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FEASIBILITY OF MANUAL COMPLETION OF A LOI BURN VOLUME II- BMAG DRIFT ABOUT THE PITCH AXIS

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Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

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FIGURES

FEASIBILITY OF MANUAL COMPLETION OF A LOI BURN

VOLUME II - BMAG DRIFT ABOUT THE PITCH AXIS

By Alexander H. Treadway

SUMMARY

This volume is the second of two studies investigating the feasibility of manually completing the LOI burn. Volume I showed the feasibility of manually completing the LOI burn if the IMU is drifting about its pitch axis.

This volume investigates the BMAGS drifting about its pitch axis. Manual completion was made with a non-G&N-controlled burn at a constant inertial attitude relative to the BMAGS drifting about its pitch axis. This type of drift is the one most likely to result in a lunar impact.

The results show that manual completion for the BMAGS drifting about the pitch axis is feasible. The lowest pericynthion altitudes at the end of manual completion occur for positive delta pitches (the algebraic difference between the BMAG FDAI and IMU FDAI at a given instant in the LOI burn). The low pericynthions are caused by the BMAG subsystem drifting with a negative rate. The vehicle will be prepericynthion for a negative drift rate. For a delta pitch between $\pm 10^\circ$, the total burn time, i.e., the guided portion plus manual portion, will have to be reduced from the nominal burn time of 383 seconds. A total burn of 290 seconds or less will guarantee a pericynthion altitude of 30 n. mi. or greater. For delta pitches between $\pm 5^\circ$, a total burn time of 330 seconds will give the same results.

INTRODUCTION

In volume I the feasibility of manually completing the LOI burn if the IMU is drifting about its pitch axis was presented. The procedure used was to complete the LOI burn with a manual non-G&N-controlled burn at a constant inertial attitude. This procedure was employed when a deviation between the FDAI driven by the IMU and the FDAI driven by the

BMAGS occurred. However, a deviation between the systems can be precipitated by either the IMU drifting or by the BMAGS drifting.

Since this is true, it is possible to make a wrong choice for the drifting system. The assumption of the investigation is that a wrong choice is made; namely, that the IMU is drifting. The LOI burn is then completed manually with a drifting BMAG system. The BMAG system is used for the constant inertial attitude reference. The purpose of volume II is to determine the feasibility of manually completing the LOI burn if the BMAGS is drifting about its pitch axis. A pitch drift is the one most likely to result in a lunar impact.

SYMBOLS

BMAGS	body-mounted attitude gyro subsystem
FDAI	flight director's attitude indicator
G&N	guidance and navigation
IMU	inertial measurement unit
LM	lunar module
LOI	lunar orbit insertion
PGNCS	primary guidance, navigation, and control subsystem
SPS	service propulsion system
h_{ac}	apocynthion altitude
h_{pc}	pericynthion altitude

METHOD

The nominal LOI maneuver of the preliminary spacecraft reference trajectory (ref. 1) which is used for the study, consists of 383-second SPS burn that reduces the incoming escape hyperbola to an 80-n. mi.

circular orbit. The inertial plane containing the landing site at the time of the lunar module (LM) landing (approximately 9 hours after LOI) provides the targeting condition for the LOI circularization guidance. The IMU and BMAG coordinate systems are collinear at burn initiation and have the following alignment: X-axis along the initial guidance-computed thrust direction, Y-axis perpendicular to the plane formed by the X-axis and the radius vector, and Z-axis completing a right-handed coordinate system (ref. 2). A positive rotation obeys the right-hand rule. The parameter delta pitch, $\Delta\alpha$, is the algebraic difference between the BMAG pitch and the IMU pitch at a given instant of the LOI burn. For the IMU drifting about its pitch axis, $\Delta\alpha$ is related to the drift rate by the equation,

$$\Delta\alpha = (\text{IMU drift rate}) \times (\text{LOI burn time}). \qquad (1)$$

However, $\Delta\alpha$ can also be obtained from the equation

$$\Delta\alpha = -(\text{BMAG drift rate}) \times (\text{LOI burn time}). \qquad (2)$$

The minus sign comes from the fact that the BMAGS must rotate in the opposite direction as the IMU to have identical $\Delta\alpha$'s. Both equations are based on the assumptions used in the study that drift begins at burn initiation. Solving (2) for the BMAG drift rate gives

$$\text{drift rate} = \frac{-\Delta\alpha}{\text{LOI burn-time}} \qquad (3)$$

For this study a nominal LOI burn is made until a preselected burn time is reached. This burn time is used in (3) to compute the associated drift rate for a given $\Delta\alpha$. The LOI burn is then completed holding the attitude constant relative to the drifting BMAGS. The total length of the burn, i.e., the guided portion plus the manual portion, is constant. This constant is varied from 260 seconds to 383 seconds, the nominal LOI burn time. The $\Delta\alpha$'s used for the study are $\pm 5°$ and $\pm 10°$, which were chosen so the results could be compared to volume I. Weights and SPS performance are the same as those in reference 2.

RESULTS

The nominal LOI pitch time history is approximately linear with a constant pitch rate of 0.0375 deg/sec (ref. 2). At nominal burnout the vehicle is in an 80-n. mi. circular orbit. Therefore, if the BMAGS are drifting with a rate less than 0.0375 deg/sec during manual completion, the vehicle will always be prepericynthion and $\Delta\alpha$ will be negative. Drift rates greater than 0.0375 deg/sec will not necessarily guarantee the vehicle to be postpericynthion unless the total burn time is 383 seconds.

The resulting $\Delta\alpha$ will be positive. Being postpericynthion is a function of when takeover occurs, the drift rate, and the length of the burn. For the shortest total burn time presented (260 seconds), a rate of 0.1 deg/sec at a takeover time of 50 seconds is necessary.

The h_{pc} and h_{ac} at the end of manual completion as a function of LOI burn time at crew takeover is presented in figures 1 and 2, respectively. Note that it is a positive $\Delta\alpha$ which results in the lowest h_{pc}. This is because the BMAGS have a negative drift rate which lowers pericynthion ahead of the vehicle. For a $\Delta\alpha$ of 5° and a takeover time of 50 seconds, h_{pc} can be as low as -34 n. mi. at the end of manual completion. Increasing $\Delta\alpha$ to 10° at this takeover time could reduce h_{pc} to almost -50 n. mi. The rates involved are -0.1 and -0.2 deg/sec, respectively. In order to assure a safe h_{pc} of around 30 n. mi. at the end of manual completion for such rates in the early part of the burn region, the total burn would have to be reduced to around 290 seconds or lower. If takeover occurs after 180 seconds of LOI burn time for $\Delta\alpha$ of 10°, any total burn time guarantees an h_{pc} of 30 n. mi. or greater. In the region where h_{pc} is less than 30 n. mi. for negative $\Delta\alpha$'s the vehicle is postpericynthion. Reducing the total burn time in this region to 350 seconds or lower increases h_{pc} to 30 n. mi. or greater.

Positive $\Delta\alpha$'s result in higher h_{ac}'s than negative $\Delta\alpha$'s (fig. 2). This is due to a rotation of the line of apsides ahead of the vehicle. Due to size of the drift rates prior to 140-seconds takeover time for the $\Delta\alpha$'s presented, there is a rapid change in the slope of the h_{ac} curves from vertical to horizontal. After 140 seconds they are approximately level. Reducing the total burn time to 260 seconds for the worse case shown, $\Delta\alpha = 10°$ at a takeover time of 50 seconds will result in a 50- by 2650-n. mi. orbit, which is a stable, non-impacting ellipse. No data has been presented prior to 50 seconds because of the higher drift rates necessary to obtain the $\Delta\alpha$'s used. The rates are on the order of 0.5 deg/sec to 1 deg/sec.

CONCLUSIONS

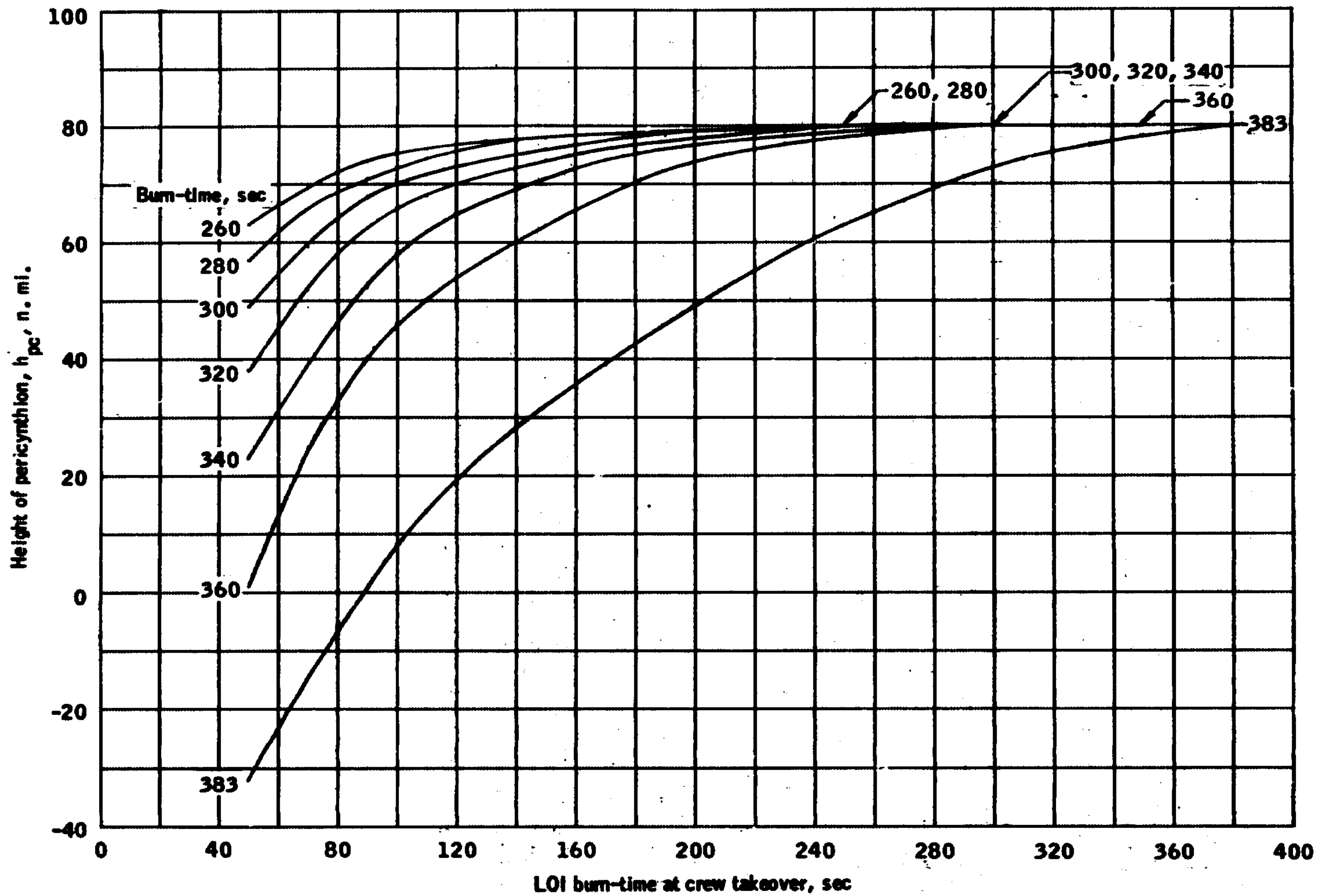
Under the assumptions of volume II, manual completion of the LOI burn is feasible for a BMAG drift about its pitch axis. The assumptions are (1) manual completion is a non-G&N-controlled burn at a constant inertial attitude relative to the BMAGS, (2) BMAG drift begins at burn initiation, (3) IMU is not drifting, (4) LOI circularization guidance is targeted for 80 n. mi., and (5) weights and SPS performance are nominal (ref. 1).

For positive $\Delta\alpha$'s the vehicle will be prepericynthion at the end of manual completion. This is due to the fact that the BMAG drift rate is negative. If manual completion is initiated early in the LOI burn with a $\Delta\alpha$ of 5° or greater and a long total burn time, i.e., the guided position plus the manual position, an unsafe h_{pc} will result. Reducing the total burn time to 290 seconds will guarantee an h_{pc} of 30 n. mi. or greater for $\Delta\alpha$ of 10° or less.

For negative $\Delta\alpha$'s being pre- or postpericynthion depends upon the burn time at crew takeover, BMAG drift rate, and total burn time. The drift rate will have to be greater than 0.0375 deg/sec which is the nominal pitch rate. In the regions of the burn where h_{pc} is less than 30 n. mi. the vehicle is postpericynthion. In the region where the vehicle is prepericynthion, h_{pc} is greater than 30 n. mi. Reducing the total burn time to 350 seconds or less in the unsafe h_{pc} region will increase h_{pc} to 30 n. mi. or greater.

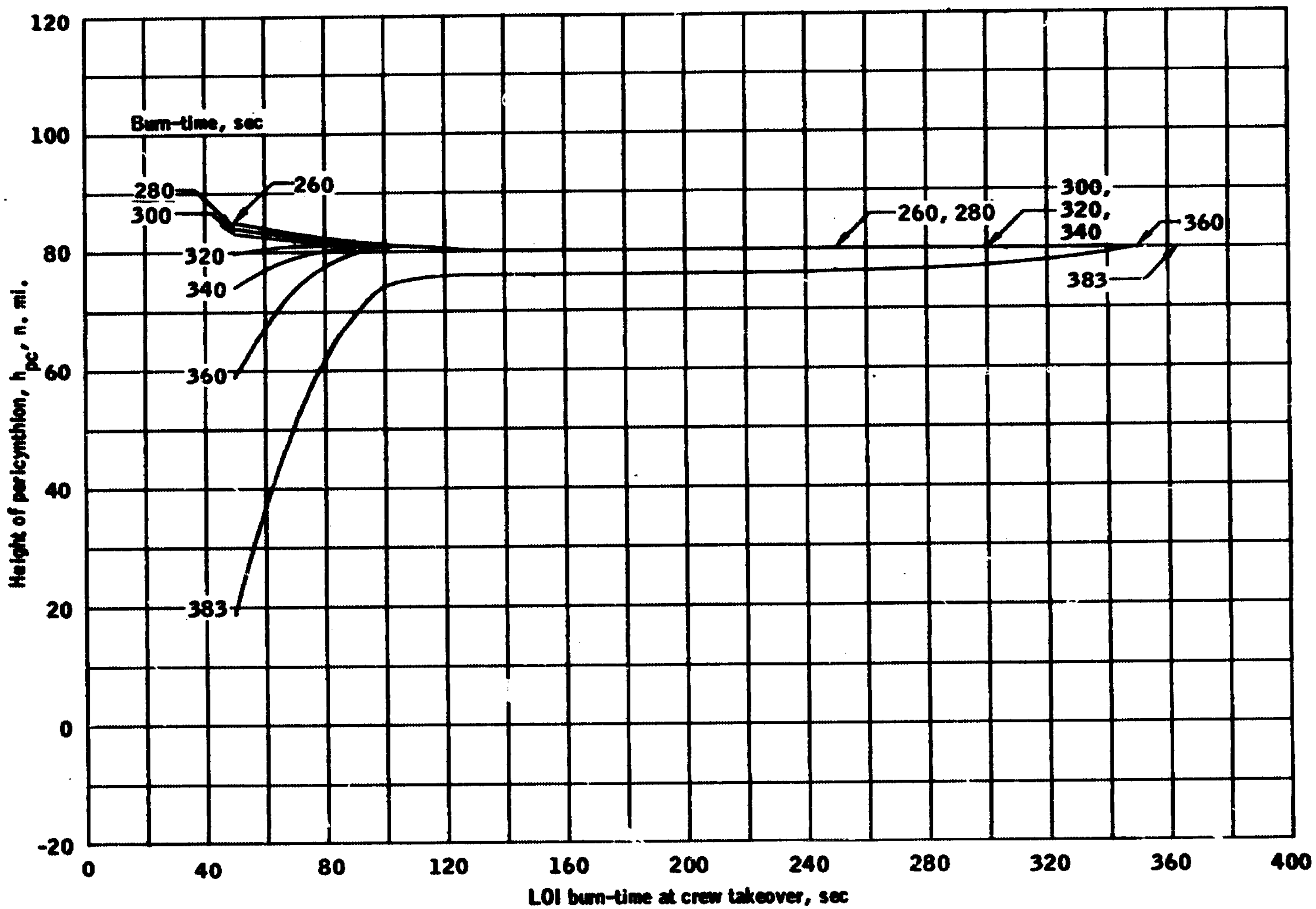
A total burn time of 290 seconds or less will therefore guarantee a h_{pc} of 30 n. mi. or greater for the $\Delta\alpha$ region between $\pm 10^\circ$. A stable, non-impacting ellipse still results with a total burn time of 260 seconds.

Since the initiation of volumes I and II, a new LOI procedure has been developed consisting of two burns. The first places the vehicle into a 60- by 170-n. mi. ellipse with a variable line of apsides and the second circularizes to 60 n. mi. Studies are being inititated to extend the results presented in volumes I and II to this new LOI procedure.



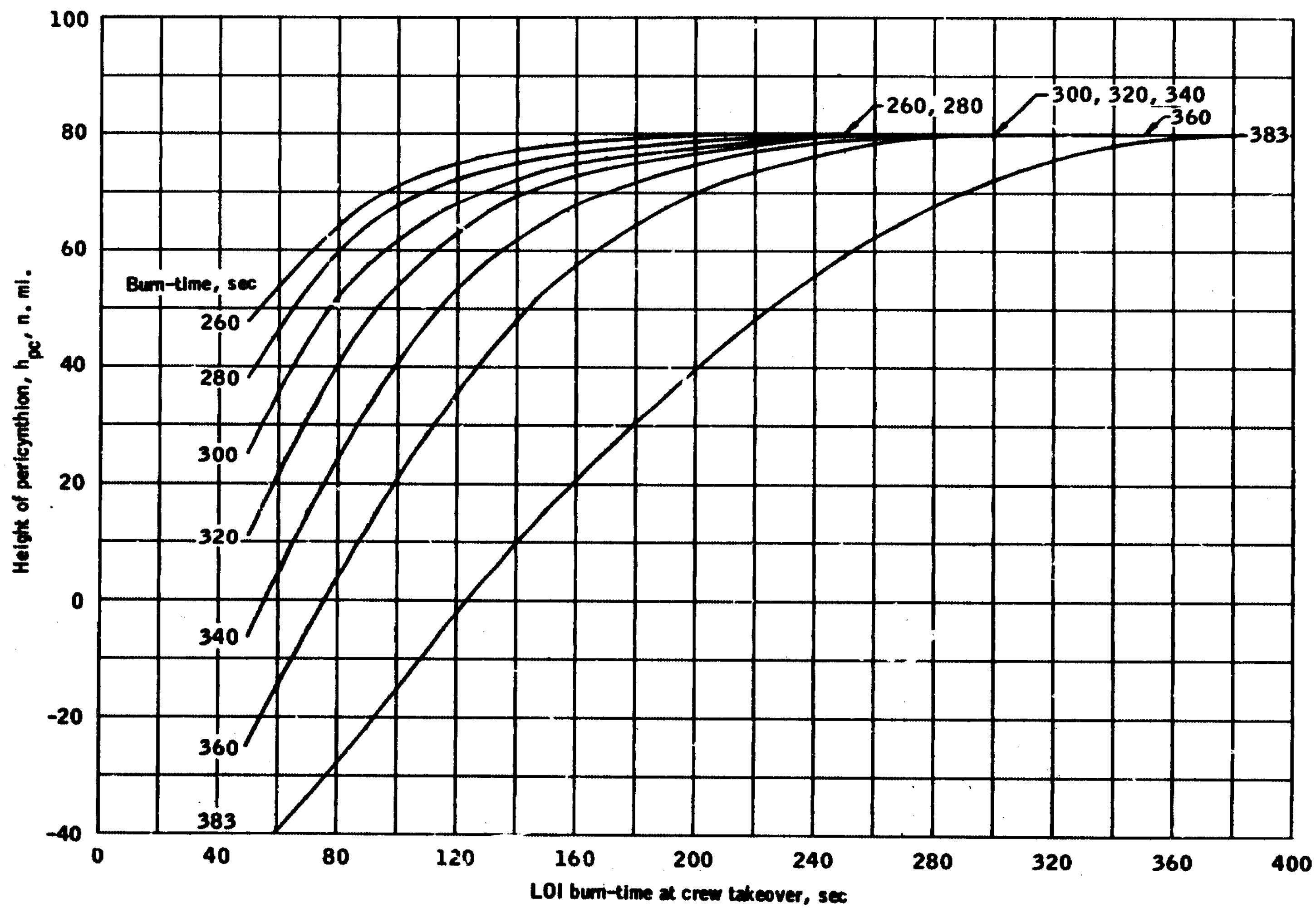
(a) $\Delta\alpha = 5$ degrees.

Figure 1.- Heights of pericynthion at the end of manual completion for various LOI burn times.



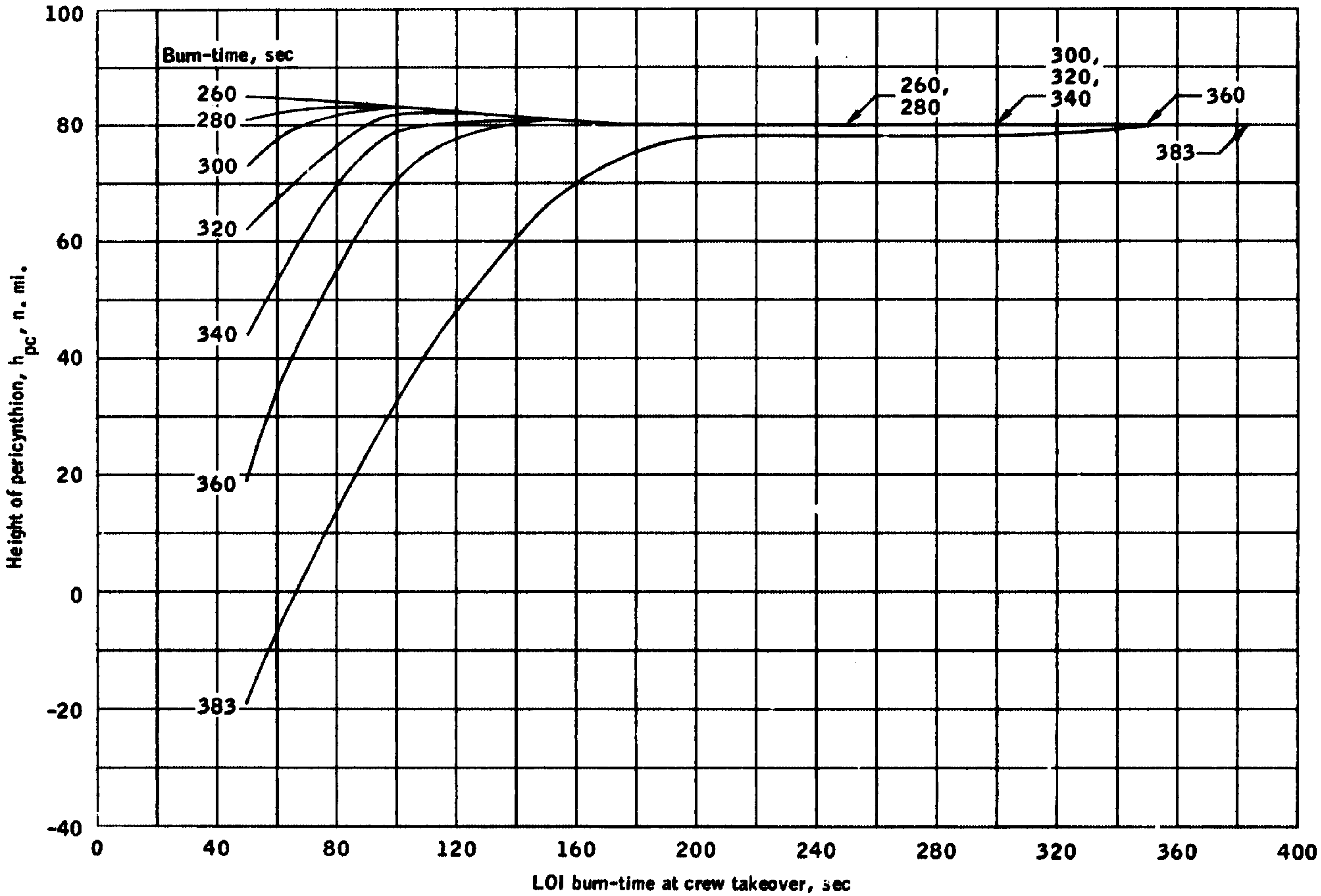
(b) $\Delta\alpha = -5$ degrees.

Figure 1.- Continued.



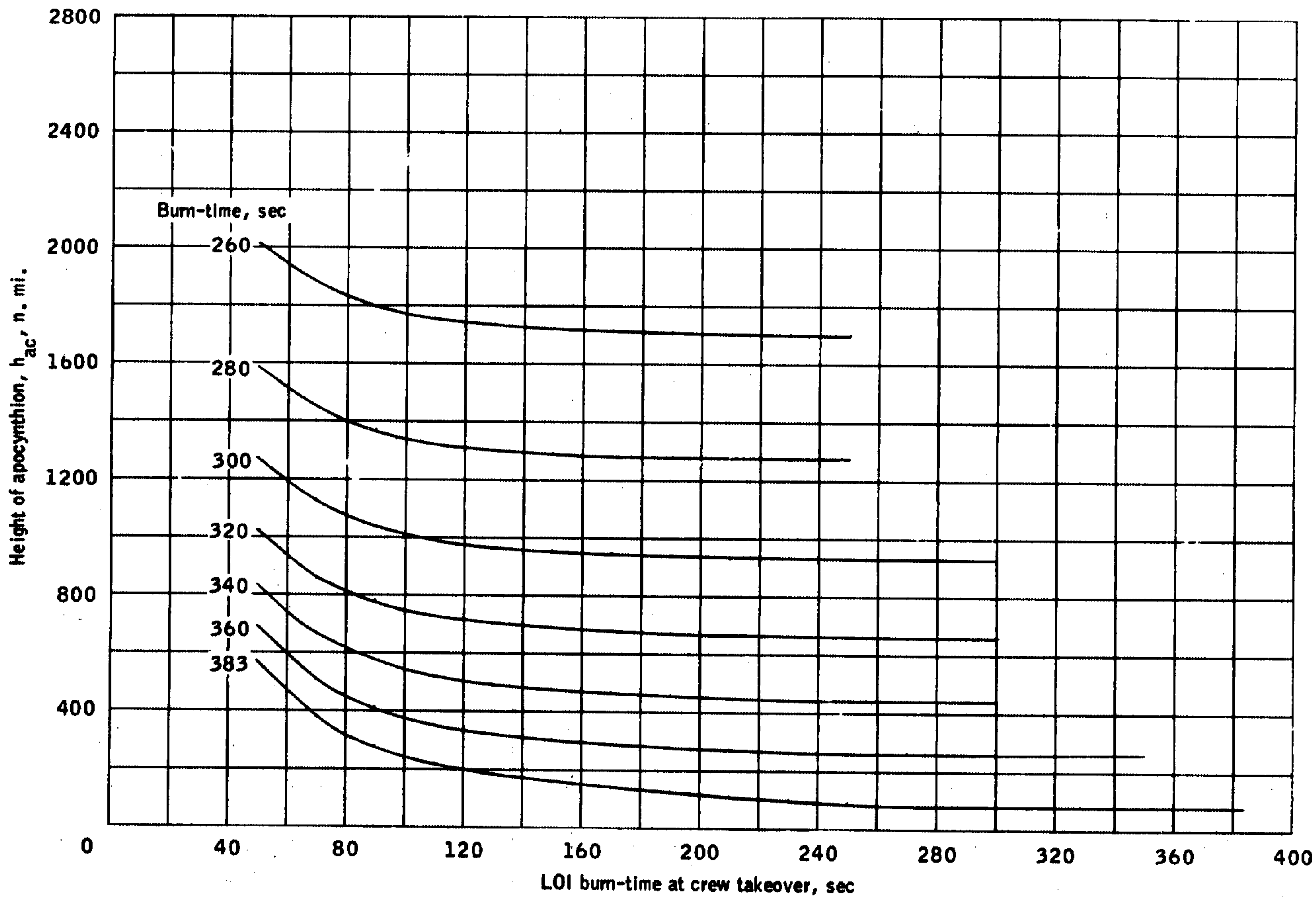
(c) $\Delta\alpha = 10$ degrees.

Figure 1.- Continued.



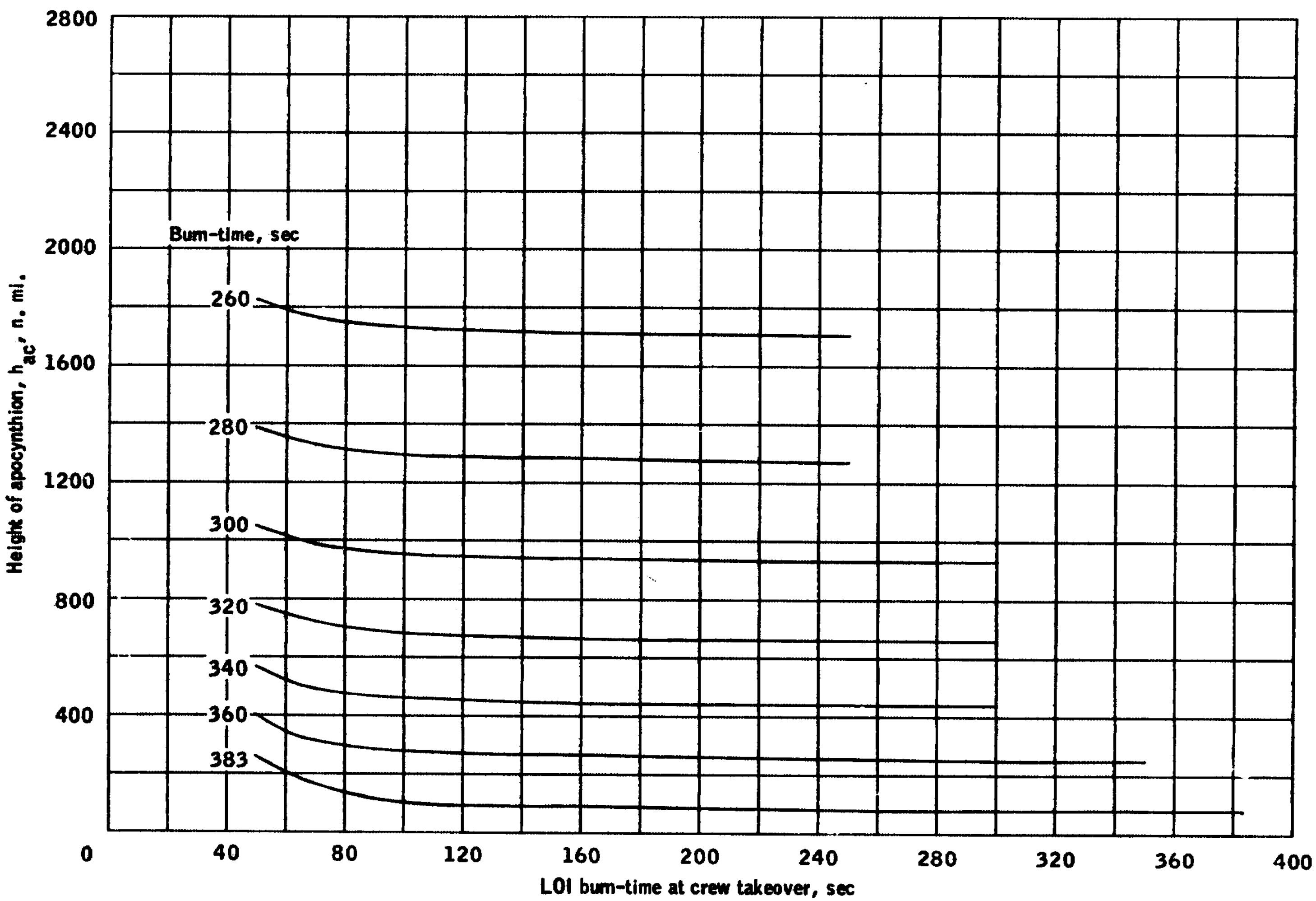
(d) $\Delta\alpha$ = -10 degrees.

Figure 1.- Concluded.



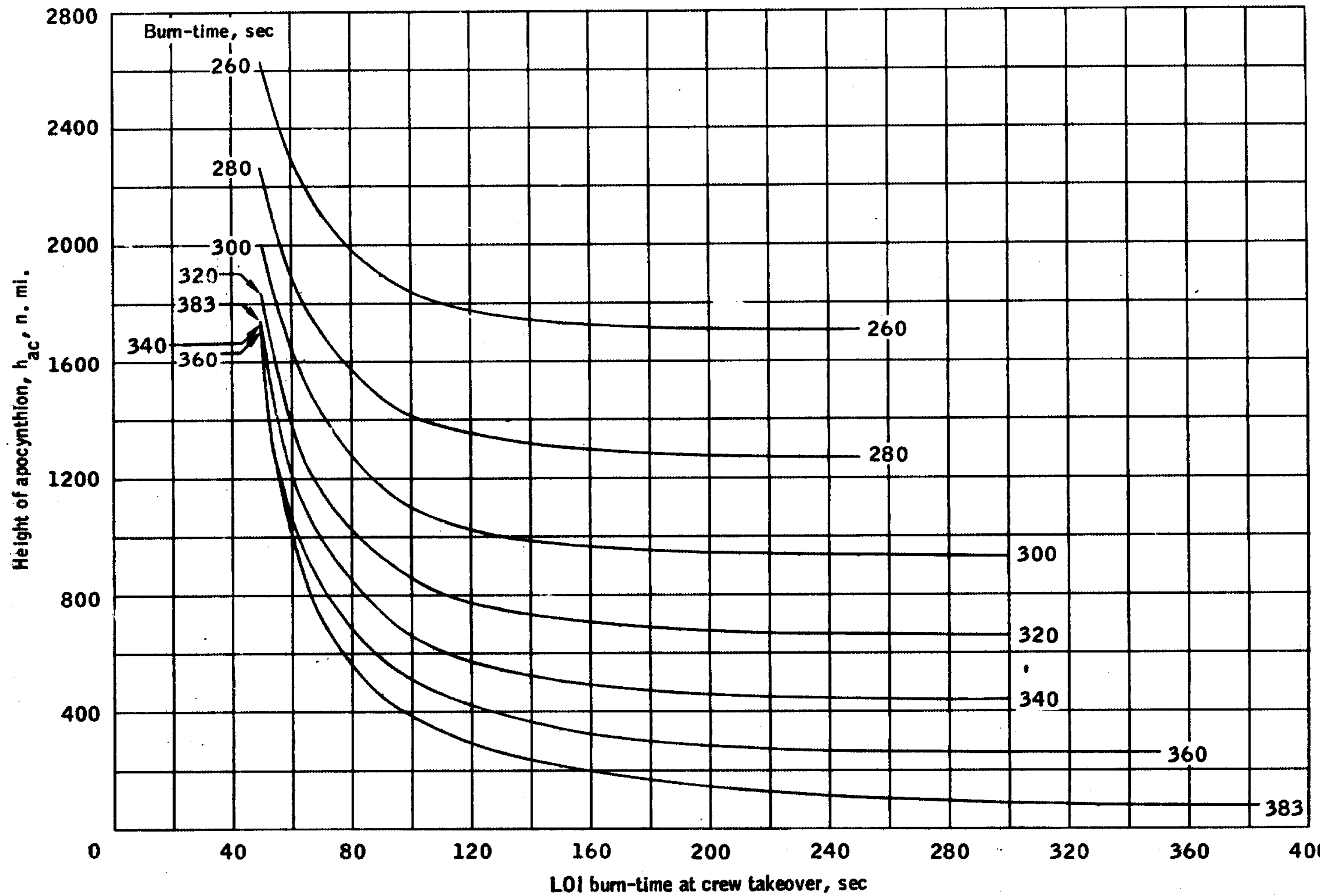
(a) $\Delta\alpha$ = 5 degrees.

Figure 2.- Heights of apocynthion at the end of manual completion for various LOI burn times.



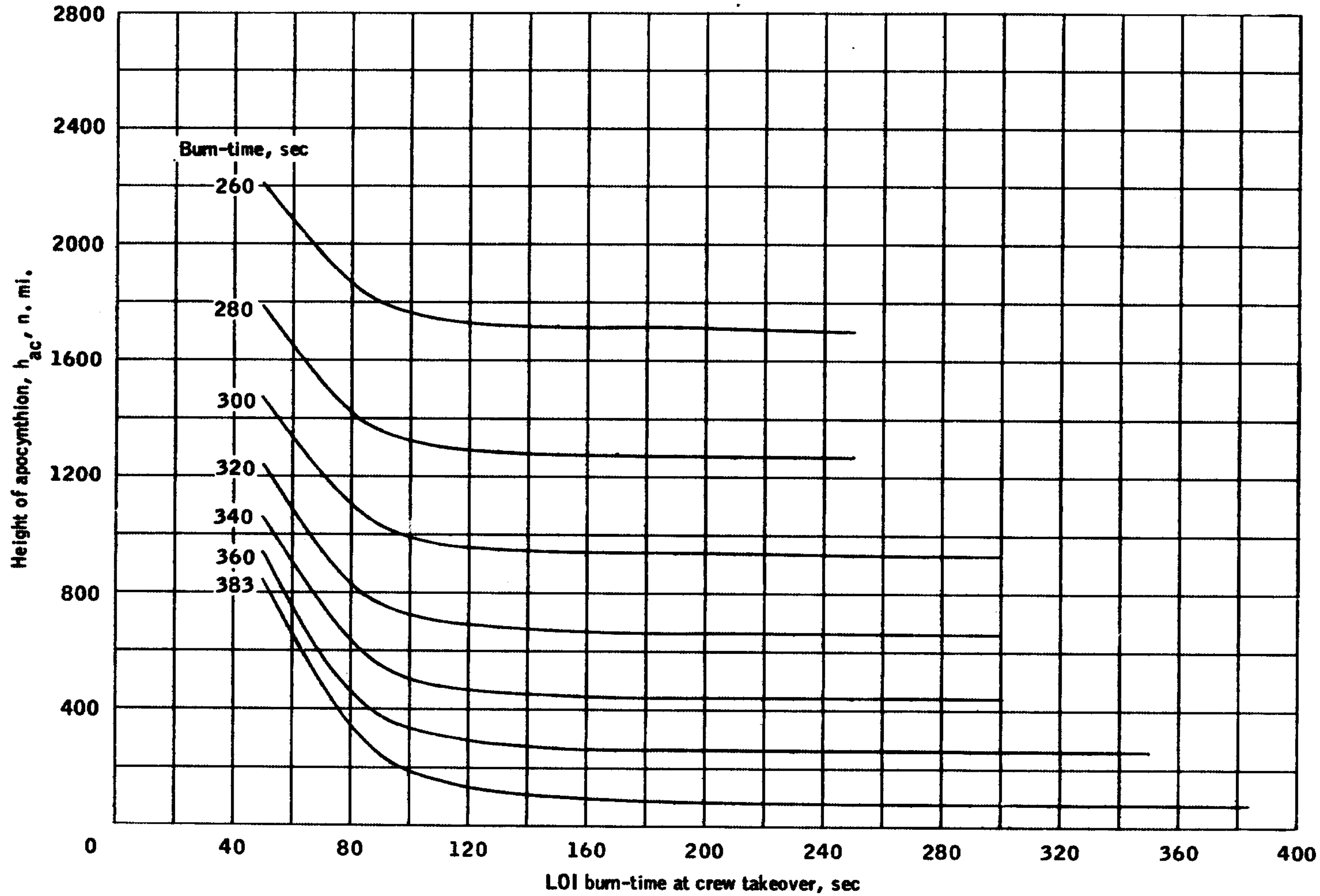
(b) $\Delta\alpha = -5$ degrees.

Figure 2.- Continued.



(c) $\Delta\alpha = 10$ degrees.

Figure 2.- Continued.



(d) $\Delta\alpha = -10$ degrees.

Figure 2.- Concluded.

REFERENCES

1. Mission Analysis Branch: AS-504A Preliminary Spacecraft References Trajectory (U). MSC IN 66-FM-70, July 1, 1966 (Confidential).

2. Treadway, Alexander H.: Feasibility of Manual Completion of a LOI Burn, Volume I - IMU Drift about the Pitch Axis. MSC IN 67-FM-173, November 15, 1967.