TARGETING WITH FIXED PROPELLANT LOAD

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ABSTRACT

The Inertial Upper Stage (IUS) for the Space Shuttle Operation employs solid rocket stages with fixed, propellant loadings. This means that, if for a given mission the satellite weight is less than the maximum, the IUS will deliver higher ΔV-s than required. Then, means must be found to waste the excess capability in order to achieve the desired orbit. One way would be to execute a nonoptimal transfer which would require higher than maximum ΔV-s. In the following, an algorithm is presented which defines take-off points on the parking orbit and the injection points on the target orbit* for which transfer orbits require a fixed ΔV_1 and a fixed ΔV_2 (defined by the satellite weight).

To have complete generality, it is assumed that both the parking and the target orbit are elliptical. This allows the use of the same algorithm for guidance, i.e., to compensate for ΔV errors. Namely the transfer orbit achieved by the erroneous ΔV_1 is regarded as a new parking orbit and the new transfer problem is solved by assuming a $\delta \Delta V_1$. The maximum value of $\delta \Delta V_1$ is the ΔV_1 variation and its minimum value is the one which still yields a solution by the algorithm. ΔV_2 errors are regarded orbit injection errors and compensated the usual way.

*For interplanetary missions the target-orbit is the IUS parking orbit from which the third stages inject the spacecraft into a departure hyperbola.

Figure 1 shows the performance of the two-stage IUS. Also shown are on the figure the minimum ΔV_1 and ΔV_2 required to transfer a satellite from the Shuttle orbit into a 2.9° inclined synchronous (circular) orbit. For a satellite which weighs ≈ 5300 lb, the IUS would produce these ΔV-s, thus a Hohmann transfer, from node to node, would be feasible. But for a satellite weighing less than 5300 lb, the IUS delivers an extra performance which has to be wasted some way. This can be done, e.g., by a non-optimum transfer scheme shown on Figure 2. Instead of transferring from node to node, transfer is made between non-nodal points D and A. If the points are correctly chosen the equations shown under the figure are simultaneously satisfied with the same h = angular momentum value. In those equations A and B are simple constants which depend on the chosen geometry, γ_i are direction cosines of the chord vector $\vec{c}$ in two coordinate systems, the first one is shown, the other would be in the target plane with the X axis through A. V_R and V_T are the radial and transverse velocity components of the parking (p) and the target (t) orbit velocities. Finally, ΔV_1 and ΔV_2 are the ideal rocket velocities delivered by the IUS to a satellite with the particular weight.

Generally the two equations do not yield simultaneous solutions, one of the points or both have to be moved to get a solution. There are many different ways to use residues to move one of the points to the correct location, any of these can be implemented on a digital computer.

The following figures show examples of transferring from a 150 n mi circular Shuttle orbit a 2900 lb satellite into different final orbits. Figure 3a shows the case of transferring from a 28.5° inclined Shuttle orbit into a 24 hour circular equatorial orbit. The angle of the first burn is measured in the parking orbit from the node where the target orbit "ascends" (northward) through the parking orbit plane. The second angle measured in the target orbit from the node where the parking orbit "descends" through the target orbit plane (same location). Values for a Hohman transfer would be 0 and 180. For a satellite weighing only 2900 lb, solutions are represented by the two curves on Figure 3a.

Figure 3b shows the corresponding angular momentum values, i.e., the simultaneous solutions of the two ΔV equations. The cross marks are serving to interrelate the corresponding branches of the curves. If two radii vectors and the angular momentum are known, then the transfer orbit is completely defined, transfer time, transfer angle, perigee, apogee altitudes, burn directions, etc., can be all calculated.

Figures 4a and b show transfer possibilities to a 12-hour critically inclined circular orbit from a 37.5° inclined Shuttle orbit. Both orbits have the same right ascension of the nodes, (most favorable case).

Figures 5a and b show "Type I"* transfers to a 12-hour critically inclined eccentric orbit from a 37.5° inclined Shuttle orbit. The perigee altitude of the final orbit is 150 n mi and its apogee altitude is 21390 n mi. The argument of the perigee is 270°. The right ascension of the target orbit is five degrees behind that of the parking orbit which was found to be approximately the best geometry. Even so the range of solution is rather restricted. A much more broad range was found for "Type II" transfers shown on Figures 6a and b. It is interesting to note that if departure is made between -98° and -70° both Type I and II transfers are possible, i.e., the quartics produce four real roots.

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* Like on interplanetary missions Type I trajectories have less than 180° transfer angles. Type II trajectories have more than 180° transfer angles.

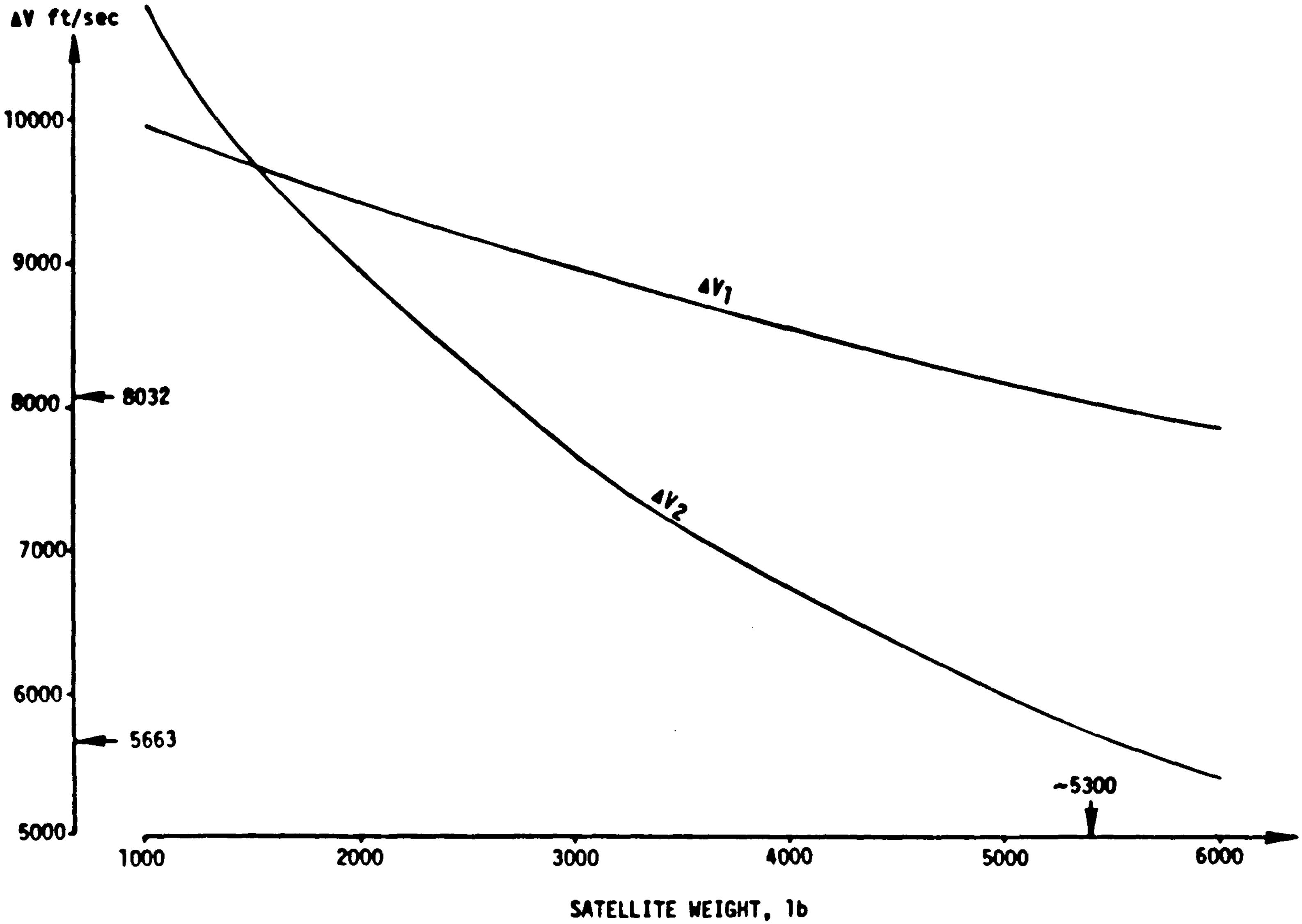
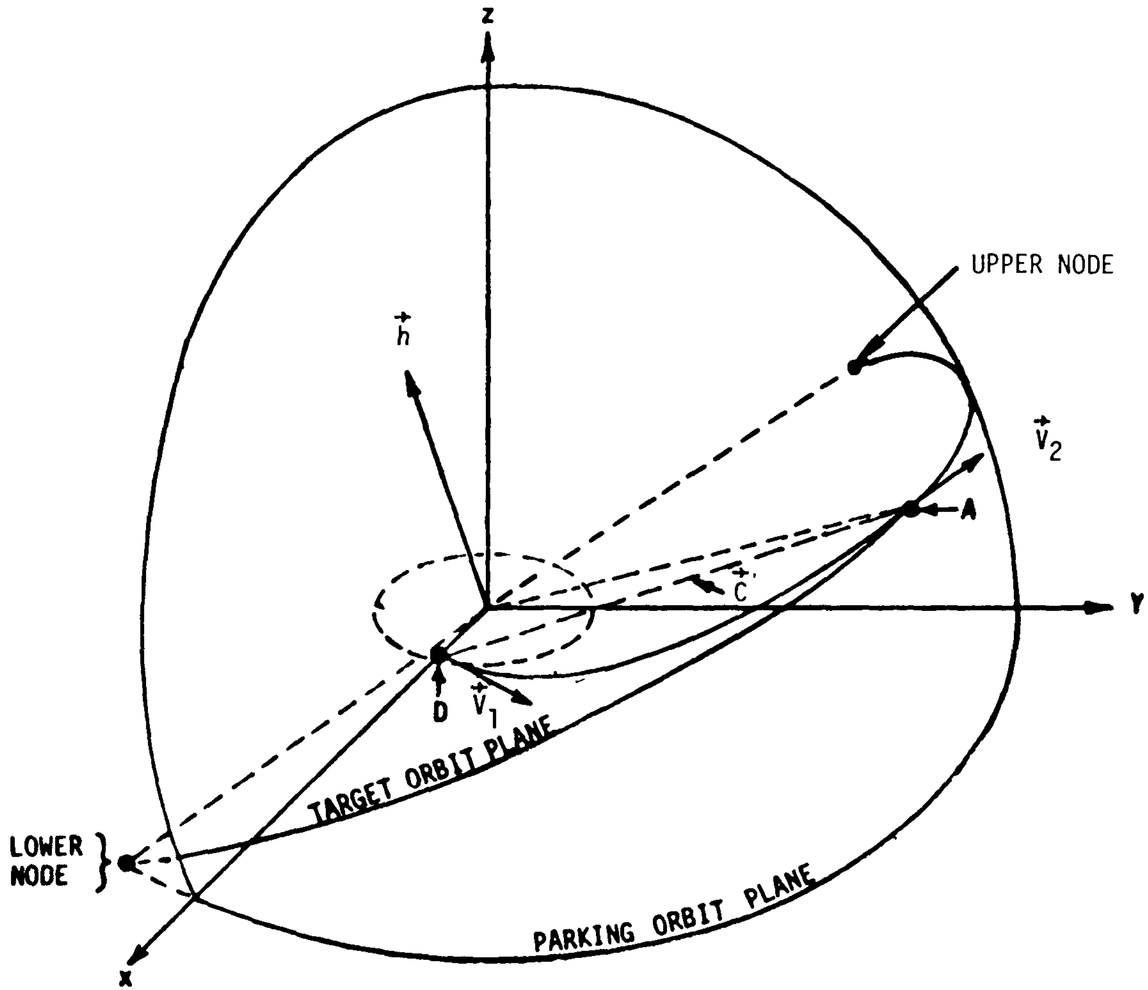


FIGURE 1. IUS PERFORMANCE



$$(\Delta V^2) = A^2h^2 - 2A(\gamma_1 V_R + \gamma_2 V_T)h + (V_R^2 + V_T^2 + 2q\gamma_1 AB) - 2qBV_R/h + B^2/h^2$$

for ΔV_1: $q = +1,\ (V_R, V_T, \gamma_1)_p$ for ΔV_2: $q = -1,\ (V_R, V_T, \gamma_1)_t$

FIGURE 2. METHOD OF SOLUTION

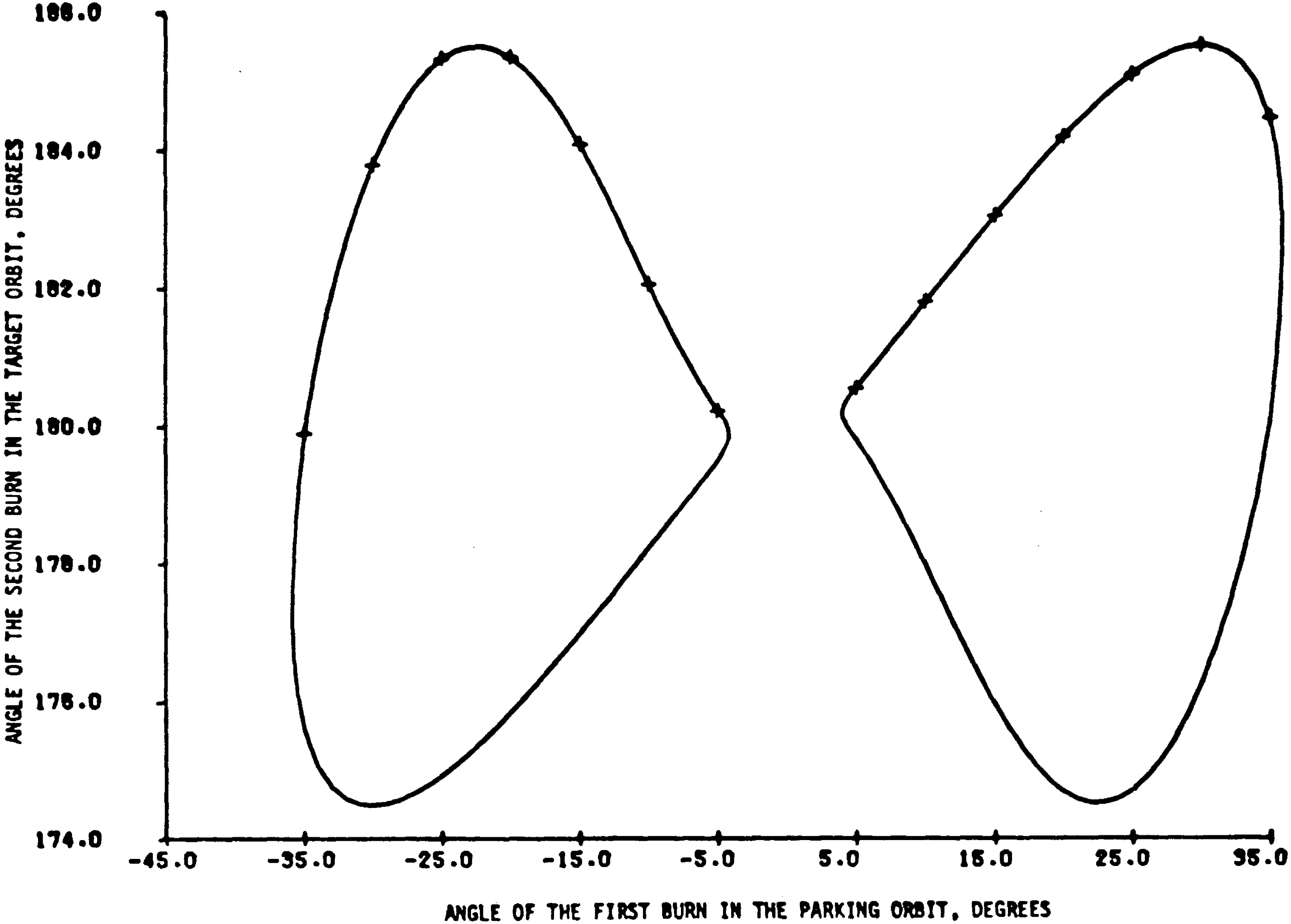


FIGURE 3a. TRANSFER TO A 24 HOUR ORBIT.
$i = 0$, $e = 0$

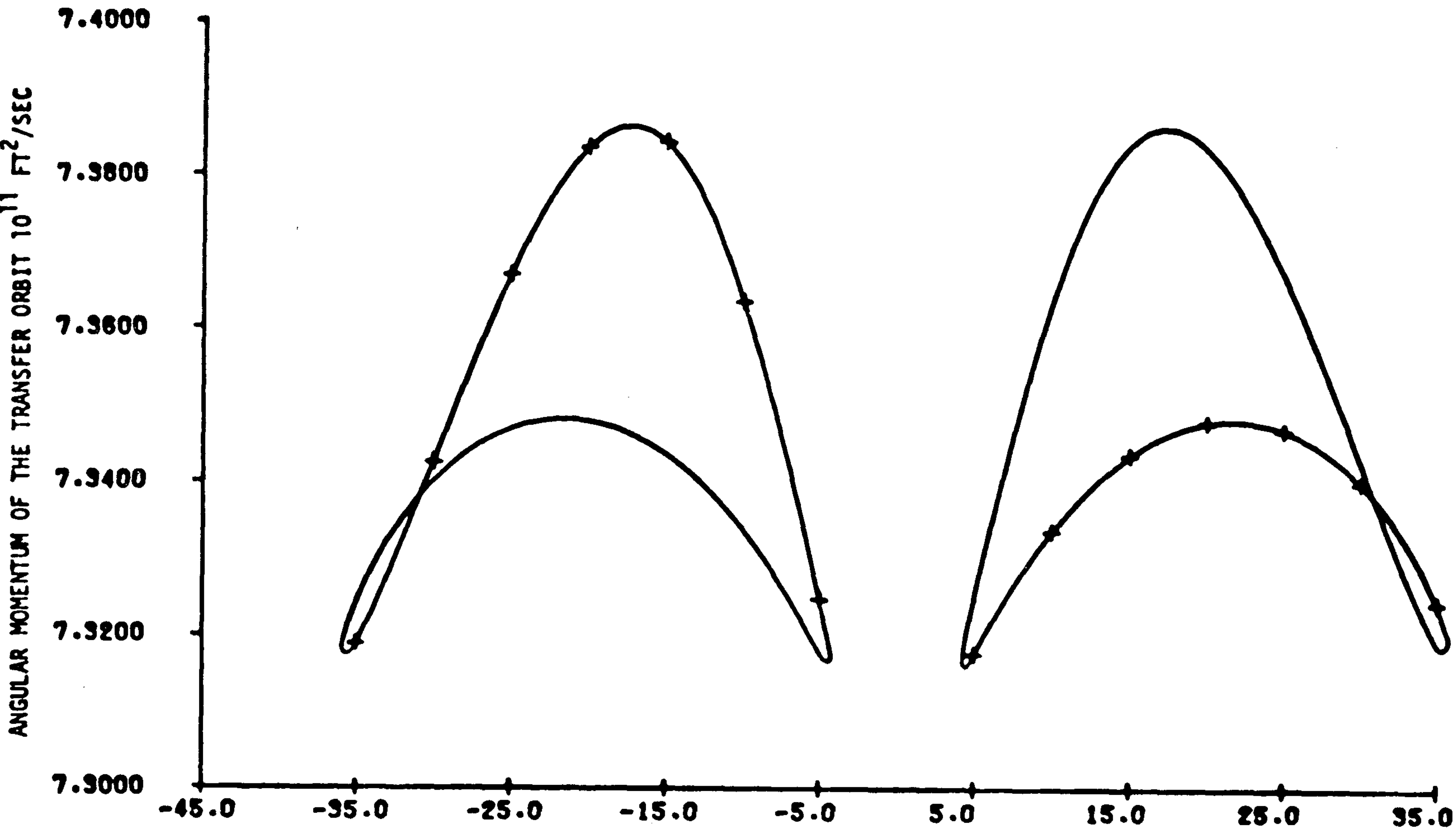


FIGURE 3b. ANGULAR MOMENTUM OF THE TRANSFER ORBIT

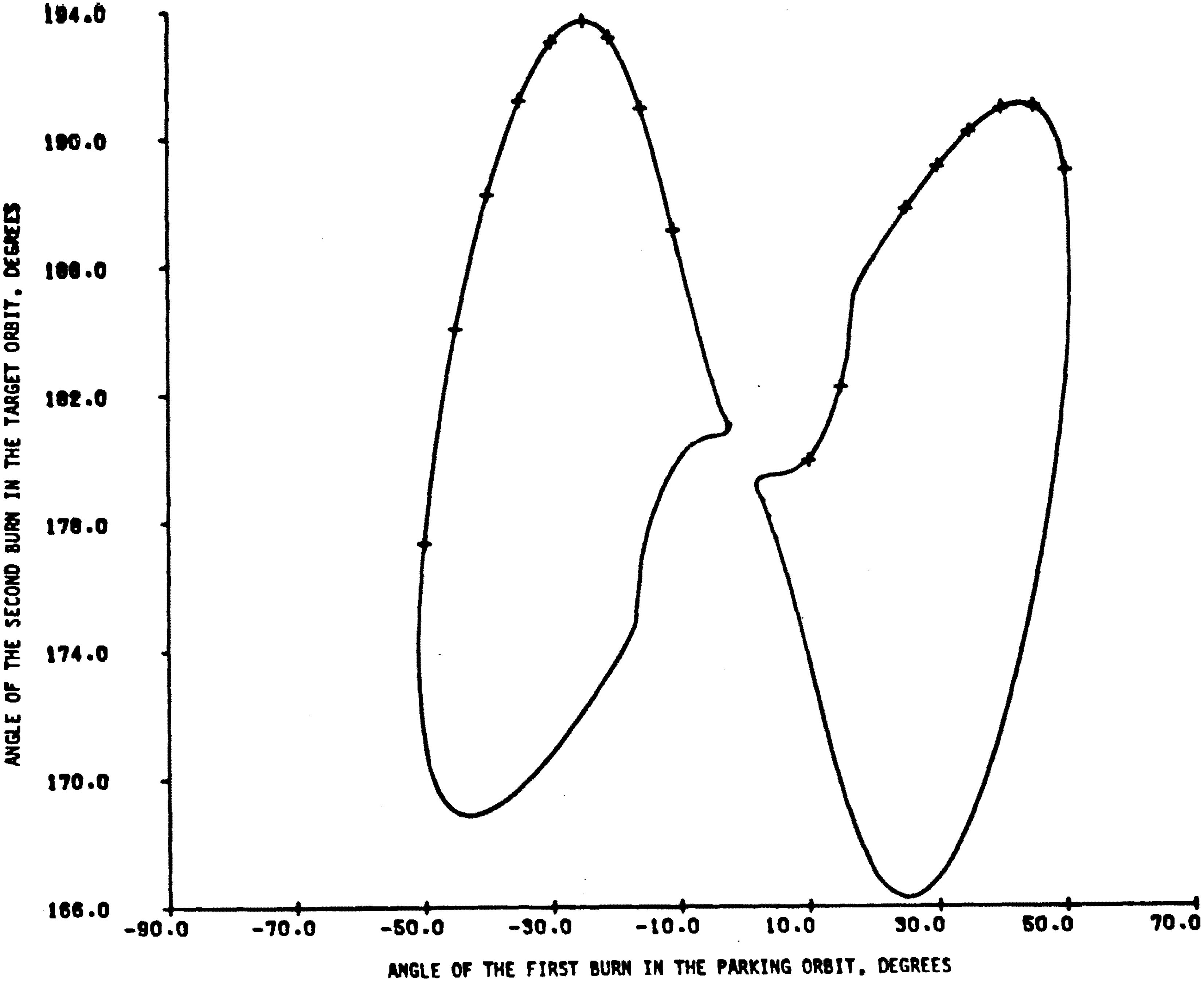


FIGURE 4a. TRANSFER TO A 12 HOUR CIRCULAR ORBIT
$i = 63°$, $e = 0$

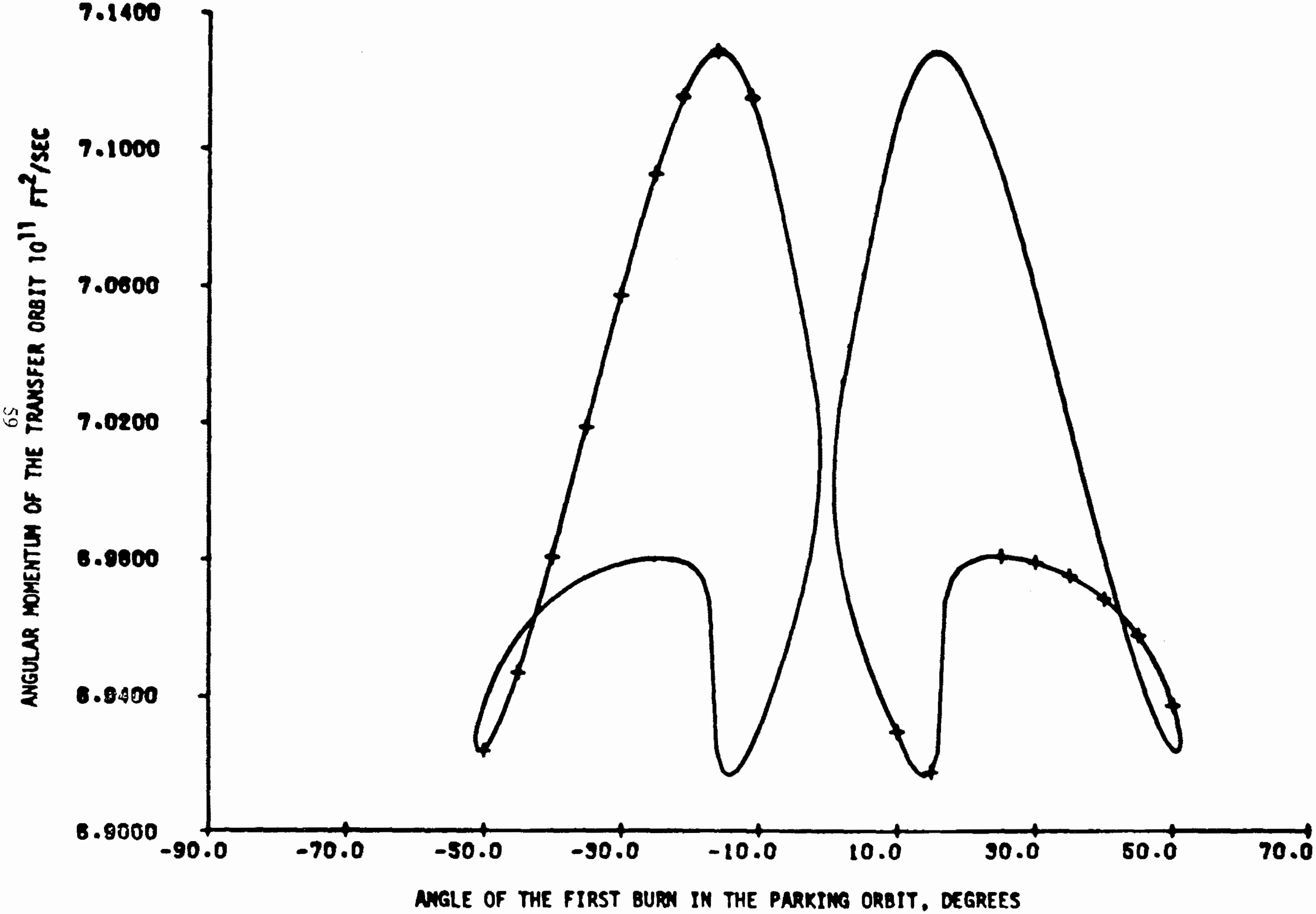


FIGURE 4b. ANGULAR MOMENTUM OF THE TRANSFER ORBIT

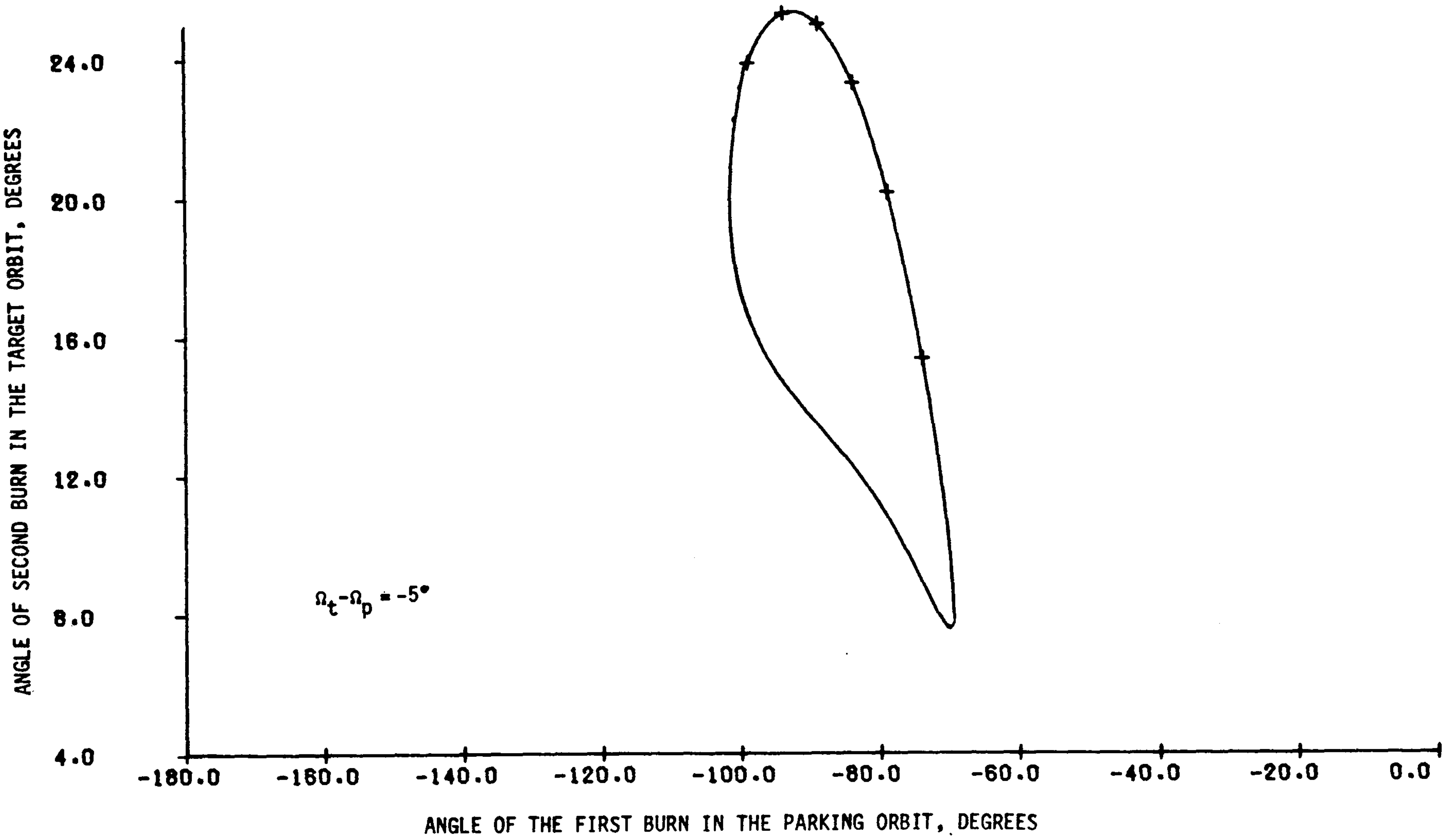


FIGURE 5a. TYPE I TRANSFER TO A 12 HOUR ECCENTRIC ORBIT

$i = 63°$ $h_p = 150$ nmi $h_a = 21390$ mi

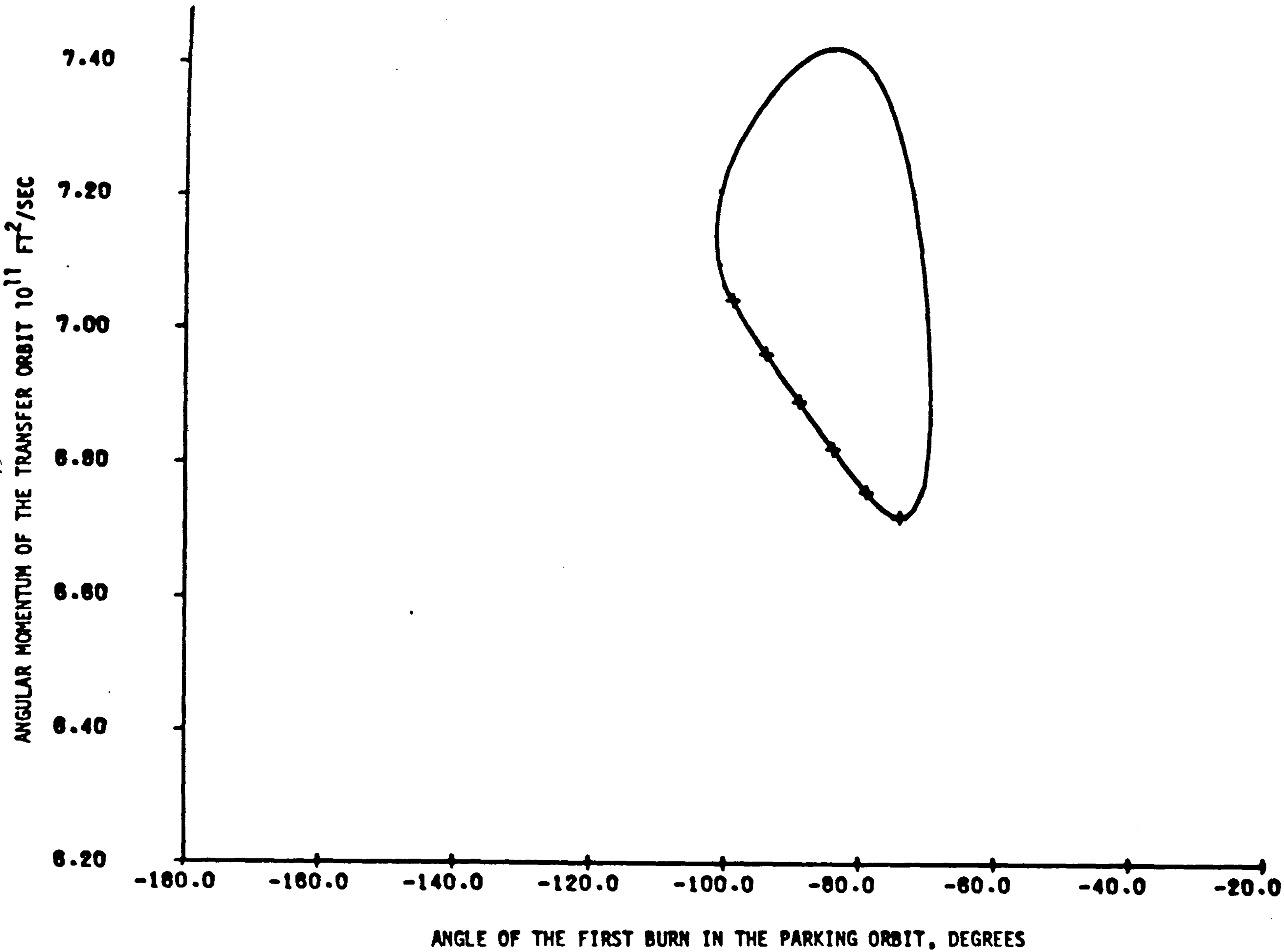


FIGURE 5b. ANGULAR MOMENTUM OF THE TRANSFER ORBIT

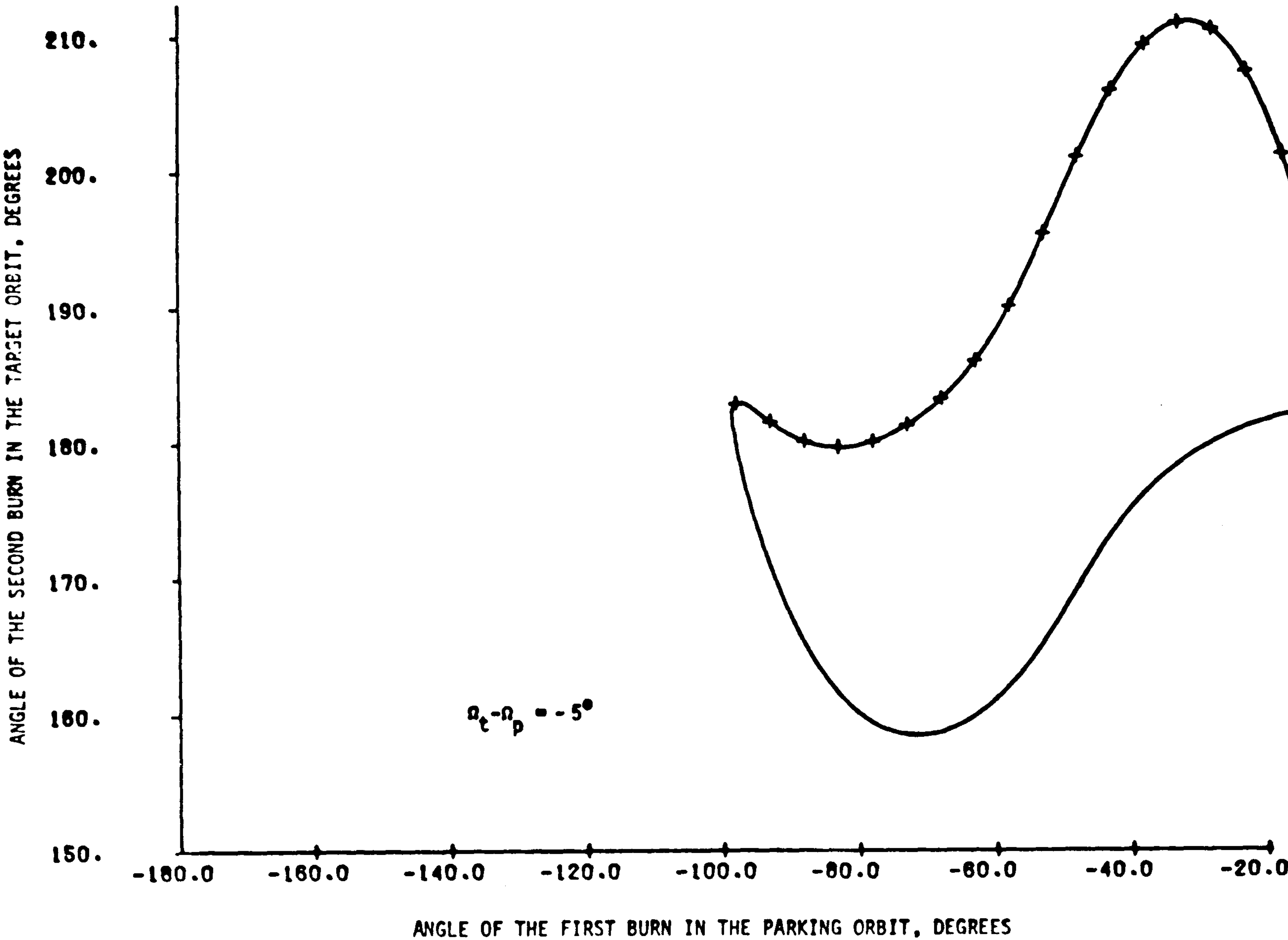


FIGURE 6a. TYPE II TRANSFER TO A 12 HOUR ECCENTRIC ORBIT

$i = 63°$ $h_p = 150$ nmi $h_a = 21390$ nmi

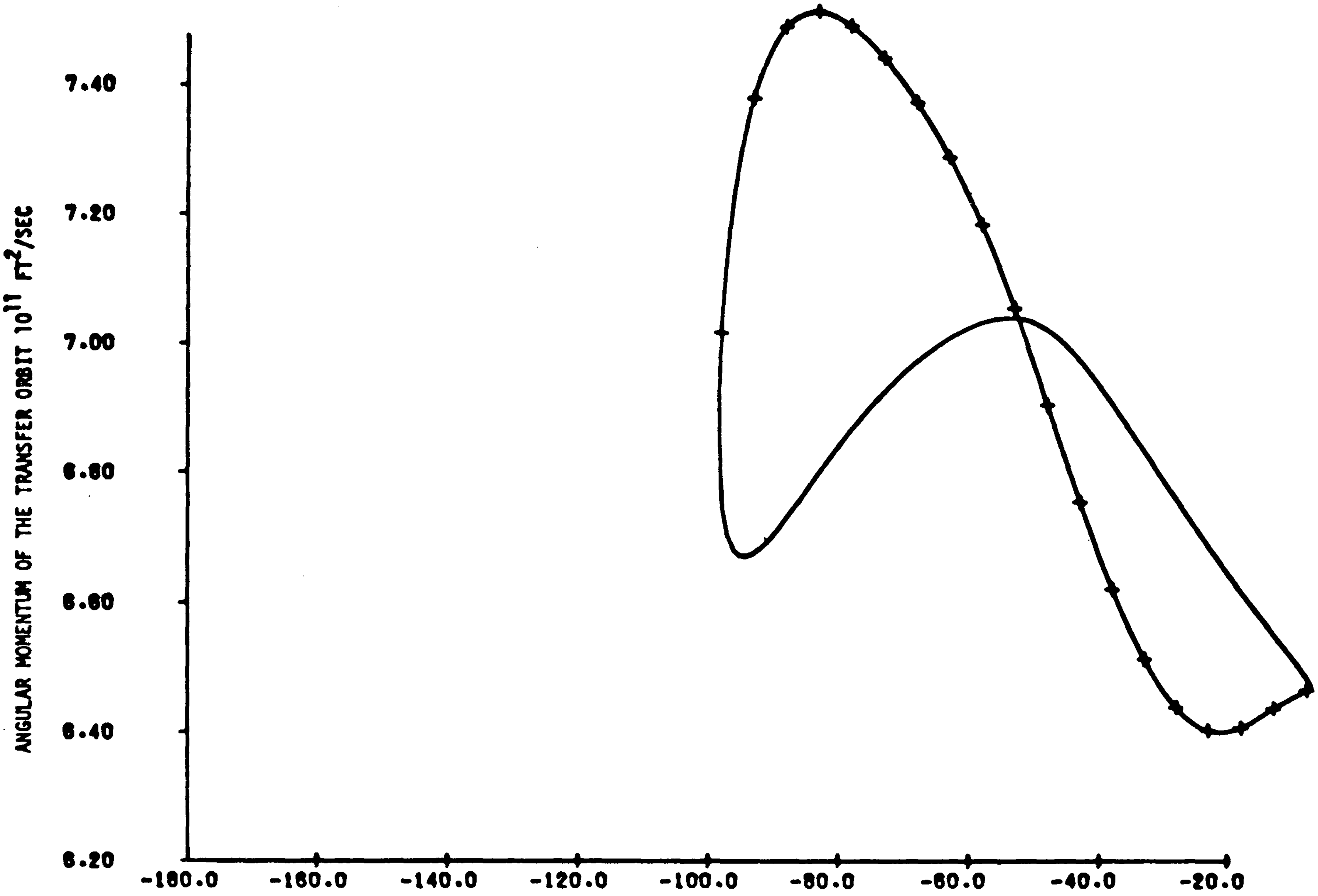


FIGURE 6b. ANGULAR MOMENTUM OF THE TRANSFER ORBIT