

\[ P_p + e_p P_p \cos (\theta_p + \Delta a) = P_S + e_p P_S \cos \theta_p \]

and

\[ e_S P_p \cos (\theta_p + \Delta a) - e_p P_S \cos \theta_p = P_S - P_p \]
Making use of the trigometric identity of the cosine of the sum of two angles,

\[ \cos(\theta_p + \Delta) = \cos \theta_p \cos \Delta - \sin \theta_p \sin \Delta \]

Factoring out \( \cos \theta_p \):

\[ \sin \theta_p (\cos \theta_p \cos \Delta - \sin \theta_p \sin \Delta) + \cos \theta_p (\cos \theta_p \cos \Delta - \sin \theta_p \sin \Delta) = P_S - P_P \]

Now let

\[ \beta = -e_S P_P \sin \Delta \]
\[ \Delta = e_S P_P \cos \Delta - e_P P_S \]
\[ P_o = P_S - P_P \]

then;

\[ \beta \sin \theta_p + \Delta \cos \theta_p = P_o \]
\[ \Delta \cos \theta_p = P_o - \beta \sin \theta_p \]
\[ \Delta^2 \cos^2 \theta_p = P_o^2 - 2P_o \beta \sin \theta_p + \beta^2 \sin^2 \theta_p \]
\[ \cos^2 \theta_p = 1 - \sin^2 \theta_p \]
\[ \Delta^2 (1 - \sin^2 \theta_p) = P_o^2 - 2P_o \beta \sin \theta_p + \beta^2 \sin^2 \theta_p \]
\[ \Delta^2 - \Delta^2 \sin^2 \theta_p = P_o^2 - 2P_o \beta \sin \theta_p + \beta^2 \sin^2 \theta_p \]

and

\[ (-\beta^2 - \Delta^2) \sin^2 \theta_p + 2P_o \beta \sin \theta_p + \Delta^2 - P_o = 0 \]
In order to solve this quadratic, let

\[ A = -B^2 - \Delta^2 \]
\[ B = 2P_o \beta \]
\[ C = \Delta^2 - P_o^2 \]

and the equation is solved by

\[ \sin \theta_p = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \]

This equation is derived as a sine function instead of a cosine function as in reference 1. The sine function is positive in the second quadrant and negative in the third quadrant. The solution that is negative should be selected and placed in the third quadrant (since the transfer is a near-Hohmann). This will always select the second orbital intersection, that is, select \( \sin \theta_p < 0 : : \theta_p = -\pi - \sin^{-1}(\theta_p) \)
Appendix B

CONSTANT DELTA HEIGHT IMPULSE

The delta velocity for the impulse into the CDH orbit below or above the space station is computed using two-body equations. Forcing the CDH orbit to be coelliptical with the space station can only be achieved by having the same differential height (ΔH) at apogee and perigee. Thus, to insure the ΔH will be the same at apogee and perigee, the following equation was developed (see reference 1 for complete derivation):

\[ \Delta H^2 + (RRP-RAT-RPT)\Delta H + RPT \cdot RAT + \frac{RRP}{2} (RPT-RAT) \]

\[ \cos \theta_D - \frac{RRP}{2} (RAT+RPT) = 0 \]

Letting

\[ A = 1 \]

\[ B = RRP-RAT-RPT \]

\[ C = RAT \cdot RPT + \frac{RRP}{2} \cdot \cos \theta_D \cdot (RPT-RAT) - \frac{RRP}{2} \cdot (RAT+RPT) \]

Then

\[ A(\Delta H)^2 + B(\Delta H) + C = 0 \]

and

\[ \Delta H = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \]

If the coelliptic CDH orbit is above the space station then B = -B.

These equations are incorporated into the logic on page D-14 of the flowchart as can be observed from this flowchart, once ΔH is computed it is utilized to construct the conic parameters of the CDH orbit.
Appendix C

SAMPLE OUTPUT: NORTHERLY LAUNCH
NORTHROP SERVICES, INC.

ORBITAL ELEMENTS OF SPACE STATION IN-PLANE POINT

TIME 2.002560000 00 AT 6.87538920E 06 ET 1.50000000E 05 XENVTO 5.30000000E 01
THOTO 1.57369960E 02 ALFA0 1.50000000E 02 PH10 1.39000000E 02

FIRST GUESS IN THE LAUNCH AZIMUTH = 4.07939855E 01

THIS IS THE SOLUTION:
INSTANTANEOUS LATITUDE OF INSERTION = 3.61399569E 01

DESIGNED LATITUDE FOR INSERTION = 3.61397341E 01

DESIGNED VALUE OF INCLINATION FOR TARGETING PURPOSE = 5.40829716E 01

ACTUAL LAUNCH AZIMUTH FROM ORBITER INSERTION = 3.09343512E 01

STATE VARIABLES OF ORBITER AT INSERTION
AP 6.35104378E 06 ZP 1.23507598E 05
XDP = 1.95517753E 03 YDP = 2.92723039E 02 ZDP 7.72573693E 03

STATE OF SPACE STATION

TIME FROM LIFT-OFF

HRS = 9 MINS = 30 SECS = 5.18836135E 01

UNIVERSAL TIME

HRS = 9 MINS = 35 SECS = 5.18361397E 01

TIME 2.2715063417 33
Y = 5.10999600E 10
AA 2.72564947E 02
E 5.33853663E 04
PH10 6.59746745E 03

X = 1.76174198E 05
Y = 1.35247199E 06
ZA 6.88944544E 06
ENC 5.30127145E 01
THN 1.57293353E 02
TH 2.89916810E 02 ALFAO 2.83331713E 02

THIS IS THE SOLUTION
STATE VECTOR OF SPACE STATION AT TIME OF ORBITER INSERTION
AT 6.13969955E 06
X = 1.76174196E 05
Y = 1.35247199E 06
XDT = 3.49167794E 03 YDT = 3.29207123E 02 ZDT = 6.75769940E 03

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PARAMETERS FOR 50X100 N.M. PHASING ORBIT

RHP 6.4767660E06 VNP 7.0764558E05 GAMMA = 2.8104583E01 EP 7.1042269E03
AP 6.5170660E05 NAP 1.0000001E02 HPP 4.9999990E02 PHOCFL 6.8766713E02

PARAMETERS FOR THE TARGET ORBIT

RMT 6.6779532E06 VMT 7.6136461E03 GAMMA = 2.8145834E-02 ET 5.3039384E-04
AT 6.5170660E05 HAT 1.0000001E02 HPP 4.9999990E02 PHOCFL 6.8756671E-02

CATCH UP RATE AND ANGLE FOR THE HALF ORBIT OF THE 50X100 NM PHASING ORBIT

ORBITAL CATCH UP RATE = 5.3515694E03
ANGLE OF CATCH UP = 1.4613127E02

TIME AT APOLLO OF 50X100 ORBIT = 2.9898113E03
FIRST MANEUVER TO CIRCULARIZE 50X100 AT ITS APOLLO

RHP 6.5633660E06 VHP 7.7730431E03 TAU 5.2917510E02 DPDCO 6.8030497E02
APH 6.4779532E06 VHAP 5.2917510E02 DELV 2.7721893E01 T5 9.0390009E03

SECOND MANEUVER OUT OF 100 NM CIRCULAR TOWARDS COELIPTIC

ORBITAL PERIOD = 5.7440173E-03
MEAN ANGELIC: RATE = 0.7798203E-02
CATCH UP RATE = 5.3313564E-03
IMPULSE NEW: IMPULSE 2.6639258E-01
TIME FROM ECLIPSE = 6.3724677E07
ORHP 6.4431645E07

COELIPTIC LIMIT PLACEMENT VEHICLE IN COH ORBIT

RH4 7.99423444E-12 TMA 7.6526309E-06 WAP 6.8563839E06 RAP 6.8563839E06
FMA 5.90026499E-04 THPO 1.6250549E07 RP 6.5637543E02 V4 7.3371034E03
GAMMA 4 6.70033649E-11 V40 7.6186758E03 GAMMA 9.2434070E03 DELV 6.70033649E01

THE TPI INITIATION ANGLE IN RELATION TO THE TARGET = 2.9000000E-01
THIS SECTION DETERMINES THE CATCH UP RATE IN THE COH ORBIT
IT ALSO SUMS UP THE DELTA VELOCITY AND CATCH UP ANGLE FOR THE TOTAL MISSION

TAU4 5.9649622E-03 RAP 6.3620227E02 DPDCCO 2.8104583E01 DELV 3.9222191E07
THP 2.3370474E-04 OMA 3.8543564E01 DVIT 2.4137214E07

C-3
NORTHROP SERVICES, INC.

RANGE ANGLE OF PURSUIT: 2.2A2157E 02
RANGE ANGLE OF TARGET: A.5656741E 00

PHASE ANGLE UP= 1.4233504E 02
9.0009000E-1 5.0009000E-1 1.5000900E 00

STATE OF SPACE STATION

TIME FROM LIFT-OFF
HRS: 0 MINS: 0 SECS: 1.1683514E 01

UNIVERSAL TIME
HRS: 0 MINS: 37 SECS: 3.1683516E 01

TIME 3.7183615E 02
V: -6.1096085E 00
A: 2.7276044E 02
C: 5.7966335E 07
PHI10 8.5009741E 00

STATE OF SPACE STATION

TIME FROM LIFT-OFF
HRS: 1 MINS: 7 SECS: 1.32016452E 01

UNIVERSAL TIME
HRS: 1 MINS: 40 SECS: 3.32016452E 01

TIME 4.0036218E 02
V: -5.9757312E 00
A: 2.7329942E 02
C: 5.7996148E 07
PHI10 7.6133413E 00

COMPUTATIONS FOR SECTION 4-A

DPM10 2.7616491E 01 DPM20 1.1944306E 02 DTM 2.5823796E 04 TST 4.00332018E 04
DT1 1.5875219E 04 T1 3.7183615E 02 TTEST1 2.7804139E 03 TTEST2 2.80136675E 04

STATE OF SPACE STATION
### TIME FROM LIFT-OFF

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### TIME 4,107645E 04

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<th>5.3577839E 02</th>
<th>6.3010956E 03</th>
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<td>2.6795393E 02</td>
<td>2.60200165E 06</td>
<td>6.87423149E 06</td>
<td>6.26517055E 06</td>
<td>6.36719382E 06</td>
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<tr>
<td>E</td>
<td>1.00577249E 03</td>
<td>5.80444925E 07</td>
<td>9.44678252E 07</td>
<td>5.52517538E 02</td>
<td>5.37361915E 02</td>
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### PHIO 1.37762019E 01

### COMPUTATIONS FOR LIGHTING CONDITIONS SECTION 4-10

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<th>AO</th>
<th>2.3444000E 01</th>
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<td>-0.00000000E 01</td>
<td>1.29483511E 01</td>
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### TIME 2,78981135E 03

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<th>4.60056973E 06</th>
<th>7.3.83216883E 06</th>
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<td>6.98714498E 06</td>
<td>6.87880378E 06</td>
<td>6.87796828E 06</td>
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<tr>
<td>E</td>
<td>1.13414145E-03</td>
<td>9.07914147E 07</td>
<td>5.49999908E 01</td>
<td>1.57556596E 02</td>
<td>1.28215230E 01</td>
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### PHIO 1.82235007E 02

### STATE OF ORBITER

### TIME FROM LIFT-OFF

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### TIME 2,79081135E 03

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<th>X</th>
<th>3.85462100E 06</th>
<th>7.3.20270513E 04</th>
<th>3.0.4111442E 05</th>
<th>3.65959461E 02</th>
<th>3.23571831E 02</th>
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<td>AA</td>
<td>1.00534986E 02</td>
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<td>6.36432008E 00</td>
<td>6.47604209E 06</td>
<td>6.51807872E 06</td>
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<tr>
<td>E</td>
<td>6.76512910E-03</td>
<td>6.11338509E 07</td>
<td>5.49920519E 01</td>
<td>1.56888900E 02</td>
<td>1.72129441E 02</td>
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### PHIO 5.36557490E 01

### Reproduced from best available copy.
TARGETING VALUES FOR THE COV 100 NM CIRCULARIZATION AT APOGEE

POSITION VECTOR FOR IGNITION

STATE OF ORBITER

TIME FROM LIFT-OFF
HRS= 0 MIN=48 SEC= 2.7813475E 01

UNIVERSAL TIME
HRS= 1 MIN=41 SEC= 4.7813475E 01

TIME 2.00781133E 03
x=8.53519358E 06
AA 1.05482044E 02
E 7.03643014E 03
PHI 0.4699772E 01

TARGETING VALUES FOR DESIRED ELLIPSE

ANGULAR MOMENTUM VECTOR
AM(1) 5.6325843E 08
AM(2) 5.1155617E 10
AM(3) 2.1156317E 09

ECCENTRICITY VECTOR
EV(1) 5.8207665E-11
EV(2) 9.0694702E+03
EV(3) 1.81899406E-12

VELOCITY TO BE GAINED VECTOR
VG(1) 2.6775496E 03
VG(2) 1.1043916E 03
VG(3) 2.73115345E 01

STATE OF ORBITER

TIME FROM LIFT-OFF
HRS= 0 MIN=42 SEC= 5.3891555E 01

UNIVERSAL TIME
HRS= 9 MIN=16 SEC= 1.3891555E 01

TIME 3.13738092E 04
x 5.16259575E 06
AA 1.0833348E 02
E 7.7794189E-04
PHI 0.7813916E 02

STATE OF SPACE STATION

TIME FROM LIFT-OFF
HRS= 6 MIN=42 SEC= 5.3891555E 01
THIS IS THE SOLUTION

THE LAUNCH TIME SHOULD BE ADJUSTED BY DELTA TUL09=2.2956903E 02
STATE OF ORBIT:

TIME FROM LIFT-OFF
HR# 7 MIN= 3 Sec= 3.7049792E 01

UNIVERSAL TIME
HR# 7 MIN= 37 Sec= 3.7049792E 01

TIME 2.49629749 E 04
x 2.70991308E 04
AP 6.56085683E 00
E 1.80979113E 04
PH10 1.51594137 E 02

STATE OF SPACE STATION

TIME FROM LIFT-OFF
HR# 7 MIN= 6 Sec= 3.7470895E 00

UNIVERSAL TIME
HR# 7 MIN= 37 Sec= 3.7049792E 01

TIME 2.50455748 E 04
x 4.40485641E 06
AP 7.74298741E 02
E 1.60190202 E 02
PH10 1.40495551 E 02

STATE OF PHILIPP

TIME FROM LIFT-OFF
HR# 7 MIN= 4 Sec= 3.7470895E 00

UNIVERSAL TIME
HR# 7 MIN= 37 Sec= 3.7049792E 01

TIME 2.69265751 E 04
x 2.70991308E 04
AP 6.56085683E 00
E 1.80979113E 04
PH10 1.51594137 E 02

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TARGETING VALUES FOR THE CONFIRMEED ENTRY

POSITION: VERTON FOR LNDT 1.

STATE OF ORBITER

TIME FROM LIFT-OFF
HRS= 7 MINS = 3 SEC= 1.5748185 00

UNIVERSAL TIME
HRS= 7 MINS= 37 SEC= 3.7088792 01

TIME 2.496865746 04
AD 1.32324160 26
E 1.86791137 C4
VEL 1.5694138 02

TARGETING VALUES FOR DESIRED ELLIPSE
ANGULAR MOMENTUM VECTOR
AM(1)=2.41979150 07 AM(2)=9.16749791 06 AM(3)=2.74236786 09
ECCENTRICITY VECTOR
EV(1)=4.2147822 02 EV(2)=5.0316139 02 EV(3)=9.05226146 01
VELOCITY TO BE GAINED VECTOR
VG(1)=9.5273241 01 VG(2)=4.7648403 00 VG(3)=3.76923233 01

AFTER ENTRY PHASE AT TIME TEST 2

STATE OF ORBITER

TIME FROM LIFT-OFF
HRS= 7 MINS = 3 SEC= 1.5748185 00

UNIVERSAL TIME
HRS= 7 MINS= 37 SEC= 3.7088792 01

TIME 2.496865746 04
AD 2.66093824 06
E 0.54795417 02
VEL 1.5694138 02

STATE OF SPACE STATION
STATE OF ORBIT:

TIME FROM LIFT-OFF
HRS= 7 MINS= 55 SEC= 3.00361934E 01

UNIVERSAL TIME
HRS= 8 MINS= 29 SEC= 4.70289707E-01

TIME 7.07700322E 04
x = 9.09623791E 06
y = 7.97274522E 06
z = 6.59556633E 06
Rx = 9.1375182E 03
Ry = 8.57573197E 06
Rz = 6.7231009E 06
Vx = 3.52437322E 12
Vy = 3.52437322E 12
Vz = 3.52437322E 12

TARGETING VALUES FOR THE COM MANEUVER FOR COV
POSITION VECTOR FOR IGNITION

STATE OF ORBIT:

TIME FROM LIFT-OFF
HRS= 7 MINS= 50 SEC= 3.00361934E 01

UNIVERSAL TIME
HRS= 8 MINS= 29 SEC= 4.70289707E-01

TIME 7.07700322E 04
x = 9.09623791E 06
y = 7.97274522E 06
z = 6.59556633E 06
Rx = 9.1375182E 03
Ry = 8.57573197E 06
Rz = 6.7231009E 06
Vx = 3.52437322E 12
Vy = 3.52437322E 12
Vz = 3.52437322E 12

TARGETING VALUES FOR DESIRED ELLIPSE
ANGULAR MOMENTUM VECTOR:
AM(1) = 4.2646220E 06
AM(2) = 5.22130226E 18
AM(3) = 2.0332034E 09

ECCENTRICITY VECTOR:
EV(1) = 2.69592258E 14
EV(2) = 4.56135238E 06
EV(3) = 1.12485878E 04

VELOCITY TO RF CAIUS VECTOR:
VRG(1) = 7.3546752E 07
VRG(2) = 9.15995398E 07
VRG(3) = 1.0151590E 01
UNIVERSAL TIME FOR TPI

STATE OF SPACE STATION

TIME FROM LIFT-OFF
HRS=13 MIN=2 SEC=7.39021945E-01

UNIVERSAL TIME
HRS=13 MIN=32 SEC=7.4494308E+01

TIME 4.6973983121 9 4 2.60390440E-06 AP 6.67243932E+06 PH#13 7.49593937E+01

STATE OF HOUSER

TIME FROM LIFT-OFF
HRS=13 MIN=2 SEC=7.39021945E-01

UNIVERSAL TIME
HRS=13 MIN=32 SEC=7.4494308E+01

TIME 4.497399733 9 4 2.67235699E+06 AP 6.70392334E+06 PH#13 7.37037447E+01

DTUEU=5.87449629E+6

WATPU 6.91169548E-06 PH#13 7.37397184E+01 PH#10 7.40595936E+01 PH#16 3.95142848E+01 PH#13 3.91459978E+01

DELPH 3.30799431E+01

THE SOLAR VECTOR ACHIEVED 1.01900410E 02

STATE VECTOR AT TARGET AT LIFT-OFF

X1=2.91639417E-06 VT 7.30983100E+05 ZT 6.22497319E+06 XDT=8.9464216E+03 YDT=1.93938596E 12 ZDT=7.31997129E 03
TIME FROM LIFT-OFF

UNIVERSAL TIME
h=0 m=0 s=0

TIME
x=2.715351477 s

STATE VECTOR OF TARGET AT INSERTION

TIME FROM LIFT-OFF
h=0 m=0 s=0

UNIVERSAL TIME
h=0 m=35 s=0

THE UPDATED TIME OF LAUNCH=1.77043419E 03

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Appendix D
PROGRAM MODULES AND DETAILED FLOWCHART

D.1 PROGRAM MODULES

<table>
<thead>
<tr>
<th>Name</th>
<th>Function or Subroutine</th>
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<tbody>
<tr>
<td>RK713</td>
<td>This is a seventh order Runge-Kutta integration routine which can integrate backward or forward</td>
</tr>
<tr>
<td>RKG</td>
<td>The main routine of the integration package. Integration is variable step-size with an accuracy tolerance of 0.0000005 for the state</td>
</tr>
<tr>
<td>CONIC</td>
<td>Computes orbital parameters given the state. (Only for elliptical orbits.)</td>
</tr>
<tr>
<td>GMAT</td>
<td>Matrix transformation from space fixed inertial launch coordinate system ($\vec{x}_S$) to the in-plane $\vec{x}'''$ system $\vec{x}''' = [-i]_1 [-\theta_N]_2 [\phi_L]_3 [\Lambda_Z - \frac{\pi}{2}]_1 \vec{x}_S$</td>
</tr>
<tr>
<td>MAROT</td>
<td>Sets up elements of transformation matrix for an angle of rotation about the X, Y, and Z axis</td>
</tr>
<tr>
<td>ARTAN</td>
<td>Arctangent from 0 to $2\pi$ or $-\pi$ to $\pi$ according to flag</td>
</tr>
<tr>
<td>POLY</td>
<td>Evaluates an $n$th order polynomial given its coefficients</td>
</tr>
<tr>
<td>ECCV</td>
<td>Computes eccentricity vector $\vec{e}$ $\vec{e} = \frac{\vec{v} \times \vec{h}}{\mu} - \frac{\vec{r}}{</td>
</tr>
<tr>
<td>DEG</td>
<td>Earth's gravitational potential function. Evaluates the acceleration due to gravity for all three components</td>
</tr>
<tr>
<td>FATT</td>
<td>Matrix transpose (3×3)</td>
</tr>
<tr>
<td>FATMU</td>
<td>Matrix multiplication (3×3 times 1×3)</td>
</tr>
<tr>
<td>PRINT</td>
<td>Calculates the U.T. in hours, min., sec, adds the U.T. to the mission Time &quot;T&quot;, and prints out state and orbital parameters of each vehicle in flight. (Note: the program integrates in mission time, thus U.T. of launch is added to mission time from lift-off to obtain instantaneous U.T. time in flight)</td>
</tr>
<tr>
<td>FATMUL</td>
<td>Matrix multiplication (3×3 times 3×3)</td>
</tr>
<tr>
<td>TIME</td>
<td>Determines Keplerian time of flight between two positions on an elliptical orbit</td>
</tr>
<tr>
<td>RANGA</td>
<td>Computes range to and from descending node w.r.t. equator to the instantaneous radius vector</td>
</tr>
<tr>
<td>TRUE</td>
<td>Computes true anomaly from perigee to the instantaneous radius vector</td>
</tr>
</tbody>
</table>
D.2 FLOWCHART

EPHEMERIS DATA OF SPACE STATION

\[ T_N, a_N, e_N, i_N, \theta_{NN}, \alpha_{PLN}, \phi_N \]
\[ T_S, a_S, e_S, i_S, \theta_{NS}, \alpha_{PLS}, \phi_S \]

JPASS = 0, KPASS = 0

\[ T_N - T_S < 0 \]

YES \[ T_N - T < TTOL \]

\[ TULLO = T_N \]
\[ NORTH = 1 \]

NO \[ TULLO = T_S \]
\[ NORTH = 0 \]

\[ TULLO = T_N \]
\[ NORTH = 1 \]

YES

\[ T = T_N \]
\[ a = a_N \]
\[ e = e_N \]
\[ i = i_N \]
\[ \theta_N = \theta_{NN} \]
\[ \alpha_{PL} = \alpha_{PLN} \]
\[ \phi = \phi_N \]

NO

\[ \theta_N < 90 \]

YES

\[ A_Z = \pi - \sin^{-1}\left(\frac{\cos i_S}{\cos \phi_L}\right) \]

NO

\[ A_Z \]

\[ \sin^{-1}\left(\frac{\cos i_N}{\cos \phi_L}\right) \]

2-0

FROM PG. D-7

2-1

TO PG. D-3

D-2
\[ \phi_T = \phi - \alpha_{PL} \]

\[
\begin{bmatrix}
\cos \phi_L & \sin \phi_L \sin \alpha_Z & -\sin \phi_L \cos \alpha_Z \\
-\sin \phi_L & \cos \phi_L \sin \alpha_Z & -\cos \phi_L \cos \alpha_Z \\
0 & \cos \alpha_Z & \sin \alpha_Z
\end{bmatrix}
\]

\[
\begin{bmatrix}
\cos \theta_N & 0 & -\sin \theta_N \\
\sin \theta_N \sin i & \cos i & -\cos \theta_N \sin i \\
-\sin \theta_N \cos i & \sin i & \cos \theta_N \cos i
\end{bmatrix}
\]

\[
\begin{bmatrix}
\cos \phi_T & 0 & \sin \phi_T \\
0 & 1 & 0 \\
-\sin \phi_T & 0 & \cos \phi_T
\end{bmatrix}
\]

\[
\hat{\eta} = \sin \phi_L \hat{i} - \cos \phi_L \sin \alpha_Z \hat{j} + \cos \phi_L \cos \alpha_Z \hat{k}
\]

\[
R_0 = a(1-e^2)/(1+e \cos \phi)
\]

\[
V_0 = \sqrt{\mu \left( \frac{2}{R_0} - \frac{1}{a} \right)}
\]

\[
\gamma_0 = \tan^{-1} \left( \frac{e \sin \phi}{1+e \cos \phi} \right)
\]
\[
\begin{pmatrix}
    x_T \\
    y_T \\
    z_T
\end{pmatrix}
= [K]^{-1}
\begin{pmatrix}
    R_0 \\
    0 \\
    0
\end{pmatrix};
\begin{pmatrix}
    \dot{x}_T \\
    \dot{y}_T \\
    \dot{z}_T
\end{pmatrix}
= [K]^{-1}
\begin{pmatrix}
    V_0 \sin \gamma_0 \\
    0 \\
    V_0 \cos \gamma_0
\end{pmatrix}
\]

\(\Delta T = 100.0\), \(MPASSI=0\)

**Flowchart Diagram**

- **JPASS = 0** → **NO** → **3-3** → **TO PAGE D-7**
- **JPASS = 0** → **YES** → **RANGA**
- **RANGA**
  - \(\theta_{NT} = \cos^{-1}[\hat{E}_{RA} \cdot \hat{D}_{NT}/|\hat{D}_{NT}|]\)
  - \(I_{NT} = \tan^{-1}\left\{\left[1.0 - (\hat{\Omega} \cdot \hat{A}_{MT})^2\right]^{1/2}/(\hat{\Omega} \cdot \hat{A}_{MT})\right\}\)
  - \(A_T = |\bar{x}_T| \mu/(2\mu - |\bar{x}_T|^2 |\bar{x}_T|)\)
- **RANGA** → **3-4** → **TO PAGE D-7**
- **RANGA** → **2-3** → **TO PAGE D-5**
\[ \psi_{DS} = \sum_{M=0}^{6} B_M I_{NT}^M \]

\[ A = (1 - \cos^2 I_{NT}/\cos^2 \psi_{DS})^{1/2} \]

\[ \phi_{LS} = \tan^{-1} \left( \frac{\tan \psi_{DN}}{A} \right) \]

\[ \phi_{LS} = \pi + \phi_{LS} \]

\[ \Delta \phi_R = \phi_{LS} - \phi_T \]

\[ \phi_T > \pi \]

\[ \Delta \phi_R > 0 \]
FROM PAGE D-5

ISURF = 1

NO

STEADY STATE TRAJ. COMP.

TO PAGE D-7

3-5

3-1

YES

INSERTION CONDITIONS FOR NORTHERNLY LAUNCH

\[
A_{ZN} = \sum_{N=0}^{6} C_N I_D^N \\
\theta_{NNP} = \sum_{N=0}^{6} D_N I_D^N \\
T_{1N} = \sum_{N=0}^{6} E_N I_D^N \\
\phi_{PN} = \sum_{N=0}^{6} Q_N I_D^N \\
\alpha_{PL} = 0.0
\]

NORTH = 1

YES

INSERTION CONDITIONS SOUTHERNLY FOR LAUNCH

\[
A_{ZS} = \sum_{N=0}^{6} F_N I_D^N \\
\theta_{NSP} = \sum_{N=0}^{6} G_N I_D^N \\
T_{1S} = \sum_{N=0}^{6} H_N I_D^N \\
\phi_{PS} = \sum_{N=0}^{6} S_N I_D^N \\
\alpha_{PL} = 0.0
\]

NO

YES

NORTH = 1

\[
\phi = \frac{\phi_{PN}}{CNV} \\
\theta_N = \frac{\theta_{NNP}}{CNV} \\
A_Z = \frac{A_{ZN}}{CNV} \\
T_1 = T_{1N}, i = I_D \\
AZO = A_Z
\]

NO

\[
\phi = \frac{\phi_{TS}}{CNV} \\
\theta_N = \frac{\theta_{NSP}}{CNV} \\
A_Z = \frac{A_{ZS}}{CNV} \\
T_1 = T_{1S}, i = I_D \\
AZO = A_Z
\]

3-2

TO PAGE D-7

D-6
\( K_{PASS} = 1, J_{PASS} = 1 \)

\[ R_0 = H_{PER} \times CF + R_\theta \]

\[ R_A = H_{AP} \times CF + R_\Theta \]

\[ e = \frac{(R_A - R_0)}{(R_A + R_0)} \]

\[ V_0 = \sqrt{\mu} \frac{(1 + e)}{R_0} \]

\[ a = \frac{(R_A - R_0)}{2} \]

\[ \gamma_0 = 0.0 \]

\[ \overline{x}_p = \overline{x}_T \]

\[ \dot{\overline{x}}_p = \dot{\overline{x}}_T \]

\[ \overline{x}_L_0 = \overline{x}_T \]

\[ \dot{\overline{x}}_L_0 = \dot{\overline{x}}_T \]

\[ \overline{x}_T = \int_{T+T_1}^{T} \dot{\overline{x}}_T \, dt \]

\[ \dot{\overline{x}}_T = \int_{T+T_1}^{T} \ddot{\overline{x}}_T \, dt \]
\[ \tau_{p4} = 2\pi \left( \frac{A_{p4}}{\mu} \right)^{1/2} \]
\[ \phi_{AP4} = \left( \frac{\mu}{A_{p4}} \right)^{1/2} \]
\[ \Delta \phi_R = SLM \cdot \Delta H \]
\[ \Delta \phi_{MR4} = \Delta \phi_{CU}(\tau_{p4})(SFN03 + x_N) + \Delta \phi_R \]
\[ TTPI = T_4 + \tau_{p4}(SFN03 + x_N) \]
\[ \Delta \phi_{MRT1} = \Delta \phi_{MR1} + \Delta \phi_{MR2} + \Delta \phi_{MR3} + \Delta \phi_{MR4} \]
\[ \Delta V_{IT} = \Delta V_2 + \Delta V_3 + \Delta V_4 + \Delta V_R \]

Diagram:

\[ \phi_{T1} = \phi_{T1} + 2\pi \]
\[ \Delta \phi_{A1} = \phi_{T1} - \phi_{P1} \]

\[ \Delta \phi_{A1} = \Delta \phi_{A1} + 2\pi \]

\[ \Delta T_1 = SFN03 \cdot \tau_{p4} + \tau_{p1}/2 + \tau_{p3}(SFN02) \]
\[ \Delta \phi_1 = \Delta \phi_{MR1} + \Delta \phi_{MR3} + \Delta \phi_{CU} \tau_{p4}(SFN03) \]
\[ \Delta \phi_2 = \Delta \phi_{A1} - \Delta \phi_1 - \Delta \phi_R, \Delta T_2 = \Delta \phi_2/\Delta \phi_2 \]

\[ TSBST = T_1 + \Delta T_1 + \Delta T_2, \quad TEST1 = T_1 + \tau_{p1}/2 - 200 \]
\[ TTEST2 = T_1 + \tau_{p1}/2 + \Delta T_2 \]

\[ \phi_{p1} \]

\[ \phi_{T1} \]

\[ \Delta \phi_{A1} = \phi_{T1} - \phi_{P1} \]

\[ \Delta \phi_{A1} = \Delta \phi_{A1} + 2\pi \]

\[ \Delta \phi_{MRT1} \geq 0 \]

\[ \Delta \phi_{A1} = \Delta \phi_{A1} \]

4-1 FROM PG. D-8

D-9

4-2 TO PG. D-10
\[ \chi_T = \chi_{TS1} \]
\[ \hat{\chi}_T = \hat{\chi}_{TS1} \]

**Orbit Integration of Orbiter and Space Station**

- **ECCV**
- **\( \tilde{E}_E \)**
- **TRUE**
- **PTA**
- **TIME**
- **TGP2**

Diamond Check:

- **NO**
- **TGP2 < 30**
- **YES**
  - **\( \Delta T = 1 \)**

Diamond Check:

- **NO**
- **TGP2 < 2**
  - **YES**

**Variables and Equations**:

\[ R_{AP} = R_{RP} = |\tilde{x}_P|, \quad V_C = (\mu/R_{AP})^{1/2}, \quad \tilde{N}_{CPP} = \tilde{x}_p \times \tilde{\chi}_p \]
\[ \tilde{V}_{CP} = \tilde{x}_P \times N_{CPP} / (|\tilde{x}_P| \times \tilde{N}_{CPP}), \quad \tilde{V}_{CP} = V_C \times \tilde{V}_{CP} \]
\[ \tilde{V}_g = \tilde{V}_{CP} - \tilde{x}_P, \quad V_{g1} = |\tilde{V}_g|, \quad \tilde{\chi}_p = \tilde{V}_{CP}, \quad TSTI = T \]
\[ \tilde{x}_{PS} = \tilde{x}_P, \quad \tilde{x}_{PS} = \tilde{x}_P, \quad \tilde{x}_{TS} = \tilde{x}_T, \quad \tilde{x}_{TS} = \tilde{x}_T \]

**Major Isolation Loop**

- **4-15**
- **From Page D-19**

**Orbit Integration of Orbiter and Space Station**

- **4-4 To PG. D-12**

[D-11]
\[ A_T = \mu |\ddot{x}_T|/(2\mu - |\dddot{x}_T|^2|\ddot{x}_T|), \quad R_{ATD} = A_T(1 + E_T) - \Delta H_D \]
\[ R_{PTD} = A_T(1 - E_T) - \Delta H_D, \quad A_T = (R_{ATD} + R_{PTD})/2 \]
\[ E_T = (R_{ATD} - R_{PTD})/(R_{ATD} + R_{PTD}), \quad P_TD = \]
\[ A_T(1 - E_T^2), \quad \text{COST} = \bar{E}_{ET} \cdot (-\bar{E}_{EP})/(E_T E_P) \]
\[ R_T = P_TD/(1 + E_T \text{COST}) \]
\[ \text{DRTEST} = R_{AP} - R_{TD} - 100.0, \quad \text{IPASSI} = 0 \]

- \[ \bar{A}_{MP} = \bar{x}_P \times \bar{\dot{x}}_P, \quad \bar{A}_{MT} = \bar{x}_T \times \bar{\dot{x}}_T, \]
- \[ \bar{D}_{NT} = \bar{A}_{M1} \times \Omega, \quad \bar{D}_{NP} = \bar{A}_{MP} \times \Omega \]
- \[ \bar{D}_{NAMP} = \bar{D}_{NP} \times \bar{A}_{MP}, \quad \bar{D}_{NAMT} = \bar{D}_{NT} \times \bar{A}_{MT} \]
- \[ \sin\alpha_T = \bar{E}_{ET} \cdot \bar{D}_{NAMT}/[E_T \bar{D}_{NAMT}], \quad \cos\alpha_T = \bar{E}_{ET} \cdot \bar{D}_{NT}/[E_T \bar{D}_{NT}] \]
- \[ \alpha_T = \tan^{-1}(\sin\alpha_T/\cos\alpha_T) \]
- \[ \sin\alpha_P = \bar{E}_{EP} \cdot \bar{D}_{NAMP}/[E_P \bar{D}_{NAMP}], \quad \cos\alpha_P = \bar{E}_{EP} \cdot \bar{D}_{NP}/[E_P \bar{D}_{NP}] \]
- \[ \alpha_P = \tan^{-1}(\sin\alpha_P / \cos\alpha_P) \]
- \[ \Delta \alpha = \alpha_T - \alpha_P, \quad D = E_T (PP) \]
- \[ \cos(\Delta \alpha) = P_TD (Ep), \quad E = -E_T \cdot (PP) \sin(\Delta \alpha), \quad F = P_TD - PP \]
- \[ A = -(E^2 + D^2), \quad B = 2FE, \quad C = D^2 - F^2 \]
- \[ \text{RAD} = B^2 - 4AC, \quad \text{STI} = (-B - \sqrt{\text{RAD}})/2A \]
- \[ \text{STII} = (-B + \sqrt{\text{RAD}})/2A \]
LIFT-OFF TIME CORRECTION

\[ ECCV \]

\[ E_T = \left| \vec{E}_T \right|, \quad \vec{N}_{PCET} = \vec{x}_p \times \vec{x}_p \]

\[ \vec{N}_{CTCT} = \vec{E}_T \times \vec{N}_{PCET} \]

\[ \text{COSTTAPP} = \vec{E}_T \cdot \vec{x}_p / |E_T| \cdot |\vec{x}_p| \]

\[ \text{SINTTAPP} = \vec{N}_{CTCT} \cdot \vec{x}_p / (|\vec{N}_{CTCT}| \cdot |\vec{x}_p|) \]

\[ P_T = A_T(1 - E_T^2) \]

\[ R_{RT} = P_T / (1 + E_T \cdot \text{COSTTAPP}) \]

\[ \Delta R_1 = R_{RT} - |\vec{x}_p|, \quad B = |\vec{x}_p| - R_{AT} - R_{PT} \]

\[ \Delta R_1 > 0 \quad \text{NO} \quad B = -B \]

\[ \Delta R_1 > 0 \quad \text{YES} \]

\[ C = R_{AT}(R_{PT}) + (|\vec{x}_p|/2)(\text{COSTTAPP}(R_{PT} - R_{AT}) - (R_{AT} + R_{PT})) \]

\[ \Delta H_1 = |[-B + (B^2 - 4C)^{1/2}] / 2|, \quad \Delta H_2 = |[-B - (B^2 - 4C)^{1/2}] / 2| \]

\[ \Delta R = |\Delta R_1|, \quad \text{DRT1} = |\Delta R - \Delta H_1|, \quad \text{DRT2} = |\Delta R - \Delta H_2| \]

\[ \Delta H_D' = \Delta H_1 \quad \text{YES} \quad \text{DRT1} \leq \text{DRT2} \quad \text{NO} \quad \Delta H_D'' = \Delta H_2 \]

\[ \Delta R_1 > 0 \quad \text{NO} \quad \Delta H_D'' = -\Delta H_D'' \]

\[ \Delta R_1 > 0 \quad \text{YES} \]

\[ R_{PP} = R_{PT} - \Delta H_D', \quad R_{AP} = R_{AT} - \Delta H_D', \quad E_P = (R_{AP} - R_{PP}) / (R_{AP} + R_{PP}) \]

\[ A_P = (R_{PP} + R_{AP}) / 2, \quad P_P = A_P(1 - E_P^2), \quad V_p = [(u/P_P)(1 + E_P^2 + 2E_P \cdot \text{COSTTAPP})]^{1/2} \]

\[ V_P = \tan^{-1}((E_P \cdot \text{SINTTAPP}) / (1 + E_P \cdot \text{COSTTAPP})), \quad \vec{N}_{CPP} = \vec{x}_p \times \vec{x}_p \]

\[ \vec{V}_{PP} = \vec{x}_p \times \vec{N}_{CPP} / (|\vec{x}_p| \times |\vec{N}_{CPP}|), \quad \vec{x}_p = \vec{x}_p / |\vec{x}_p|, \quad V_P = V_p \cdot \cos \gamma_p \cdot \vec{V}_{PP} \]

\[ V_P + V_P \cdot \sin \gamma_p \cdot \vec{x}_p, \quad V_{G3} = \vec{V}_P - \vec{x}_p, \quad V_{G3} = |\vec{V}_{G3}|, \quad \vec{x}_P = \vec{V}_P \]

\[ \text{ICOR} = \text{ICOR} + 1 \]

\[ \text{ORBIT INTEGRATION OF ORBITER AND SPACE STATION TO TUTP} \]

\[ 4-11 \text{ TO PG. D-15} \]

\[ 4-4A \text{ FROM PG. D-12} \]
4-12 FROM PG. D-15

WATP > WATOL

[Diagram]

\[ \Delta \phi = \phi_{NT} - \phi_{NP} \]

\[ \phi_{NT} > \pi \]

NO

YES

\[ \phi_{NP} > \pi \]

NO

YES

\[ \Delta \phi = \phi_{NT} - \phi_{NP} \]

\[ |\Delta \phi| < \pi \]

YES

\[ \phi_{NP} = \phi_{NP} + 2\pi \]

\[ \Delta \phi = \phi_{NT} - \phi_{NP} \]

NO

\[ \Delta \phi = \phi_{NT} - \phi_{NP} \]

[Diagram]

4-13 TO PG. D-17

\[ \Delta \phi = \phi_{NT} - \phi_{NP} \]

\[ \phi_{NP} > \pi \]

YES

\[ \phi_{NT} > \pi \]

NO

\[ \Delta \phi = \phi_{NT} - \phi_{NP} \]

[Diagram]

\[ |\Delta \phi| < \pi \]

NO

\[ \phi_{NT} = \phi_{NT} + 2\pi \]

\[ \Delta \phi = \phi_{NT} - \phi_{NP} \]

[Diagram]

4-13 TO PG. D-17
\[ \Delta E = \Delta \phi - \Delta \phi_R \]

4-17 FROM PG. D-18

4-18 FROM PG. D-18

YES \[ |\Delta E| > 0.05 \]

NO \[ |\Delta E| > 0.02 \]

TO PAGE D-18

LAST PASS NODE CORRECTION

\[ \Delta T_L = \Delta E / \alpha_o \]
\[ \dot{x}_{TR1} = \dot{x}_{TS} \]
\[ T = T_{STI}, \dot{x}_T = \dot{x}_{TS}, \ddot{x}_T = \ddot{x}_{TS} \]
\[ TULO = TULO + \Delta T_L, \Delta T_{LOT} = \]
\[ TULOS - TULO, TUTP = TUTP - \Delta T_L, TULOS + TULO \]

TO PAGE D-18

THIS IS THE SOLUTION RECYCLE AND PRINT OUT ISOLATED TIMELINE AND TARGETING PARAMETERS

ISOLAS = 0

NO \[ \text{YES} \]

TO PAGE D-20

SPACE STATION ORBIT INTEGRATION (ONLY)

FROM \( T = T_{STI} \) TO \( T = T_{STI} + \Delta T_L \)

(\text{IF } \Delta T_L < 0 \text{ INTEGRATE BACKWARDS})

\[ x_{TR2} = x_T \theta T = T_{STI} + \Delta T_L \]
\[ \Delta \phi_{LOC} = \text{COS}^{-1} \left[ \frac{x_{TR1} \cdot x_{TR2}}{1} \right] \]
\[ \Delta E_{LOC} = [\Delta T_L / \Delta T_L] \Delta \phi_{LOC} \]
\[ \Delta T_{TI} = [\Delta \phi_{LOC} - (\Delta \phi_{LOC} \Delta E_{CU} / \Delta \phi_2)] \]
\[ - \Delta T_L \Delta E_{CU} / \Delta \phi_2 \]
\[ TTEST2 = TTEST2 + \Delta T_{TI} \]

4-19 TO PAGE D-18

ACCUMULATED VALUE* OF LAUNCH TIME CORRECTION

\[ \dot{x}_T = \dot{x}_{TS}, \ddot{x}_T = \ddot{x}_{TS} \]
\[ \ddot{x}_p = \ddot{x}_{PS}, \dddot{x}_p = \dddot{x}_{PS} \]
\[ T = T_{STI} \]
\[ \Delta T_{LOT} = TULO - TULOS \]

4-16 FROM PG. D-18

4-21

4-15 \{ MAJOR ISOLATION LOOP \}

TO PG. D-11

D-19
\[ \dot{x}_T = \dot{x}_{TLO}, \quad \ddot{x}_T = \ddot{x}_{TLO} \]

Space Station Integration from \( T = TULO \) to \( T = TULO + \Delta T_{LO} \)

\[ \Delta \theta_E = \omega \cdot \Delta T_{LO} \]

\( KINS = 0 \)

\( JINS = 1 \)

---

\[ \dot{x}_T = \dot{x}_{TSI}, \quad \ddot{x}_T = \ddot{x}_{TSI} \]

Space Station Orbit Integration from \( T = TULOS \) to \( T = TULOS + \Delta T_{LO} \)

\( KINS = 1 \)

---

FROM PG. D-18

4-20

KINS = 0

YES

STOP READ ANOTHER CASE

4-19 TO PAGE D-18

4-21 FROM PAGE D-19

4-19 TO PAGE D-18
D.3 SUBROUTINES

\[ \bar{A}_M = \bar{x} \times \bar{\dot{x}} \]

\[ \bar{e} = -\left( \frac{\bar{x}}{|x|} + \frac{\bar{A}_M \times \bar{\dot{x}}}{\mu} \right) \]

RETURN
TRUE

\[ N_{EC} = \dot{x} \times \vec{x}, \quad \vec{N}_{CEC} = \dot{e} \times \vec{N}_{EC} \]
\[ \COS(TA) = \dot{e} \cdot \vec{x}/(|\dot{e}| \vec{x}|) \]
\[ \SIN(TA) = \vec{N}_{CEC} \cdot \vec{x}/(|\vec{N}_{CEC}| \vec{x}|) \]
\[ TA = \tan^{-1}\left[\frac{\SIN(TA)}{\COS(TA)}\right] \]

RETURN

RANGA

\[ \vec{A}_{M} = \dot{x} \times \vec{x}, \quad \vec{D}_{N} = \vec{A}_{M} \times \vec{n}, \quad \vec{D}_{CH} = \vec{A}_{M} \times \vec{D}_{N} \]
\[ \SIN \phi = \vec{D}_{CH} \cdot \vec{x}/(|\vec{D}_{CH}| \vec{x}|) \]
\[ \COS \phi = \vec{D}_{N} \cdot \vec{x}/(|\vec{D}_{N}| \vec{x}|) \]
\[ \phi = \tan^{-1}(\SIN \phi/\COS \phi) \]

RETURN
Appendix E

PROGRAM LISTING
PROGRAM TARG

PROGRAM TARG
DIMENSION XP(3), XDP(3), XT(3), XDT(3), XTR1(3), XTR2(3), TEMP1(3)
1, TEMP2(3), TEMP3(3), TEMP4(3), TEMP5(3), XMEGA(3), AAA(3,3), BBB
2, CCC(3,3), DDD(3,3), XPS(3), XDP(3), XTS(3), XDTS(3), EV(3)
3, AM(3), XTS1(3), XDS1(3), XDP1(3), XPS1(3)
DIMENSION A(7), B(7), C(7), D(7), E(7), F(7), G(7), H(7), Q(7), S(7)
4, XOMEGA(3), AAA(3,3), B88
5, A(7), B(7), C(7), D(7), E(7), F(7), G(7), H(7), Q(7), S(7)
6, DIMENSION XTP(3), XDTLO(3)
7, CF=1052
8, CH=3960032E15
9, RE=6378166
10, GH2=7972064E15
11, OMEGA=729211585E-04
12, PI=6.2831852
13, PI=3.1415926
14, ZERO=0.0
15, ONE=1
16, TWO=2.0
17, CNV=57.29577951
18, MATOL=1/CNV
19, KPASSE=0
20, JPASSE=0
21, READ 1750, ISURF, ILIG
22, READ 1760, A, B, C, D, E, F, G, H, O, S
23, READ 2100, T, TN, TS, TTOL, HAP, HPER
24, READ 2100, AN, EN, XENCN, THNN, ALFAN, PHIN
25, READ 2100, AS, ES, XENCS, THNS, ALFAS, PHIS
26, READ 2100, PHI, XALMAL, BSVD, A1, B1, C1, TOLE, TY, DLH, DLHB, SFNO, SFNO2
27, SFNO3=SLH
28, JINS=0
29, DT1=5.0
30, DT1=5.0
31, DT1=20.0
32, SSFNO3=SFNO3
33, DLIGHT=0
34, DTS=DT
35, PH=PHI
36, A20=A2
37, DELTH=DLH
38, DLH=DLH=CF
39, DLHB=DLHB=CF
40, PH=PHI/CNV
41, A20=A2/CNV
42, XALMAL=XALMAL/CNV
43, BSVD=BSVD/CNV
44, A1=A1/CNV
45, B1=B1/CNV
46, C1=C1/CNV
47, XENCN=XENCN/CNV
48, THNN=THNN/CNV
49, E-2
PROGRAM TARG

ALFAN=ALFAN/CNV
PHIN=PHIN/CNV
XENCX=XENC/CNV
THNST=THNS/CNV
ALFAS=ALFAS/CNV
PHIS=PHIS/CNV

IF (TN-TS) 20,50,50
20 IF ((TN-T)-TTOL) 40,30,30
30 NORTH=1
    TULO=TN
    PRINT 1770
    GO TO 60
40 NORTH=0
    TULO=TS
    PRINT 1780
    GO TO 60
50 IF ((TS-T)-TTOL) 30,40,40
60 IF (NORTH=1) 80,70,80
70 T=TN
    AT=AN
    ET=EN
    XENCl=XENCN
    THNT=THNS
    ALFAT=ALFAN
    PH1=PHIN
    GO TO 90
80 T=TS
    AT=AS
    ET=ES
    XENCX=XENC
    THNST=THNS
    ALFAS=ALFAS
    PHIS=PHIS
    GO TO 90
90 IF (JPASS-1) 100,140,140
100 IF (THNT-PI/2.) 110,110,120
110 AZL=PI-ARSIN(COS(XENC)/COS(PH))
    AZ0=AZL-CNV
    AZ=AZL
    GO TO 130
120 AZL=ARSIN(COS(XENC)/COS(PH))
    AZ=AZL
    AZ0=AZL-CNV
130 PRINT 1800
    PHIO=PH1=CNV
    ALFATO=ALFAT=CNV
    XENCX=XENC=CNV
    THNST=THNS=CNV
    PRINT 1790, T,AT,ET,XENC,THNS,ALFAT,PHIO
    PRINT 1810, AZO
140 PHIT=PHI=ALFAT
CALL MAROT (AAA, AZ-PI/2., 1, 1)
CALL MAROT (BBB, PHI, 3, +1)
CALL MAMUL (CCC, BBB, AAA)
CALL MAROT (AAA, THNT, 2, -1)
CALL MAROT (BBB, XENCT, 1, -1)
CALL MAMUL (DDD, BBB, AAA)
CALL MAMUL (AAA, DDD, CCC)
CALL MAROT (BBB, XENCT, 1, -1)
CALL MAROT (BBB, PHI, 2, +1)
CALL MAMUL (CCC, BBB, AAA)
CALL FATT (DDD, CCC)
XOMEGA(1) = SIN(PHI)
XOMEGA(2) = COS(PHI) * SIN(AZ)
XOMEGA(3) = COS(PHI) * COS(AZ)
IF (KPASS = 1) 150, 160, 150
150 RO = AT*(ONE - ET*ET)/(ONE - ET*COS(PHI))
VO = SQRT(GM*(TWO/RO - ONE/AT))
GAMMO = ARTAN(ET*SIN(PHI), ONE - ET*COS(PHI), 1)
160 CONTINUE
TEMP1(1) = RO
TEMP1(2) = ZERO
TEMP1(3) = ZERO
TEMP2(1) = VO*SIN(GAMMO)
TEMP2(2) = ZERO
TEMP2(3) = VO*COS(GAMMO)
CALL FATMU (XT, DDD, TEMP1)
CALL FATMU (XT, DDD, TEMP2)
DTY3 = 100, 0
MPASSI = 0
IF (MPASSI = 1) 170, 370, 170
170 CALL RANGA (XT, XDT, XOMEGA, PHI)
CALL VCROSS (TEMP1, XT, XDT)
CALL VCROSS (TEMP2, TEMP1, XOMEGA)
RRT = VMAG(XT)
PSI = ARSIN(VDOT(XT, XOMEGA)/RRT)
PSIO = PSI*CNV
TEME(1) = COS(PHI)
TEME(2) = SIN(PHI)*SIN(AZ)
TEME(3) = SIN(PHI)*COS(AZ)
THNT = ARCOS(VDOT(TEME, TEMP2)/VMAG(TEMP2))
CALL UNIT (TEMP4, TEMP1)
DUM1 = VDOT(XOMEGA, TEMP4)
DUM2 = DUM1*DUM1
XENC = ARTAN(SQRT(ONE - DUM1), DUM1, 1)
AT = RRT*GM*(TWO*GM - VDOT(XDT, XDT)*RRT)
XENC = XENC*CNV
PHI0 = PHI*CNV
THNTQ = THNT*CNV
PRINT 1700, PSIO
IF (MPASSI = 1) 180, 380, 180
180 IF (THNT = PI/2.) 200, 190, 190
PROGRAM TARG

190 NORTH=1
  GO TO 210
A 191

200 NORTH=0
SOUTHERNLY LAUNCH COEFFICIENTS
A 192

210 IF (NORTH=1) 220,230,230
220 PSIDO=POLY(B,XENCO,6)
PSID=PSIDO/CNV
DUM=COS(XENC)/COS(PSID)
AA=SQRT(ONE-DUM*DUM)
PHILS=ARCTAN((SIN(PSID)/COS(PSID)),AA,-1)
PHILS=PI2-PHILS
DPHRR=PHILS-PHIT
GO TO 240
A 193
A 194

230 NORTHERNLY LAUNCH COEFFICIENTS
PSIDO=POLY(A,XENCO,6)
PSID=PSIDO/CNV
DUM=COS(XENC)/COS(PSID)
AA=SQRT(ONE-DUM*DUM)
PHILS=ARCTAN((SIN(PSID)/COS(PSID)),AA,-1)
PHILS=PI2-PHILS
DPHRR=PHILS-PHIT
240 CONTINUE
DPPHRR=DPHRR/CNV
PRINT 1710, PSIDO
IF (PHIT=PI) 290,290,250
250 IF (DPHRR) 290,290,260
260 PHID=SQRT(GM/(AT*AT*AT))
TGR=DPHRR/PHID
IF (TGR=100.0) 270,270,290
270 DTT3=10.0
IF (TGR=20.0) 280,280,290
280 DTT3=TGR
MPASSI=1
290 TF=T+DTT3
CALL RKG (PHIO,AZO,XT,XDT,T,TF)
T=TF
TULOD=0,0
PRINT 2210
CALL PRINT (TF,XT,XDT,AZ,PHI,TULOD)
GO TO 170
A 195

300 PRINT 1840
PRINT 1820, PSIO
PRINT 1830, PSIDO
XIDO=XENC0
PRINT 1850, XENC0
IF (ISURF=1) 310,330,310
THIS IS WHERE THE STEADY STATE SHOULD BE PROGRAMED IN THE FUTURE
A 196
A 197

310 DO 320 I=1,3
XP(I)=0,0
A 198
320 XDP(I)=0,0
A 199
A 200
PROGRAM TARG

PRINT 1860
GO TO 400

330 IF (NORTH = 1) 350, 340, 350
340 AZN=POLY(C,XID0,6)
AZO=AZN
THONP=POLY(D,XID0,6)
T1N=POLY(E,XID0,6)
PHIPN=POLY(Q,XID0,6)
PHII=PHIPN/CNV
ALFAT=0,0
THON=THONP/CNV
AZ=AZN/CNV
T1=T1N
GO TO 360

350 AZS=POLY(F,XID0,6)
AZO=AZS
THONSP=POLY(G,XID0,6)
T1S=POLY(H,XID0,6)
PHIPS=POLY(S,XID0,6)
PHII=PHIPS/CNV
ALFAT=0,0
THON=THONSP/CNV
AZ=AZS/CNV
T1=T1S
GO TO 360

360 XENCT=XID0/CNV
PRINT 1870, AZO
KPASS=1
JPASS=1
RO=HPR*CF*RE
RA=HAP*CF*RE
ET=(RA-RO)/(RA+RO)
AT=(RA*RO)/TWO
VO=SQRT(GM*(ONE+ET)/RO)
GAMMA=0,0
GO TO 140

370 IF (KPASS = 1) 410, 380, 380
380 DO 390 I=1,3
XP(I)=XT(I)
390 XDP(I)=XDT(I)
400 KPASS=0
PRINT 1880, XP,XDP
PUNCH 2350, XP,XDP
JPASS=1
GO TO 60

420 TF=T+T1
DO 420 I=1,3
XTLO(I)=XT(I)
420 XTLO(I)=XDT(I)
PRINT 2320
CALL RKG (PHIO,AZO,XT,XDT,T,TF)
CALL PRINT (TF,XT,XDT,AZ,PHI,TULOD)
PRINT 1840
PRINT 1890, XT,XDT
TULOS=TULO
DO 430 I=1,3
XTS(I)=XT(I)
XDTS(I)=XD(T(I)
XPS(I)=XP(I)
430 XDPS(I)=XD(P(I)
440 RRP=SQRT(VDOT(XP,XP))
VVP=SQRT(VDOT(XDP,XDP))
AP=GM*RRP/(GM2-VVP*VVP*RRP)
RRT=SQRT(VDOT(XT,XT))
VVT=SQRT(VDOT(XDT,XDT))
AT=GM*RRT/(GM2-VVT*VVT*RRT)
PDA1=SQRT(GM/(AP*AP*AP))
PDTA1=SQRT(GM/(AT*AT*AT))
DLPD1=DLPD1+PDTA1
DLMR1=DLPD1+P1*SQRT(A1*AP*AP/GM)
GAMAP=ARNS(VDOT(XP,XDP)/(RRP*VVP))
HP=RRP*VVP*COS(GAMAP)
EP=SQRT(ONE-HP/HP/(GM*AP))
RPP=AP*(ONE-EP)
RAP=AP*(ONE+EP)
VAP=SQRT(GM/AP)*SQRT((ONE-EP)/(ONE+EP))
GAMAT=ARNS(VDOT(XT,XDT)/(RRT*VVT))
HT=RRT*VVT*COS(GAMAT)
ET=SQRT((ONE-ET)/(GM*AT))
RAT=AT*(ONE+ET)
RPP=AT*(ONE-ET)
TAUP1=P12*SQRT(AP*AP*AP/GM)
T2=T1+TAUP1/TWO
DRP=RAP-RRT
GAMAP0=GAMAP*CNV
HAT=(RAP-RE)/CF
PHDTP=PDA1*CNV
HPT=(RAP-RE)/CF
PHDOT=PDTA1*CNV
HAP=(RAP-RE)/CF
DLPD10=DLPD1*CNV
HPP=(RAP-RE)/CF
GAMATO=GAMAT*CNV
DLMR10=DLMR1*CNV
PRINT 2110
PRINT 2120, RRP, VVP,GAMAP0,EP,AP,HAP,HPP,PHDTP
PRINT 2130
PRINT 2140, RRT, VVT,GAMATO,ET,AT,HAT,HPT,PHDOT
PRINT 2150
PRINT 2160, DLPD10, DLMR10, T2
PROGRAM TARG

RCP*RAP
VCP=SQRRT(GM/RCP)
DUM=SQRRT(RCP*RCP/RCP/GM)
TAUCP=PI2*DUM
PDOTCP=ONE/DUM
DLPD2=PDOTCP-PDTA1
DLMR2=SFN01+DLPD2*TAUCP
DELV2=VCP*VAP
T3=T2*SFN01*TAUCP
PDOTCO=PDOTCP*CNV$DLMR20=DLMR2*CNV
PRINT 2170
PRINT 2180, RCP, VCP, TAUCP, PDOTCO, DLPD2, DLMR20, DELV2, T3
IF (ILIG=1) 450, 460, 450
450 XN=ZERO
GO TO 470
460 XN=ONE
470 CONTINUE
RPP3=RCP
RAP3=RPT-DLHD*DLHB
AP3=(RPP3*RAP3)/TWO
DUM=SQRRT(AP3+AP3+AP3/GM)
TAUP3=PI2*DUM
PDPA3=ONE/DUM
DLPD3=PDPA3-PDTA1
DLMR3=SFN02+DLPD3*TAUP3
T4=T3*SFN02*TAUP3
VPP3=SQRRT(GM2*RAP3/(RPP3*(RPP3*RPP3)))
DELV3=VPP3-VCP
PRINT 2190
PDPA30=PDPA3*CNV$DLPD30=DLPD3*CNV
DLMR30=DLMR3*CNV
PRINT 2200, TAU3, PDPA30, DLPD30, DELV3, T4, DLMR30
CIRCULARIZATION AT CDH ALTITUDE
RAP3=RAI-DLHD*DLHB
AP3=(RPP3*RAP3)/TWO
EP3=(RAP3*RPP3)/(RPP3*RPP3)
RPP4=RPT-DLHD
RAP4=RAT-DLHD
AP4=(RPP4*RAP4)/TWO
EP4=(RAP4*RPP4)/(RPP4*RPP4)
P3=(ONE-EP3*EP3)
TH4=ARCOS((P3-P4)/(EP3*P4-EP4*P3))
R4=(ONE-EP4*COS(TH4))
V4=SQRRT((GM2*AP3/R4-GM)/AP3)
GAM4=ARTAN(R4*EP3*Sin(TH4),P3,1)
VT4=SQRRT((GM2*AP4/R4-GM)/AP4)
GAMT4=ARTAN(R4*EP4*Sin(TH4),P4,1)
DELV4=SQRRT(VT4*VT4+V4*V4-TWO*VT4*V4*COS(GAMT4-GAMA4))

E-8
TH40=TH4*CNV
GAMA40=GAMA4*CNV
GAMT40=GAMT4*CNV
PRINT 2210
DUM=SORT(AP4*AP4*AP4/GM)
TAUP4=PI2*DUM
PDPA4=ONE/DUM
PDPA40=PDPA4*CNV
DPDCU=PDPA4-PDTA1
DPHO=SLM*DELTH
DPHR=DPHO/CNV
PRINT 2230, DPHO
DELVR=0.0
DLHR40=DPDCU*TAUP4*(SFNO3+XN)*DPHR
TPRI=T4+TAUP4*(SFNO3+XN)*DPHR/DPDCU
DPDCU0=PDPCU-CNV
DVIT=DELV2*DELV3*DELV4*DELVR
DLHR40=DLHR4*CNV
DPHRT1=DLHR1+DLHR2+DLHR3+DLHR4
DMRT0=DPHRT1*CNV
PDPA40=PDPA4*CNV
DPDCU0=DPDCU*CNV
PRINT 2240
PRINT 2250
PRINT 2260, TAUP4, PDPA40, DPDCU0, DLHR40, TPRI, DMRT0, DVIT
CALL RANGA (XP, XDP, XOMEGA, PHIP1)
CALL RANGA (XT, XDT, XOMEGA, PHIT1)
ISOLAS=0
ICOR=0
PHIP10=PHIP1*CNV
PHIT10=PHIT1*CNV
PRINT 2270, PHIP10, PHIT10
IF (PHIT1-P1) 480,490,490
480 PHIT1=PHIT1-P12
DPA1=PHIT1-PHIP1
GO TO 500
490 DPA1=PHIT1-PHIP1
500 IF (DPA1-DPHRT1) 510,520,520
510 DPA1=DPA1+P12
GO TO 530
520 DPA1=DPA1
530 D1=SFNO3*TAUP4*TAUP1/TWO*TAUP3*SFNO2
DPH1=DLHR1+DLHR3+DPDCU*TAUP4*SFNO3
DPA10=DPA1*CNV
PRINT 1910, DPA10
DPHR2=DPA1-DPH1-DPHR
DT2=DPHR2/DLPD2
TTST1=T1+TAUP1/TWO=200,
TIDYY

PROGRAM TARG

TTEST2=TAUPTWO+DT2
TBSBT=TAUPTWO+DT2
PRINT 1920, SFNO1, SFNO2, SFNO3
PRINT 2320
CALL PRINT (T1, XT, XDT, AZ, PH1, TULO)
CALL RKG (PH1O, AZO, XT, XDT, T1, TBSBT)
PRINT 2320
CALL PRINT (TBSBT, XT, XDT, AZ, PH1, TULO)
PRINT 2280
DPhiO=DPhi*CNV
DPhi2=DPhi*CNV
PRINT 2290, DPhiO, DPhi2, DT2, TBSBT, DT1, T1, TTEST1, TTEST2
IF (ILIG-1) 630, 540, 630
TULO=SHUTTLE LIFT-OFF TIME IN SECONDS UNIVERSAL TIME
TY=NUMBER OF DAYS PAST JAN.1 OF LAUNCH YEAR
LAMDA,L=LONGITUDE OF LAUNCH SITE
A1, B1, C1=INPUT CONSTANTS
OMEGA=EARTH'S ROTATION

540 T=TBSBT
550 DUM=P1*XLAMAL-OMEGA*TULO
PHSV=DUM
CALL MAROT (AAA, DUM, 2, -1)
DUM=A1*COS(B1+C1*TY)
ALSV=DUM
CALL MAROT (BBB, DUM, 3, -1)
CALL MARUL (CCC, BBB, AAA)
CALL MAROT (AAA, AZ-P1/THO, 1, 1)
CALL MAROT (BBB, PHI, 3, 1)
CALL MARUL (DDD, BBB, AAA)
CALL MARUL (AAA, CCC, DDD)
CALL FATT (BBB, AAA)
TEMP1(1)=ONE
TEMP1(2)=ZERO
TEMP1(3)=ZERO
CALL FATHU (TEMP2, BBB, TEMP1)
JFLAG=0
360 CALL VCROSS (TEMP3, XT, XDT)
BSD=VMAG(TEMP3)/VDOT(XT, XT)
CALL VUNIT (TEMP4, TEMP3)
CALL VCROSS (TEMP5, TEMP4, TEMP2)
CALL VUNIT (TEMP5, TEMP5)
CALL VCROSS (TEMP2, TEMP5, TEMP4)
BSVPT=ARTAN(VEOT(XT, TEMP5), VDOT(XT, TEMP2), 1)
IF (JLIGHT-1) 570, 1450, 570
570 IF ((BSVPT-BSVD)-.0001) 580, 580, 610
580 IF (JFLAG-1) 590, 620, 610
590 CHECK=BSVPT*BSD*DT
IF (CHECK-BSVD) 610, 600, 600
610 JFLAG=1
DT=(BSVD-BSVPT)/BSD

E-10
PROGRAM TARG

610 T2=T+DT
   CALL RKG (PHIO, AZO, XT, XDT, T, T2)
   T=T2
   GO TO 560

620 PRINT 2320
   CALL PRINT (T2, XT, XDT, AZ, PHI, TULO)
   PRINT 2300
   PHSV0=PHSV*CNV
   ALSV0=ALSV*CNV
   BSVPT0=BSVPT*CNV
   A0=A1*CNV$BO=B1*CNV$CO=C1*CNV
   XLMDO=XLAMAL*CNV
   PRINT 2310, AO, BO, CO, TY, XLMDO, PHSV0, ALSV0, BSVPT0
   TUTP=T
   DT3=T-TSBST
   DPH1=DPH1+DPDCU+DT3
   DPH2=DPH2+DPHR
   DT2=DPH2/DPD2
   TTEST2=T1+TAUP1+DT2
   GO TO 640

630 TUTP=TSBST

640 DO 650 I=1,3
   XT(I)=XTS1(I)
   XDT(I)=XDTS1(I)
   CALL RKG (PHIO, AZO, XT, XDT, T1, TTEST1)
   CALL RKG (PHIO, AZO, X, XDP, T1, TTEST1)
   PRINT 2320
   CALL PRINT (TTEST1, XT, XDT, AZ, PHI, TULO)
   PRINT 2330
   CALL PRINT (TTEST1, X, XDP, AZ, PHI, TULO)
   T=TTEST1

660 CALL ECCV (GM, X, XDP, TEMP3)
   CALL TRUE (X, XDP, TEMP3, PTA)
   EP=VMAG(TEMP3)
   RPM=VMAG(XP)
   AP=RPM*GM/(GM2-VDOT(XDP, XDP)*RPM)
   CALL TIME (AP, EP, PTA, PI, GM, PI, TGP2)
   IF (TGP2-30.0) 670, 670, 680

670 DT12=ONE
   IF (TGP2-TWO) 690, 690, 680

680 T12=T+DT12
   CALL RKG (PHIO, AZO, XT, XDT, T, T12)
   CALL RKG (PHIO, AZO, X, XDP, T, T12)
   T=T12
   GO TO 660

690 RAP=VMAG(XP)
   PRINT 2320
   CALL PRINT (T12, XT, XDT, AZ, PHI, TULO)
   PRINT 2330
   CALL PRINT (T12, X, XDP, AZ, PHI, TULO)
PROGRAM TARG

TSTI=X
VQ=SQRT(GM/RAP)
CALL VCROSS (TEMP1, XDP, XP)
CALL VCROSS (TEMP2, XP, TEMP1)
CALL VUNIT (TEMP2, TEMP2)
DO 700 I=1,3

700 TEMP3(I) = VQ*TEMP2(I)
DO 710 I=1,3

710 TEMP1(I) = TEMP3(I)*XDP(I)
VQ=VHAG(TEMP1)
PRINT 1990
PRINT 2000
PRINT 2330
CALL PRINT (TSTI, XP, XDP, AZ, PHI, TULO)
CALL VCROSS (AM, XP, TEMP3)
CALL ECCV (GH, XP, TEMP3, EV)
PRINT 2010, AM(1), AM(2), AM(3), EV(1), EV(2), EV(3), TEMP1(1), TEMP1(2), TEMP1(3)
DO 720 I=1,3

720 XP(I) = TEMP3(I)
DO 730 I=1,3

730 XDP(I) = XP(I)
XTPS(I) = XDP(I)
XTPS(I) = XTP(I)

740 CALL RKG (PHIO, AZO, XT, XDT, TSTI, TTEST2)
CALL RKG (PHIO, AZO, XP, XDP, TSTI, TTEST2)
PRINT 2330
CALL PRINT (TTEST2, XP, XDP, AZ, PHI, TULO)
PRINT 2320
CALL PRINT (TTEST2, XT, XDT, AZ, PHI, TULO)
T0TTEST2
CALL ECCV (GH, XT, XDT, TEMP3)
RD=VHAG(XT)
AT=ATM=GH=(GH2*VDOT(XDT, XDT))*RTM
ET=VHAG(TEMP3)
RPP=VHAG(XP)
RAT=AT=(ONE+ET)-DLHD
RPT=AT=(ONE+ET)-DLHD
ETD=(RAT+RPT)/(RAT+RPT)
DO 750 I=1,3

750 TEMP2(I) = XP(I)
RPP=VHAG(XP)
CTYAPA=VDOT(TEMP3, TEMP2)/(ET*RPP)
RAPOTH=RATD*RPTD/((RATD*RPTD)+RATD*RPTD)*CTTAPA)*DLHB
EPO=(RAP+RPP)/(RAT+RPP)
VPP=SQRT((GH/RPP)*ONE+EP))
PRINT 2330
CALL PRINT (TTEST2, XP, XDP, AZ, PHI, TULO)
PRINT 2390
CALL VCROSS (TEMP1, XDP, XP)
CALL VCROSS (TEMP3, XP, TEMP1)
CALL VUNIT (TEMP3, TEMP3)
Do 760 I=1,3
760 TEMP2(I)=VPP*TEMP3(I)
Do 770 I=1,3
770 TEMP1(I)=TEMP2(I)-XDP(I)
VG2=V MAG (TEMP1)
IF (ISOLAS=1) 790, 780, 780
780 PRINT 2020
PRINT 2000
PRINT 2330
CALL PRINT (TTEST2, XP, XDP, AZ, PHI, TULO)
CALL VCROSS (AM, XP, TEMP2)
CALL ECCV (GM, XP, TEMP3, EV)
PRINT 2010, AM(1), AM(2), AM(3), EV(1), EV(2), EV(3), TEMP1(1), TEMP1(2), TEMP1(3)
790 CONTINUE
Do 800 I=1,3
800 XDP(I)=TEMP2(I)
PRINT 1940
PRINT 2330
CALL PRINT (TTEST2, XP, XDP, AZ, PHI, TULO)
AP=(RPP*RAP)/TWO
TAUP2=PI2*SQRG(AP*AP*AP/GM)
TTEST3=T+(TAUP2*SPNO2)-250
JPAS=0
KPAS=0
CALL RKG (PHIO, AZO, XT, XDT, TTEST2, TTEST3)
CALL RKG (PHIO, AZO, XP, XDP, TTEST2, TTEST3)
PRINT 2320
CALL PRINT (TTEST3, XT, XDT, AZ, PHI, TULO)
PRINT 2330
CALL PRINT (TTEST3, XP, XDP, AZ, PHI, TULO)
DT22=5.0
T=TTEST3
810 CALL ECCV (GM, XP, XDP, TEMP1)
EP=V MAG (TEMP1)
CALL ECCV (GM, XT, XDT, TEMP4)
ET=V MAG (TEMP4)
RM=V MAG (XP)
AP=RM*GM/(GM2-VDOT(XDP, XDP)*RM)
RAP=AP*(ONE*EP)
DRTEST=RAP-V MAG (XT)*DLHD-100.
CALL TRUE (XT, XDP, TEMP1, PTA)
IF (ET=TOLE) 820, 940, 940
820 IF (DRTEST) 830, 830, 900
830 IF (PTA=PI) 840, 870, 870
840 CALL TIME (AP, EP, PTA, PI, GM, PI, TG3)
**PROGRAM TARG**

```
PRINT 1720, TG3
IF (TG3-10.) 860,850,850

850 T18=T+DT22
CALL RKG (PHIO, AZO, XP, XDP, T, T18)
CALL RKG (PHIO, AZO, XT, XDT, T, T18)
T=T18
IF (JPAS=1) 810,870,810

860 DT22=TG3
JPAS=1
GO TO 850

870 RCP=VMAG(XP)
PRINT 1730
VCP=SQRT(GM/RCP)
CALL VCROSS (TEMP1, XDP, XP)
CALL VCROSS (TEMP4, XP, TEMP1)
CALL VUNIT (TEMP4, TEMP4)
DO 880 I=1,3

880 TEMP2(I)=VCP*TEMP4(I)
DO 890 I=1,3

890 TEMP3(I)=TEMP2(I)-XDP(I)

V03=VMAG(TEMP3)
GO TO 1140

900 RS=VMAG(XT)-DLHD
PTASI=-ARCSIN((PP-RS)/(EP*RS))*PI2
PRINT 1900
CALL ECCV (GM, XP, XDP, TEMP1)
CALL TRUE (XP, XDP, TEMP1, PTA)
PHTST=PTASI-PTA
IF (PHTST) 870,910,910

910 CALL TIME (AP, EP, PTA, PTASI, GM, PI, TG3)
PRINT 1740, TG3
IF (TG3-10.) 930,920,920

920 T18=T+DT22
CALL RKG (PHIO, AZO, XT, XDT, T, T18)
CALL RKG (PHIO, AZO, XP, XDP, T, T18)
T=T18
IF (KPAS=1) 810,870,810

930 DT22=TG3
KPAS=1
GO TO 920

940 RMT=VMAG(XT)
AT=RMT*GM/(GM2-VDOT(XDT,XDT)*RMT)
RADT=AT*(ONE+ET)-DLHD
RPTD=AT*(ONE+ET)-DLHD
ATD=(RATD=RPTD)/TWO
STD=(RATD=RPTD)/(RATD=RPTD)
PTD=ATD*(ONE+ETD+ETD)
DO 950 I=1,3

950 TEMP2(I)=TEMP1(I)
GYPAA=VDOT(TEMP2, TEMP4)/(ET*EP)
```
PROGRAM TARG

RTD=PTD/(ONE+ETD*CTAPA)
DRTEST=RATP-RTD=100.0
IPASSI=0
IF (DRTEST) 1020,960,960
960 CALL VCRS (TEMP2,XP,DP)
CALL VCRS (TEMP3,TEMP2,TMega)
CALL VCRS (TEMP5,TEMP3,TEMP2)
SINAP=VDOT(TEMP1,TEMP5)/(EP*VMAG(TEMP5))
COSAP=VDOT(TEMP1,TEMP3)/(EP*VMAG(TEMP3))
ALFAP=ARTAN(SINAP,COSAP,1)
CALL VCRS (TEMP2,XT,XT)
CALL VCRS (TEMP3,TEMP2,TMega)
CALL VCRS (TEMP5,TEMP3,TEMP2)
SINAT=VDOT(TEMP4,TEMP5)/(ET*VMAG(TEMP5))
COSAT=VDOT(TEMP4,TEMP3)/(ET*VMAG(TEMP3))
ALFAT=ARTAN(SINAT,COSAT,1)
DELAL=ALFAT-ALFAP
D=ETD*PP*COS(DELAL)-PTD*EP
E=ETD*PP*SIN(DELAL)
F=PTD-PP
A=(E*D+F)
B=THO*F*E
C=D*D-F*F
RAD=(B+B*4,A*C)
STI=(-B-SQRT(RAD))/(2*A)
STII=(-B-SQRT(RAD))/(2*A)
IF (STI) 970,970,980
970 PTASI=-PI-ARSIN(STI)
GO TO 990
980 PTASI=PI-ARSIN(STI)
990 CALL TIME (AP,EP,PTA,PTASI,GM,P,TG3)
IF (TG3=1.) 1000,1000,1010
1000 DT22=TG3
IPASSI=1
1010 T18=T+DT22
CALL RKG (PHI0,AZ,XP,DP,T,T18)
CALL RKG (PHI0,AZ,XT,XT,T,T18)
T=T18
IF (IPASSI=1) 910,940,910
1020 IF (PTA=PI) 1030,1030,1040
1030 PTASI=PI
GO TO 990
1040 RPM=VMAG(XP)
PRINT 2320
CALL PRINT (T18,XT,XT,DP,T,XD,TU)
PRINT 2330
CALL PRINT (T18,XP,DP,PHI,TU)
CALL ECCV (GM,XT,XT,TEMP1)
RTM=VMAG(XT)
AT=RTM*GM/(GM2-VDOT(XD,T,XD)+RTM)

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PROGRAM TARG

ET=VMAG(TEMP1)
RAT=AT*(ONE-ET)
RPT=AT*(ONE-ET)
CALL VCROSS (TEMP2,XDP,XP)
CALL VCROSS (TEMP3,TEMP1,TEMP2)
CTTAPP=VDOT(TEMP1,XP)/(RPM*ET)
STTAPP=VDOT(TEMP3,XP)/(VMAG(TEMP3)*RPM)
P=T=AT*(ONE-ET)
RRT=P/T/(ONE-ET*CTTAPP)
DELR1=RRT-RPM
DELR=RP=RAT*RPT
IF (DELR) 1050,1050,1060
1050 B=8
1060 C=RAT*RPT/RPM/TWO*(CTTAPP*(RPT=RAT)*(RAT*RPT))
DLH1=ABS((-B*SQRT(B*B-4.*C))/TWO)
DLH2=ABS((-B*SQRT(B*B-4.*C))/TWO)
DELR=ABS(DELR1)
DRT1=ABS(DELR-DELR1)
DRT2=ABS(DELR-DELR2)
IF (DRT1>DRT2) 1070,1070,1080
1070 DLHDP=DLH1
GO TO 1090
1080 DLHDP=DLH2
1090 IF (DELR1) 1100,1100,1110
1100 DLHDP=-DLHDP
1110 RPP=RPT=DLHDP
RAP=RAT=DLHDP
EP=(RPP-RAP)/(RPP*RPP)
AP=(RPP-RAP)/TWO
GAMMP=ARTAN((EP*STTAPP,ONE-EP*CTTAPP,-1))
CALL VCROSS (TEMP1,XDP,XP)
CALL VCROSS (TEMP2,XP,TEMP1)
CALL VUNIT (TEMP3,TEMP2)
CALL VUNIT (TEMP1,XP)
DO 120 1=1,3
120 TEMP2(I)=VP*COS(GAMMP)*TEMP3(1)+VP*SIN(GAMMP)*TEMP1(1)
DO 130 I=1,3
130 TEMP1(I)=TEMP2(I)-XDP(I)
VG3=VMAG(TEMP1)
1340 IF (ISOLAS-1) 1160,1150,1150
1150 PRINT 2030
PRINT 2000
PRINT 2330
CALL PRINT (T18,XP,XDP,AZ,PR1,TULO)
CALL VCROSS (AM,XP,TEMP2)
CALL ECCV (GAMMP,XD,TEMP2,EV)
PRINT 2010, AM(1),AM(2),AM(3),EV(1),EV(2),EV(3),TEMP1(1),TEMP1(2),
1TEMP1(3)
PROGRAM TARG

1160 CONTINUE
1170 XDP(I)=TEMP2(I)
       ICOR=ICOR+1
       T=T18
       PRINT 2040
       PRINT 2320
       CALL PRINT (T18,XT,XDT,AZ,PHI,TULO)
       PRINT 2330
       CALL PRINT (T18,XP,XT,PHI,TULO)
       CALL RKG (PHIO,AZO,XT,XDT,T,TUTP)
       CALL RKG (PHIO,AZO,XP,XT,PHI,TUTO)
       PRINT 2050
       PRINT 2320
       CALL PRINT (TUTO,XT,XDT,AZ,PHI,TULO)
IF (T18>TUTP+SSFNO3*TAUP4=1000,) 1200,1200,1180

1180 SFNO3=SFNO3+.5
       DO 1190 I=1,3
       XT(I)=XTS1(I)
       XDT(I)=XDS1(I)
       XP(I)=XPST1(I)
       XDP(I)=XDS1(I)
       PRINT 1950
       TULO=TULOS
       DT=DTS
       GO TO 440
1200 CALL VCROSS (TEMP1,XP,XDP)
       CALL VCROSS (TEMP2,XT,XDT)
       CALL VCROSS (TEMP5,TEMP1,TEMP2)
       WATP=ARCOS (VDOT(TEMP1,TEMP2)/(VMAG(TEMP1)*VMAG(TEMP2)))
       CALL RANGA (XP,XDP,XOMEGA,PHI)
       CALL RANGA (XT,XDT,XOMEGA,PHI)
       CALL VCROSS (TEMP1,XT,TEMP5)
       CALL VCROSS (TEMP2,TEMP5,TEMP1)
       SINPNT=VDOT(TEMP2,XT)/(VMAG(TEMP2)*VMAG(TEMP2))
       COSPNT=VDOT(TEMP5,XT)/(VMAG(TEMP5)*VMAG(TEMP5))
       PHINT=ARTAN (SINPNT,COSPNT,1)
       CALL VCROSS (TEMP1,XP,TEMP5)
       CALL VCROSS (TEMP2,TEMP5,TEMP1)
       SINNP1=VDOT(TEMP2,XP)/(VMAG(TEMP2)*VMAG(TEMP2))
       COSNP1=VDOT(TEMP5,XP)/(VMAG(TEMP5)*VMAG(TEMP5))
       PHINP=ARTAN (SINNP1,COSNP1,1)
       TEMP1(1)=COS(PHI)
       TEMP1(2)=SIN(PHI)*SIN(AZ)
       TEMP1(3)=SIN(PHI)*COS(AZ)
       CALL VCROSS (TEMP2,XT,XDT)
       CALL VCROSS (TEMP3,TEMP2,XOMEGA)
       THINT=ARCOS (VDOT(TEMP1,TEMP3)/(VMAG(TEMP1)*VMAG(TEMP3)))
CALL VCROSS (TEMP2, XP, XDP)
CALL VCROSS (TEMP3, TEMP2, XOMEGA)
THNP = ARCS (VDOT (TEMP1, TEMP3) / (VMAG (TEMP1) * VMAG (TEMP3)))
DTHE = THNT - THNP
DTHEO = DTHE * CNV
PRINT 2070, DTHEO
IF (WATP - WATOL) 1320, 1210, 1210
1210 IF (PHINT - PI) 1220, 1220, 1270
1220 IF (PHINP - PI) 1240, 1240, 1230
1230 DELPH = PHINT - PHINP
GO TO 1420
1240 DELPH = PHINT - PHINP
IF (ABS (DELPH) - PI) 1260, 1260, 1250
1250 PHINP = PHINP + PI
DELPH = PHINT - PHINP
GO TO 1420
1260 DELPH = PHINT - PHINP
GO TO 1420
1270 IF (PHINT - PI) 1290, 1290, 1280
1280 DELPH = PHINT - PHINP
GO TO 1420
1290 DELPH = PHINT - PHINP
IF (ABS (DELPH) - PI) 1300, 1300, 1310
1300 DELPH = PHINT - PHINP
GO TO 1420
1310 PHINT = PHINT + PI
DELPH = PHINT - PHINP
GO TO 1420
1320 IF (PHIT - PI) 1330, 1330, 1370
1330 DELPH = PHIT - PHIP
IF (PHIP - PI) 1420, 1420, 1340
1340 IF (ABS (DELPH) - PI) 1350, 1360, 1360
1350 DELPH = PHIT - PHIP
GO TO 1420
1360 PHIT = PHIT + PI
DELPH = PHIT - PHIP
GO TO 1420
1370 IF (PHIP - PI) 1380, 1380, 1380
1380 DELPH = PHIT - PHIP
IF (ABS (DELPH) - PI) 1390, 1400, 1400
1390 DELPH = PHIT - PHIP
GO TO 1420
1400 PHIP = PHIP + PI
DELPH = PHIT - PHIP
GO TO 1420
1410 DELPH = PHIT - PHIP
1420 DELPH = DELPH * CNV
WATP = WATP * CNV
PHIP = PHIP * CNV
PHIT = PHIT * CNV

E-18
PROGRAM TARG

PHINTO=PHINT*CNV
PHINPO=PHINP*CNV
PRINT 1970, WATPO,PHIPO,PHITO,PHINTO,PHINPO
PRINT 2070, DELPH0
IF (ILIG-1) 1460,1430,1460
1430 IF (ISOLAS-1) 1460,1440,1460
1440 JLIGHT=1
GO TO 550
1450 BSVPAD=BSVPT*CNV
PRINT 1960, BSVPAD
GO TO 1650
1460 CONTINUE
PRINT 2080, ICOR
IF (ICOR-2) 1470,1530,1460
1470 IF (ABS(DTHE)-.02/CNV) 1530,1480,1480
1480 DLTLO=DTHE/OMEGA
TULO=TULO + DLTLO
T=TSTI
PRINT 1980, DLTLO
TUTP=TUTP + DLTLO
DO 1490 I=1,3
XTR1(I)=XTS(I)
XT(I)=XTS(I)
1490 XDT(I)=XDS(I)
DpHEE=DELPH-DPHR
TDLO=T+DLTLO
CALL RKG (PHIO,AZO,XT,XDT,TSTI,TDLLO)
PRINT 2320
CALL PRINT (TDLTO,XT,XDT,AZ,PHI,TULO)
DO 1500 I=1,3
1500 XTR2(I)=XT(I)
DLPLOC=ARCCOS(VDOT(XTR1,XTR2)/VMAG(XTR1)*VMAG(XTR2))
DLPLOC=(DLTLO/ABS(DLTLO))*DLPLOC
DLTT1=(DLPLOC-(DLPLOC+DPDCU)/DLPD2)-DLTLO*DPDCU)/DLPD2
DLTT2=DPHEE/(DLPD2-DPDCU)
DLTTT2=DLTT1+DLTT2
TTEST2=TTEST2+DLTLO
1510 CALL RANGA (XT,XDT,XOMEGA,PHITT)
CALL VCROSS (TEMP1,XT,XDT)
CALL VCROSS (TEMP2,TEMP1,XOMEGA)
CALL VUNIT (TEMP4,TEMP1)
DUM=VDOT(XOMEGA,TEMP4)
DUM=DUM1=DUM1
XINT=ARTAN(SQRT(ONE-DUM),DUM1,1)
TEMP1(1)=COS(PHI)
TEMP1(2)=SIN(PHI)*SIN(AZ)
TEMP1(3)=-SIN(PHI)*COS(AZ)
THTN=ARCCOS(VDOT(TEMP1,TEMP2)/(VMAG(TEMP2)))
THN=THTN-DTHE
CALL MAROT (AAA,AZ-P1/2,1,1)
CALL MAROT (BBB, PHI, 3, 1)
CALL MAMUL (CCC, BBB, AAA)
CALL MAROT (AAA, THTNE, 2, -1)
CALL MAROT (BBB, XINT, 1, -1)
CALL MAMUL (DDD, BBB, AAA)
CALL MAMUL (AAA, DDD, CCC)
CALL MAROT (BBB, PHITT, 2, -1)
CALL MAMUL (CCC, BBB, AAA)
CALL FATT (DDD, CCC)

A 901

RRT=VMAG(XT)
VVT=VMAG(XDT)

A 902

GAMMA=ARSIN(VDOT(XT, XDT)/ (RRT*VVT))

A 903

TEMP1(1)=RRT
TEMP1(2)=ZERO
TEMP1(3)=ZERO

A 904

CALL FATHU (XT, DDD, TEMP1)

A 905

TEMP1(1)=VVT*SIN(GAMMA)
TEMP1(2)=ZERO
TEMP1(3)=VVT*COS(GAMMA)

A 906

CALL FATHU (XDT, DDD, TEMP1)

A 907

T=TSTI

A 908

1520 IF (JINS) 1670, 740, 1670

A 909

DPHEE=DELPH-DPHR

A 910

IF (ABS(DPHEE)-.05/CNV) 1580, 1580, 1540

A 911

DFTT2=DPTH/ (DLPD2-DPDCU)

A 912

IF (ABS(DPHEE)-.05/CNV) 1670, 1540, 1570

A 913

PRINT 2090

A 914

IF (CISOLAS-i) 1590, 1540

A 915

DTULOT= TULO-TULOS

A 916

IF (ABS(DPHEE)-.05/CNV) 1570, 1570, 1540

A 917

PRINT 1980

A 918

IF (ISOLAS=1) 1590, 1650, 1650

A 919

DO 1600 I=1, 3

A 920

E-20
PROGR A M TARG

\[
\begin{align*}
XP(I) &= XPS(I) \\
XDP(I) &= XDPS(I) \\
XT(I) &= XTS(I) \\
1600 & \text{ XDT}(I) = \text{XDTS}(I) \\
& \text{GO TO 740} \\
1610 & \text{DLTLO} = D\text{THE}/\text{OMEGA} \\
& \text{DO 1620 } I = 1,3 \\
& \text{XTR}(I) = XTS(I) \\
& \text{XT}(I) = XTS(I) \\
1620 & \text{XDT}(I) = \text{XDTS}(I) \\
& \text{DULO} = \text{TULO} + \text{DLTLO} \\
& T = \text{TST1} \\
& \text{PRINT 1980, DLTLO} \\
& \text{TUTP} = \text{TUP} = \text{D}\text{TLO} \\
& \text{DO 1630 } I = 1,3 \\
& \text{XTR}(I) = XTS(I) \\
& \text{XT}(I) = XTS(I) \\
1630 & \text{XDT}(I) = \text{XDTS}(I) \\
& T = \text{TST1} + \text{DLTLO} \\
& \text{TF} = \text{TST1} + \text{D}\text{LTLO} \\
& \text{CALL RKG (PHIO, AZO, XT, XDT, TST1, TF)} \\
& \text{PRINT 2320} \\
& \text{CALL PRINT (TF, XT, XDT, AZ, PHI, TULO)} \\
& \text{DO 1640 } I = 1,3 \\
1640 & \text{XTR2}(I) = \text{XT}(I) \\
& \text{DLPLOC} = \text{ARCOS}\{(\text{VDOT}(\text{XTR1}, \text{XTR2})/ (\text{VMAG}(\text{XTR1})* \text{VMAG}(\text{XTR2}))) \\
& \text{DLPLOC} = (\text{DLTLO}/\text{ABS}(\text{DLTLO}))+\text{DLPLOC} \\
& \text{DLT1} = (\text{DLPLOC}+\text{DLPD2})-\text{DLTLO}\text{+}\text{D}\text{PDCU})/\text{DLPD2} \\
& \text{TTEST2} = \text{TTEST2} + \text{DLT1} \\
& \text{GO TO 1510} \\
\end{align*}
\]

C

1650 \text{TIMLAU} = \text{TULOS} + \text{DTULOT} \\
\text{TMIN} = \text{TULOS} + \text{DTULOT} + \text{T1} \\
& \text{CALL RKG (PHIO, AZO, XT, XDT, TULOS, TIMLAU)} \\
& \text{DO 1660 } I = 1,3 \\
& \text{XT}(I) = \text{XTLO}(I) \\
1660 & \text{XDT}(I) = \text{XTLO}(I) \\
& \text{JINS} = i \\
& \text{KINS} = 0 \\
& \text{D}\text{THE} = \text{OMEGA} + \text{DTULOT} \\
& \text{GO TO 1510} \\
1670 & \text{IF (KINS)} 1680, 1690, 1680 \\
1680 & \text{PRINT 2340} \\
& \text{PUNCH 2350, XT, XDT} \\
& \text{PUNCH 2350, XT, XDT} \\
& \text{PUNCH 2100, XT, XDT} \\
& \text{CALL PRINT (T1, XT, XDT, AZ, PHI, TULOS + DTULOT)} \\
& \text{GO TO 1710} \\
1690 & \text{CALL RKG (PHIO, AZO, XTS1, XDT1, TULOS + T1, TMIN)} \\
& \text{KINS} = 1
PRINT 2370
PRINT 2360, XT,XDT
CALL PRINT (0.0,XT,XDT,AZ,PHI,TIMLAU)
DO 1700 I=1,3
XT(I)=XTS1(I)
3700 XDT(I)=XDTSI(I)
GO TO 1510
1710 PRINT 2380, TIMLAU

1720 FORMAT (1E16.8/)
1730 FORMAT (32H CIRCULARIZE W/O C D H EQUATIONS/)
1740 FORMAT (1E16.8/)
1750 FORMAT (212)
1760 FORMAT (5E15.8/2E15.8)
1770 FORMAT (17H NORTHERLY LAUNCH/)
1780 FORMAT (17H SOUTHERLY LAUNCH/
1790 FORMAT (7H TIME=15.8,7H ATE15.8,7H ETE15.8,7H XE15.8/15.8
1800 FORMAT (49H ORBITAL ELEMENTS OF SPACE STATION IN-PLANE POINT/)
1810 FORMAT (35H FIRST GUESS ON THE LAUNCH AZIMUTH=E15.8/
1820 FORMAT (38H INSTANTANEOUS LATITUDE OF INSERTION=E15.8/
1830 FORMAT (32H DESIRED LATITUDE FOR INSERTION=E15.8/
1840 FORMAT (21H THIS IS THE SOLUTION)
1850 FORMAT (52H DESIRED VALUE OF INCLINATION FOR TARGETING PURPOSE=E15.8/
1860 FORMAT (61H INSERTION CONDITIONS DETERMINED FROM STEADY STATE TRAJ
1870 FORMAT (46H ACTUAL LAUNCH AZIMUTH FROM ORBITER INSERTION=E15.8/
1880 FORMAT (40H STATE VARIABLES OF ORBITER AT INSERTION/7H XPE15.8
1890 FORMAT (59H STATE VECTOR OF SPACE STATION AT TIME OF ORBITER INSER
1900 FORMAT (39H INTERSECTION ASSUMING CIRCULAR ORBIT=E15.8/
1910 FORMAT (18H PHASE ANGLE DPA1=E15.8/
1920 FORMAT (3E16.8/)
1930 FORMAT (35H BEFORE PERIGEE BURN AT TIME TTEST2/
1940 FORMAT (35H AFTER PERIGEE BURN AT TIME TTEST2/
1950 FORMAT (72HIFNO3 HAS BEEN BUMPED BY .5 BECAUSE THE TIME OF TPI OC
1960 FORMAT (33H THE SOLAR VECTOR ANGLE ACHIEVED=E15.8/
1970 FORMAT (7H WATPE15.8,7H PHITOE15.8,7H XITE15.8,7H XDTE15.8/7H
1980 FORMAT (50H THE LAUNCH TIME SHOULD BE ADJUSTED BY DELTA TULO=E15.8
1990 FORMAT (62H TARGETING VALUES FOR THE C0 V 100 NM CIRCULARIZATION AT
2000 FORMAT (29H POSITION VECTOR FOR IGNITION/
2010 FORMAT (37H TARGETING VALUES FOR DESIRED ELLIPSE/24H ANGULAR MOMEN
1. TUM VECTOR/7H AM(1)E15.8,7H AM(2)E15.8,7H AM(3)E15.8/20H ECCENT  
2. RIGITY VECTOR/7H EV(1)E15.8,7H EV(2)E15.8,7H EV(3)E15.8/29H VEL.  
3. CITY TO BE GAINED VECTOR/7H VG(1)E15.8,7H VG(2)E15.8,7H VG(3)E  
   415,8/  

2020 FORMAT (42H TARGETING VALUES FOR THE COV PERIGEE BURN//)  
2030 FORMAT (46H1 TARGETING VALUES FOR THE CDH MANUVER FOR COV/)  
2040 FORMAT (26H1CDH HAS BEEN ACCOMPLISHED//)  
2050 FORMAT (23H1UNIVERSAL TIME FOR TPI//)  
2060 FORMAT (6H DTHE5E15,8//)  
2070 FORMAT (7H DELPHOE15,8//)  
2080 FORMAT (32H1BEGIN NEXT ISOLATION LOOP ICOR=112)  
2090 FORMAT (21H THIS IS THE SOLUTION///)  
2100 FORMAT (6E13,8)  
2110 FORMAT (42H PAPAMETERS FOR 90X100 N.M. PHASING ORBIT///)  
2120 FORMAT (7H RRPE15,8,7H VVPE15,8,7H GAMMAE15,8,7H EPE15,  
   18/7H APE15,8,7H HAPE15,8,7H HPPE15,8,7H PHDOTPE15,8//)  
2130 FORMAT (32H PAPAMETERS FOR THE TARGET ORBIT////)  
2140 FORMAT (7H RRTE15,8,7H VVTE15,8,7H GAMATOE15,8,7H ETE15,  
   18/7H ATE15,8,7H HATE15,8,7H HPTE15,8,7H PHDOTTE15,8//)  
2150 FORMAT (74H CATCH UP RATE AND ANGLE FOR THE HALF ORBIT OF THE 50X  
   100 NM PHASING ORBIT///)  
2160 FORMAT (23H ORBITAL CATCH UP RATE=E15,8/19H ANGLE OF CATCH UPEE15,  
   18/32H TIME AT APOGEE OF 50X100 ORBIT=15,8)  
2170 FORMAT (51H FIRST MANUVER TO CIRCULARIZE 80X100 AT ITS APOGEE///)  
2180 FORMAT (7H RCPE15,8,7H VCPE15,8,7H TAUCE15,8,7H PDOTCOE15,  
   18/7H DLG2E15,8,7H DLMR2E15,8,7H DELV2E15,8,7H TSE15,8///)  
2190 FORMAT (7H CATCH UP RATE AND ANGLE FOR THE HALFB ORBIT OF THE 50X  
   100 NM PHASING ORBIT///)  
2200 FORMAT (16H ORBITAL PERIOD=E15,8/19H MEAN ORBITAL RATE=15,8/15H C  
   1ATCH UP RATE=E15,8/21H IMPULSE REQUIREMENT=15,8/18H TIME INTO FLI  
   2GHT=15,8/7H DPH3E15,8///)  
2210 FORMAT (45H COELLIPIC ORBIT PLACING VEHICLE IN CDH ORBIT///)  
2220 FORMAT (7H EP3E15,8,7H RPP4E15,8,7H RAP4E15,8,7H AP4E15,  
   18/7H EP4E15,8,7H TH4DE15,8,7H R4E15,8,7H V4E15,8,7H  
   2AMA40E15,8,7H VT4E15,8,7H QAM40E15,8,7H DELV4E15,8///)  
2230 FORMAT (50H THE TPI IGNITION ANGLE IN RELATION TO THE TAAGET=E15,8  
   1)  
2240 FORMAT (61H THIS SECTION DETERMINES THE CATCH UP RATE IN THE CDH  
   1 ORBIT//)  
2250 FORMAT (7H IT ALSO SUMS UP THE DELTA VELOCITY AND CATCH UP ANGLE  
   1 FOR THE TOTAL MISSION/)  
2260 FORMAT (7H TAUPE15,8,7H PDPA4E15,8,7H PDPC4OE15,8,7H DLMR4OE15,  
   18/7H TTPE15,8,7H DMROE15,8,7H DVITE15,8//)  
2270 FORMAT (24H RANGE ANGLE OF PURSUIT=E15,8/23H RANGE ANGLE OF TARGE  
   1T=E15,8///)  
2280 FORMAT (29H COMPUTATIONS FOR SECTION 4-8/)  
2290 FORMAT (7H DPH1OE15,8,7H DPW2OE15,8,7H DT2E15,8,7H TSBSTE15,  
   18/7H DT1E15,8,7H TJE15,8,7H TTESTE15,8,7H TTEST2E15,8///)  
2300 FORMAT (50H COMPUTATIONS FOR LIGHTING CONDITIONS SECTION 4-10//)  
2310 FORMAT (7H AOE15,8,7H B0E15,8,7H COE15,8,7H TYE15,8///)  

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PROGRAM TARG

18/7H LAMDAOE15,8,7H PHSVOE15,8,7H ALSVOE15,8,7H BSVPTOE15,8//) A1101
2320 FORMAT (23H STATE OF SPACE STATION//) A1102
2330 FORMAT (17H STATE OF ORBITER//) A1103
2340 FORMAT (36H STATE VECTOR OF TARGET AT INSERTION//) A1104
2350 FORMAT (6E13.6) A1105
2360 FORMAT (7H XTE15,8,7H YTE15,8,7H ZTE15,8,7H XDTE15. A1106
18,7H YDTE15,8,7H ZDTE15,8,/) A1107
2370 FORMAT (35H STATE VECTOR OF TARGET AT LIFT OFF//) A1108
2380 FORMAT (28H THE UPDATED TIME OF LAUNCH=E15,8//) A1109
END A1110

E-24
SUBROUTINE RK713 (TO, TF, TOL, XI, X, N, KT, M, BETA, ALPH, CH, TI, AB)

SUBROUTINE RK713 (TO, TF, TOL, XI, X, N, KT, M, BETA, ALPH, CH, TI, AB)

SEVENTH ORDER RUNGE-KUTTA INTEGRATION WITH STEPSIZE CONTROL

TF CAN BE GREATER THAN TI OR LESS THAN TI AND RK713 WILL WORK

M IS THE NUMBER OF STEPS NEEDED

N IS THE NUMBER OF DIFFERENTIAL EQUATIONS

KT IS MAX NUMBER OF ITERATIONS

ARRAY F STORES THE 13 EVALUATIONS OF THE DIFFERENTIAL EQUATIONS

SUBSCRIPTS FOR ALPHA, BETA, AND CH ARE +1 GREATER THAN FEHLBERGS

F(0) IN FEHLBERGS REPORT IS IN F(1, J)

F(1) IS IN F(I+1, J)

FEHLBERGS REPORT REFERENCED IS NASA TR R-287

PARAMETERS FOR DEQ SUBROUTINE MUST BE STORED IN COMMON

DIMENSIONS MUST AGREE WITH NUMBER OF DIFFERENTIAL EQUATIONS AND

NUMBER OF CONSTANTS IN THE PARTICULAR FEHLBERG FORMULA USED

DIMENSION F(13, 6), XDUM(6), TE(6), XI(6), ALPH(13), BETA(13, 12), X

1(6), CH(13), AB(3), ACCO(3)

T = TO

DT = TF - TO

M = 0

DO 10 I = 1, N

10 X(I) = XI(I)

20 CALL DEQ (X, T, TE, AB, TI)

20 F(I, I) = TE(I)

DO 30 I = 1, N

30 DO 40 K = 2, 13

40 XDUM(I) = X(I)

50 NN = K - 1

50 DO 50 I = 1, N

50 DO 50 J = 1, NN

60 F(K, I) = TE(I)

60 CONTINUE

70 CONTINUE

80 XDUM(I) = X(I)

80 DO 90 I = 1, N

90 X(I) = X(I) + DT * CH(L) * F(L, I)

90 EPS = 1.

100 DO 120 I = 1, N

120 IF ALL THE VARIABLES BEING INTEGRATED HAVE MAGNITUDES WHOSE

120 ABSOLUTE VALUES ARE ALWAYS MUCH LESS THAN 1., THEN A VALUE

120 OF EPS LESS THAN ONE MAY NEED TO BE USED TO ACHIEVE AN ACCURACY

120 AS SPECIFIED BY TOL.

120 IF (ABS(XDUM(I)) - EPS) 100, 110, 110

100 A = EPS

GO TO 120
SUBROUTINE RK713 (TO, TF, TOL, XI, X, N, KT, M, BETA, ALPH, CH, TI, AB)

110 A=XDUM(I)
120 TE(I)=DT*(F(1, I)+F(11, I)-F(12, I)-F(13, I))*41./840./A
   ER=ABS(TE(I))
   DO 140 I=2,N
   IF (ABS(TE(I))-ER) 140,140,130
130   ER=ABS(TE(I))
140 CONTINUE
   DT1=DT
   M=M+1
   AK=8
   DT=AK*DT1*(TOL/ER)**.125
   IF (ER-TOL) 150,150,180
150   T=T+DT1
160   DT=TF-T
170 CONTINUE
   GO TO 190
190   XC 190 I=1,N
195   X(I)=XDUM(I)
200   IF (M-KT) 210,220,220
210   IF (T-TF) 20,230,20
220   TF=T
230 RETURN
END
SUBROUTINE RKG (PHIL, AZ, XI, DXI, T, TF)

DIMENSION X(6), DX(6), ALPH(13), BETA(13,12), CH(13), AB(3), XI(3)

1. DXI(3)

DO 10 I=1,3

10 X(I)=XI(I)

10 X(I*3)=DXI(I)

GM=3.9860319E14

RCONV=1.17E-01

RPHIL=PHIL*RCONV

HAZ=AZ*RCONV

AC3=COS(RPHIL)

AB(2)=-AC3*SIN(RAZ)

AB(3)=AC3*COS(RAZ)

DO 30 1=1,13

30 CH(I)=O.

CH(6)=34./105.

CH(7)=9./35.

CH(8)=CH(7)

CH(9)=9./280.

CH(10)=CH(9)

CH(12)=41./840.

CH(13)=CH(12)

ALPH(2)=2./27.

ALPH(3)=1./9.

ALPH(4)=1./6.

ALPH(5)=5./12.

ALPH(6)=5.

ALPH(7)=5./6.

ALPH(8)=1./6.

ALPH(9)=2./3.

ALPH(10)=1./3.

ALPH(11)=1.

ALPH(13)=1.

BETA(2,1)=2./27.

BETA(3,1)=1./36.

BETA(4,1)=1./24.

BETA(5,1)=5./12.

BETA(6,1)=.05

BETA(7,1)=-25./108.

BETA(8,1)=31./300.

BETA(9,1)=2.

BETA(10,1)=-91./108.

BETA(11,1)=2333./4100.

BETA(12,1)=3./205.

BETA(13,1)=-1777./4100.

BETA(3,2)=1./12.
SURROUTINE RKG (PHIL, AZ, XI, DXI, TI, TF)

\[
\begin{align*}
\beta_{4,3} & = 1/8, \\
\beta_{5,3} & = -25/16, \\
\beta_{5,4} & = -\beta_{4,3}, \\
\beta_{6,4} & = 25, \\
\beta_{7,4} & = 125/108, \\
\beta_{9,4} & = -53/6, \\
\beta_{10,4} & = 23/108, \\
\beta_{11,4} & = -341/164, \\
\beta_{13,4} & = \beta_{11,4}, \\
\beta_{6,5} & = 2, \\
\beta_{7,5} & = -65/27, \\
\beta_{8,5} & = 61/225, \\
\beta_{9,5} & = 704/45, \\
\beta_{10,5} & = 976/135, \\
\beta_{11,5} & = 4496/1025, \\
\beta_{13,5} & = \beta_{11,5}, \\
\beta_{7,6} & = 125/54, \\
\beta_{8,6} & = -2/9, \\
\beta_{9,6} & = -107/9, \\
\beta_{10,6} & = 311/54, \\
\beta_{11,6} & = -301/82, \\
\beta_{12,6} & = 6.41, \\
\beta_{13,6} & = -249/82, \\
\beta_{8,7} & = 13/900, \\
\beta_{9,7} & = 67/90, \\
\beta_{10,7} & = -19/60, \\
\beta_{11,7} & = 2133/4100, \\
\beta_{12,7} & = 3/205, \\
\beta_{13,7} & = 2193/4100, \\
\beta_{9,8} & = 3, \\
\beta_{10,8} & = 17/6, \\
\beta_{11,8} & = 45/82, \\
\beta_{12,8} & = 3/41, \\
\beta_{13,8} & = 51/82, \\
\beta_{10,9} & = -1/12, \\
\beta_{11,9} & = 45/164, \\
\beta_{12,9} & = 3/41, \\
\beta_{13,9} & = 33/164, \\
\beta_{11,10} & = 1H/41, \\
\beta_{12,10} & = 6/41, \\
\beta_{13,10} & = 12/41, \\
\beta_{13,12} & = 3, \\
\end{align*}
\]

CALL NEQ (X, TI, DX, AB, TI)

TOL = 5E-06
TI = TI
CALL RK713 (TO, TF, TOL, X, 6, 2000, M, BETA, ALPH, CH, TI, AB)

\[
\begin{align*}
\text{UN} 40 \ I &= 1.3 \\
\text{XI} (I) &= X(I) \\
40 \text{UXI} (I) &= X(I+3)
\end{align*}
\]
TIDY*

SUBROUTINE RKG (PHIL, AZ, XI, DXI, TI, TF)

RETURN
END
SUBROUTINE CONIC (R, V, AZ, PHI, AA, AP, ENC, THTN, TH, E, P, A, ALFAD, RA, RP, C)


W(1) = SIN(PHI)
W(2) = COS(PHI) * SIN(AZ)
W(3) = COS(PHI) * COS(AZ)
CALL VUNIT (RU, R)
CALL VCROSS (H, P, V)
CALL VUNIT (HU, H)
CALL VCROSS (THNV, H, W)
CALL VUNIT (THNU, THNV)
CALL VCROSS (QU, HU, RU)
CALL VCROSS (PU, THNU, HU)
GM = 3.986031979E14
RM = SQRT(VDOT(R, R))
P = VDOT(H, H) / GM
RD = VDOT(V, RU)
A = GM * RM / (2. * GM - RM * VDOT(V, V))
TEST = (1. - P / A)
IF (TEST) 20, 20, 10
10 = SQRT(TEST)
GO TO 30
20 = 0.0
30 = CONTINUE
COSTH = (P * RM) / (E * RM)
SINTH = (RD / E) * SQRT(P / GM)
DO 40 I = 1, 3
40 X(I) = RU(I) * COSTH = QU(I) * SINTH
ALFAD = ARTAN(VDOT(XI, PU), VDOT(XI, THNU), 1)
TH = ARTAN(SINTH, COSTH, 1)
CALL VCROSS (CU, HU, THNU)
PHII = ARTAN(VDOT(CU, RU), VDOT(THNU, RU), 1)
T(1) = COS(PHI)
T(2) = SIN(AZ) * SIN(PHI)
T(3) = -COS(AZ) * SIN(PHI)
CALL VCROSS (SU, W, T)
THTN = ARTAN(VDOT(THNU, SU), VDOT(THNU, T), 1)
CALL VCROSS (R, W, THNU)
ENC = ARTAN(VDOT(HU, B), VDOT(HU, W), -1)
RA = 6378166.
CNV = 1852.
C3 = GM / A
RA = A * (1. + E)
RP = A * (1. - E)
AA = (RA - RE) / CNV
AP = (RP - RE) / CNV
RETURN
END
SUBROUTINE GMAT (PHI, AZI, THTN, ENC, G, PI)

DIMENSION AA(3,3), B(3,3), C(3,3), D(3,3), TE(3,3), G(3,3)

CALL MAROT (AA, AZI - PI/2., 1, 1)
CALL MAROT (B, PHI, 3, 1)
CALL MAROT (C, THTN, 2, -1)
CALL MAROT (D, ENC, 1, -1)
CALL MAMUL (G, B, AA)
CALL MAMUL (TE, C, G)
CALL MAMUL (G, D, TE)
RETURN
END
SUBROUTINE MAROT (A, ANGLE, K, L)

DIMENSION A(3,3), C(3,3)
SANG = SIN(ANGLE)
CANG = COS(ANGLE)

DO 10 I = 1, 3
   DO 10 J = 1, 3
   A(I,J) = 0.
   M = (-3*K**2+11*K-4)/2
   N = (3*K**2-13*K+16)/2
   A(K,K) = 1, 0
   A(M,M) = CANG
   A(N,N) = CANG
   A(M,N) = SANG
   A(N,M) = SANG
   IF (L) 20, 20, 50
10   CONTINUE

20   DO 30 I = 1, 3
      DO 30 J = 1, 3
      C(I,J) = A(J,I)
30   CONTINUE
   DO 40 I = 1, 3
      DO 40 J = 1, 3
      A(I,J) = C(I,J)
40   CONTINUE
50 RETURN
END
FUNCTION ARTAN (SANG, CANG, ISW)

This subroutine uses the sine and cosine of the function and places the angle in the proper quadrant.

IF ISW=1 the angle is put between 0 and 2 PI
IF ISW=-1 the angle is put between - PI and + PI

PI=3.14159265

IF (SANG) 1, 7, 10
1 IF (CANG) 2, 3, 4
2 ARTAN=PI+ATAN(SANG/CANG)
   GO TO 5
3 ARTAN=PI/2.
   GO TO 5
4 ARTAN=ATAN(SANG/CANG)
5 IF (ISW) 14, 14, 6
6 ARTAN=2*PI*ARTAN
   GO TO 14
7 IF (CANG) 8, 9, 9
8 ARTAN=PI
   GO TO 14
9 ARTAN=0.
   GO TO 14
10 IF (CANG) 11, 12, 13
11 ARTAN=PI+ATAN(SANG/CANG)
12 ARTAN=PI/2.
   GO TO 14
13 ARTAN=ATAN(SANG/CANG)
14 RETURN

END
FUNCTION POLY (C,X,N)

C IS THE COEFFICIENT ARRAY
X IS THE INDEPENDENT VARIABLE
N IS THE DEGREE OF THE POLYNOMIAL
DIMENSION C(1)

POLY=0.0
K=N+1

10 POLY=C(K)+POLY*X
K=K-1
IF (K.GT.0) 10,20

20 RETURN
END
SUBROUTINE ECCV(GM, XP, XDP, TEMP1)
DIMENSION XP(3), XDP(3), TEMP1(3), TEMP2(3), TEMP3(3)
CALL VCROSS (TEMP1, XP, XDP)
CALL VUNIT (TEMP2, XP)
CALL VCROSS (TEMP3, TEMP1, XDP)
DO 360 I = 1, 3
360 TEMP1(I) = -(TEMP2(I) + TEMP3(I))/GM
RETURN
END

FORTRAN DIAGNOSTIC RESULTS FOR ECCV
SUBROUTINE DEQ (X, T, DX, AB, TI)

DIMENSION X(6), DX(6), AB(3), XDUM(6), ACCO(3)

GM=3.9860319E14
AA=6378166E+07
FJ=1.62345E-03
FH=-5.75E-06
FD=7.875E-06

DO 20 I=1,3

20 DX(I)=X(I+3)

R2=X(I)*X(I)+X(2)*X(2)+X(3)*X(3)
R=SQRT(R2)
RI=1./R
R21=1./R2

B=AA*AA*R21
BB=AA*RI

A=(AB(I)*X(I)+AB(2)*X(2)+AB(3)*X(3))*RI
A2=A*A

A4=A2*A2

GR=B*(FJ*(1.-5.*A2)+3.*FD*(1./7.-2.*A2+3.*A4)+FH*BB*A*(3.-7.*A2)
1)

GP=B*(2.*FJ*A+4.*FD*A*(3./7.+A2)*B+3.*FH*BB*(A2-1./5.))

DO 30 I=1,3

30 DX(I+3)=-GM*R21*((1.+GR)*X(I)*RI+GP*AB(I))

RETURN
END
SUBROUTINE FATT (BBB, AAA)

DIMENSION BH8(3,3), AAA(3,3)

DO 10 L=1,3
DO 10 M=1,3

10 BBB(L,M) = 0.

DO 20 J=1,3
DO 20 I=1,3

20 BBB(J,1) = AAA(I, J)

RETURN

END
SUBROUTINE FATMU (EEE, AAA, DDD)

DIMENSION EEE(3), AAA(3,3), DDD(3)

DO 10 L=1,3
10 EEE(L)=.

DO 20 I=1,3
DO 20 J=1,3
20 EEE(I)=EEE(I)+AAA(I,J)*DDD(J)

RETURN

END
SUBROUTINE PRINT (T, RI, VI, AZ, PH, TULO)

DIMENSION RI(3), VI(3)
TULO=TULO*T

T = T
ICOR = 0
10 HR = T/3600.
IHR = HR
XMIN = (T - IHR*3600.)/60.
MIN = XMIN
SEC = T - IHR*3600. - MIN*60.
IF (ICOR = 1) 20,30,30
20 PRINT 40, IHR, MIN, SEC
TT = TULO
ICOR = 1
GO TO 10
30 PRINT 50, IHR, MIN, SEC
CNV = 57.29579513
CALL CONIC (RI, VI, AZ, PH, AA, AP, ENC, THN, TH, E, P, A, ALF, RA, RP, C3, PHI1)
ENC1 = ENC*CNV
THN1 = THN*CNV
TH1 = TH*CNV
ALF1 = ALF*CNV
PHI11 = PHI1*CNV
PRINT 60, T, RI, VI, AA, AP, RA, RP, P, A, E, C3, ENC1, THN1, TH1, ALF1, PHI11
RETURN

40 FORMAT (2X, 19H TIME FROM LIFT-OFF/5H HRS=, I2, 3X, 5H MIN=, I2, 3X, 5H SEC=, E15.8//)
50 FORMAT (2X, 19H UNIVERSAL TIME/5H HRS=, I2, 3X, 5H MIN=, I2, 3X, 5H SEC=, E15.8//)
60 FORMAT (/3X, 4HTIME, E15.8/5X, 2H X, E15.8, 6X, 1HY, E15.8, 6X, 1HZ, E15.8, 5X, 1X, 2H XD, E15.8, 5X, 2HYD, E15.8, 5X, 2HZD, E15.8, 4X, 3H AA, E15.8, 4X, 3H AP, E
215.8, 4X, 3H RA, E15.8, 4X, 3H RP, E15.8, 5X, 2H P, E15.8, 2X, 5H A, E15.8,
3/5X, 2H X, E15.8, 4X, 3H C3, E15.8, 4X, 3H ENC, E15.8, 4X, 3H THN, E15.8, 5X, 2H
4H, E15.8, 2X, 5HALFAN, E15.8/7H PHI10E15.8//)
END
SUBROUTINE FATML (CCC, BBB, AAA)

DIMENSION CCC(3,3), BBB(3,3), AAA(3,3)

DO 10 L=1,3
DO 10 M=1,3
10 CCC(L,M)=0,
DO 20 J=1,3
DO 20 I=1,3
DO 20 K=1,3
20 CCC(I,J)=CCC(I,J)+BBB(I,K)*AAA(K,J)
RETURN
END
SUBROUTINE TIME (A,E,THA,THB,GM,PI,TF)

THIS SUBROUTINE DETERMINES THE KEPLERIAN TIME OF FLIGHT BETWEEN TWO POSITIONS ON AN ELLIPTICAL ORBIT

DIMENSION TH(2), SINE(2), COSE(2), ECA(2), XM(2)
TH(1)=THA
TH(2)=THB
DO 10 I=1,2
SINE(I)=SQR(1.-E**2)*SIN(TH(I))/(1.+E*COS(TH(I)))
COSE(I)=(E+COS(TH(I)))/(1.+E*COS(TH(I)))
ECA(I)=ARCTAN(SINE(I),COSE(I))
XM(I)=ECA(I)-E*SIN(ECA(I))
XMTR=XM(2)
ET1=ECA(1)
ET2=ECA(2)
T=SQR(A**3/GM)
TFA=T*XM(1)
TFB=T*XM(2)
IF (TFB-TFA) 20,30,30
20 TFB=TFB+2.*PI*T
30 TF=TFB-TFA
RETURN
END
SUBROUTINE HANGA(XT, XDT, XOMEGA, PHIT)
DIMENSION TEMP1(3), TEMP2(3), TEMP3(3), XOMEGA(3), XT(3), XDT(3)
CALL VCROSS (TEMP1, XT, XDT)
CALL VCROSS (TEMP2, TEMP1, XOMEGA)
CALL VCROSS (TEMP3, TEMP1, TEMP2)
RRT = VMAG(XT)
SINPHI = VDOT(TEMP3, XT) / (VMAG(TEMP3) * RRT)
COSPHI = VDOT(TEMP2, XT) / (VMAG(TEMP2) * RRT)
PHIT = ARTAN(SINPHI, COSPHI, 1)
RETURN
END
SUBROUTINE TRUER(XP,XDP,TEMP1,PTA)
DIMENSION XP(3),XDP(3),TEMP1(3),TEMP2(3),TEMP3(3)
EP=VMAG(TEMP1)
RMP=VMAG(XP)
CALL VCROSS (TEMP2,XDP,XP)
CALL VCROSS (TEMP3,TEMP1,TEMP2)
COSPTA=VDOT(TEMP1,XP)/(EP*RMP)
SINPTA=VDOT(TEMP3,XP)/(VMAG(TEMP3)*RMP)
PTA=ARTAN(SINPTA,COSPTA,1)
RETURN
END

FORTRAN DIAGNOSTIC RESULTS FOR TRUE