(130)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 68-FM-113

May 9, 1968

THE EFFECTS OF IU PLATFORM PITCH DRIFT RATES ON TLI FOR THE LUNAR LANDING MISSION

By Alexander Treadway,
Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

MSC INTERNAL NOTE NO. 68-FM-113

PROJECT APOLLO

THE EFFECTS OF IU PLATFORM PITCH DRIFT RATES ON TLI FOR THE LUNAR LANDING MISSION

By Alexander Treadway
Flight Analysis Branch

May 9, 1968

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Approved: Charlie C. Allen
for C. R. Hicks, Jr., Chief
Flight Analysis Branch

Approved: R P Parten for
John P. Mayer, Chief
Mission Planning and Analysis Division

PRECEDING PAGE BLANK NOT FILMED.

CONTENTS

Section	Page
SUMMARY	1
INTRODUCTION	1
SYMBOLS	2
ANALYSIS AND RESULTS	2
CONCLUSIONS	6
REFERENCES	21

FIGURES

Figure		Page
1	Time history of osculating perigee altitude for various IU pitch drift rates	
	(a) $0 \leq t_b \leq 320$ seconds.	7
	(b) $304 \leq t_b \leq 328.4$ seconds.	8
2	Time history of osculating apogee altitude for various IU pitch drift rates	
	(a) $0 \leq t_b \leq 320$ seconds.	9
	(b) $304 \leq t_b \leq 328.4$ seconds.	10
3	Osculating perigee altitude at TLI cutoff as a function of IU pitch drift rate.	11
4	Osculating apogee altitude at TLI cutoff as a function of IU pitch drift rate.	12
5	Time history of altitude for IU drift rates of 0 degrees and ± .2 degrees per second.	13
6	Time history of the argument of perigee for various IU pitch drift rates	14
7	Rotation of the line of apsides and true anomaly as a function of IU pitch drift rate	15
8	Osculating apogee altitude at TLI cutoff as a function of the relative rotation of the line of apsides	16
9	Time history of osculating perigee altitude for various IU pitch misalignments	
	(a) $0 \leq t_b \leq 320$ seconds.	17
	(b) $304 \leq t_b \leq 328.4$ seconds.	18
10	Time history of osculating apogee altitude for various IU pitch misalignments	
	(a) $0 \leq t_b \leq 320$ seconds	19
	(b) $304 \leq t_b \leq 328.4$ seconds	20

THE EFFECTS OF IU PLATFORM PITCH DRIFT RATES ON TLI FOR THE LUNAR LANDING MISSION

By Alexander Treadway

SUMMARY

Since TLI for the lunar landing mission may be performed without tracking, the crew must have limits for the values displayed onboard in order to evaluate the progress of the burn and, hence, to determine what procedure to follow if a limit is violated. The purpose of this internal note is to present data used in determining the 15° attitude deviation limit recommended as a TLI shutdown criteria. The data is based on an IU platform drifting about its pitch axis. This type of drift is the one most likely to result in a crew safety problem.

The study shows that, for the IU platform drifting about its pitch axis for the lunar landing mission, (1) a crew safety problem does not exist within the recommended 15° attitude deviation limits, and (2) a positive drift rate produces the worst trajectory effects.

For two pitch drift rates of equal magnitude but opposite sign, the positive drift rate results in a lower apogee altitude and rotates the line of apsides in a negative direction from the nominal orientation. Since the nominal orientation places the vehicle on the correct trajectory, the trajectory resulting from a positive pitch drift rate will trail the moon for pitch drift rates large enough to be detected. Since a trailing trajectory is highly undesirable, the attitude deviation limits for the lunar landing mission will have to be defined so as to take this into account. The magnitude of the limits will depend upon how much fuel can be expended to return to an acceptable trajectory.

Osculating perigee and apogee altitude data are also included for the IU platform misaligned about the pitch axis. The data shows that a crew safety problem does not exist for misalignments between ±14.5°.

INTRODUCTION

Since TLI for the lunar landing mission may be performed without tracking, the crew must have limits for the values displayed onboard to evaluate the progress of the burn and, hence, to determine what procedure to follow if a limit is violated. The purpose of this document is to present data used in determining the 15° attitude deviation limit recommended as a TLI shutdown criteria (ref. 1). The major portion of the data presented is based on an IU platform drifting about its pitch axis. This type of drift is the one most likely to result in a crew safety problem. In addition, data is also included for the IU platform misaligned about the pitch axis.

SYMBOLS

IU	instrument unit
IMU	inertial measurement unit
h_p	perigee altitude
h_c	apogee altitude
LLM	lunar landing mission
TLI	translunar injection
Ω	right ascension of ascending node
ω	argument of perigee
$\Delta\omega$	rotation of line of apsides
$\Delta\omega_{rel}$	$\Delta\omega$ measured relative to nominal value
θ	true anomaly
θ_{rel}	θ measured relative to nominal value
δ	angle between right ascension and position vector at TLI
ω_i	ω at TLI burn initiation
ω_f	ω at TLI cutoff

ANALYSIS AND RESULTS

TLI consists of S-IVB burn of approximately 328 seconds (ref. 2) which places the spacecraft on a free-return lunar trajectory. If the IU platform is drifting or misaligned, the lunar trajectory is no longer free return. The TLI burn in the study is targeted for the first injection opportunity of a February 1, 1968 launch on a 72° launch azimuth. The IU platform is initially aligned as follows: x-axis along the initial guidance-computed thrust direction, y-axis perpendicular to the plane formed by the radius vector and the x-axis, and the z-axis completing a right-hand coordinate and consequently pointing toward the earth. This system is used since a pitch drift has less of a yaw effect than it would in the nominal IU platform alignment. The IU system would normally be aligned at launch with the z-axis along launch azimuth, x-axis along the negative gravity vector, and y-axis completing the right-hand system. The IMU alignment is the same except that it is rotated -90° about the y-axis where a positive rotation obeys the right-hand rule. The weights and S-IVB engine performance of reference 1 are used in the study.

It is assumed that all systems are correct prior to burn initiation and that the platform begins drifting about its pitch axis (y-axis) at that time.

The time histories of the osculating h_p and h_a for various pitch drift rates are shown in figures 1 and 2, respectively. The (b) parts of these figures show an expanded view from 304 seconds to the nominal shutdown time (328.4 sec). It can be seen from the figures that a positive drift rate has a greater effect on h_p and h_a than its negative counterpart. This is due to the effect of drift rate on the rotation of the line of apsides which will be discussed later. For a drift rate of 0.2 deg/sec, h_p will be around -85 n. mi., but the vehicle is postperigee. With a -0.2 deg/sec drift rate, h_p is lowered to only 45 n. mi.; however, the vehicle is preperigee. With this negative drift rate atmospheric entry will occur at approximately 310-seconds burn time, 18 seconds before the end of the nominal burn. Figure 1 also shows that several of the drift rates used (e.g., -0.1 and 0 deg/sec) have very similar perigee time histories. This is again due to the rotation of the line of apsides. For the range of the drift rates shown, h_a lies between 20 000 n. mi. for 0.2 deg/sec to 312 000 n. mi. for the nominal. In reference 1 it is proposed that the attitude deviation does not exceed ±15°. Using the ±0.05 deg/sec curves gives a good approximation to this limit value in figures 1 and 2. These rates still give a fair approximation in the early part of the burn where larger rates are required, since the curves converge.

The effect of drift rate on h_p and h_a at the end of burn is shown in figures 3 and 4, respectively. On the h_p plot, the points labeled "75 n. mi. perigee" are the drift rates (approximately -0.175 and 0.08 deg/sec) which result in an h_p of 75 n. mi. At a drift rate of approximately -0.13 deg/sec, the vehicle will be at perigee at cutoff. For rates to the left of this value, the vehicle will be preperigee and to the right, postperigee. The h_p for the preperigee rates is the true perigee altitude while for postperigee rates h_p will be affected by the moon's perturbations. The h_a's of figure 4 will also be affected by the moon's perturbations. The exact effect will depend upon whether the trajectory leads or trails the moon. For a 15° attitude deviation or less by the end of the burn, h_a will be between 170 000 n. mi. and 312 000 n. mi., the nominal h_a.

Figure 5 is included to show how the altitude during the burn is affected by drift rate. Shown in the plot is the nominal altitude time history along with those for the largest rates used in the study ($\pm$0.2 deg/sec). These values are selected to show the widest variation. The nominal altitude at cutoff is around 168 n. mi. For the 0.2 deg/sec rate the altitude steadily increases over the nominal trace, and at the end of the burn is around 260 n. mi. For the -0.2 deg/sec rate, the altitude is decreasing with atmospheric entry occurring at 310 seconds.

The resulting effect of a drift rate on the line of apsides is presented in figures 6 and 7. Figure 6 shows the time history of the argument of perigee, ω, during the TLI burn. A negative drift rate causes ω to increase in a positive direction, and a positive drift rate causes an increase in the negative direction. ω is measured relative to the right ascension of the ascending node, Ω, and is positive in the direction of motion. For the TLI burn Ω is approximately constant, and for the trajectory used, is around -133°. Since a negative drift rate is toward the earth, a negative delta velocity component along the radius vector exists and, hence, a reduction in the flight-path angle occurs. Nominally the vehicle will be postperigee at the end of the burn; therefore, a negative drift rate rotates the line of apsides toward the vehicle and, if sufficiently large, will rotate beyond the vehicle. A positive drift rate has a positive delta velocity component along the radius vector and, hence, produces the opposite effect. The vehicle is therefore closer to apogee which explains why a larger reduction in h_a and h_p is caused by a positive drift rate. The recommended $\pm$15° limits are shown on the plot.

At the end of the TLI burn, the angle between the position vector and the right ascension of the ascending node vector is approximately constant and largely independent of the in-plane drift rate. In general, then, true anomaly at the end of the burn can be computed approximately as follows:

$$\theta = -(\omega_i + \Delta\omega - \delta)$$

where

θ = true anomaly measured from ω_f

ω_f = value of ω at TLI cutoff

ω_i = value of ω at TLI burn initiation

$\Delta\omega = \omega_f - \omega_i$

δ = angle between position vector and Ω at TLI cutoff

For the trajectory used, ω_i and δ are approximately -25.3° and -2.6°, respectively. The equation expresses the effect of a rotation of the line of apsides on the position in the orbit. Figure 6 shows the angular rotation of the line of apsides, $\Delta\omega$, and true anomaly, θ, at the end of the burn as a function of pitch drift rate. The dashed curves, $\Delta\omega_{rel}$ and θ_{rel}, are the above two curves with the nominal values of $\Delta\omega$ and θ subtracted. It is obvious from the plots, therefore, that $\Delta\omega$ and θ are linear and that drift rates of equal magnitude but opposite sign produce t[illegible] the nominal. Since the nominal value of $\Delta\omega$ places the vehicle on the correct lunar trajectory which leads the moon, a negative drift rate will increase the lead while a positive drift rate results in a trajectory trailing the moon. The parameter $\Delta\omega_{rel}$ shows how successful the TLI burn is in plane. Figure 8 is a cross plot between figures 5 and 7. It shows h_a as a function of $\Delta\omega_{rel}$. A positive value of $\Delta\omega_{rel}$ corresponds to a negative drift rate and a negative value to a positive drift rate. If $\Delta\omega_{rel}$ is zero, then h_a corresponds to the nominal value. If it is non-zero, then h_a will be different from the nominal and depending upon the sign of $\Delta\omega_{rel}$, the trajectory will either lead or trail the moon.

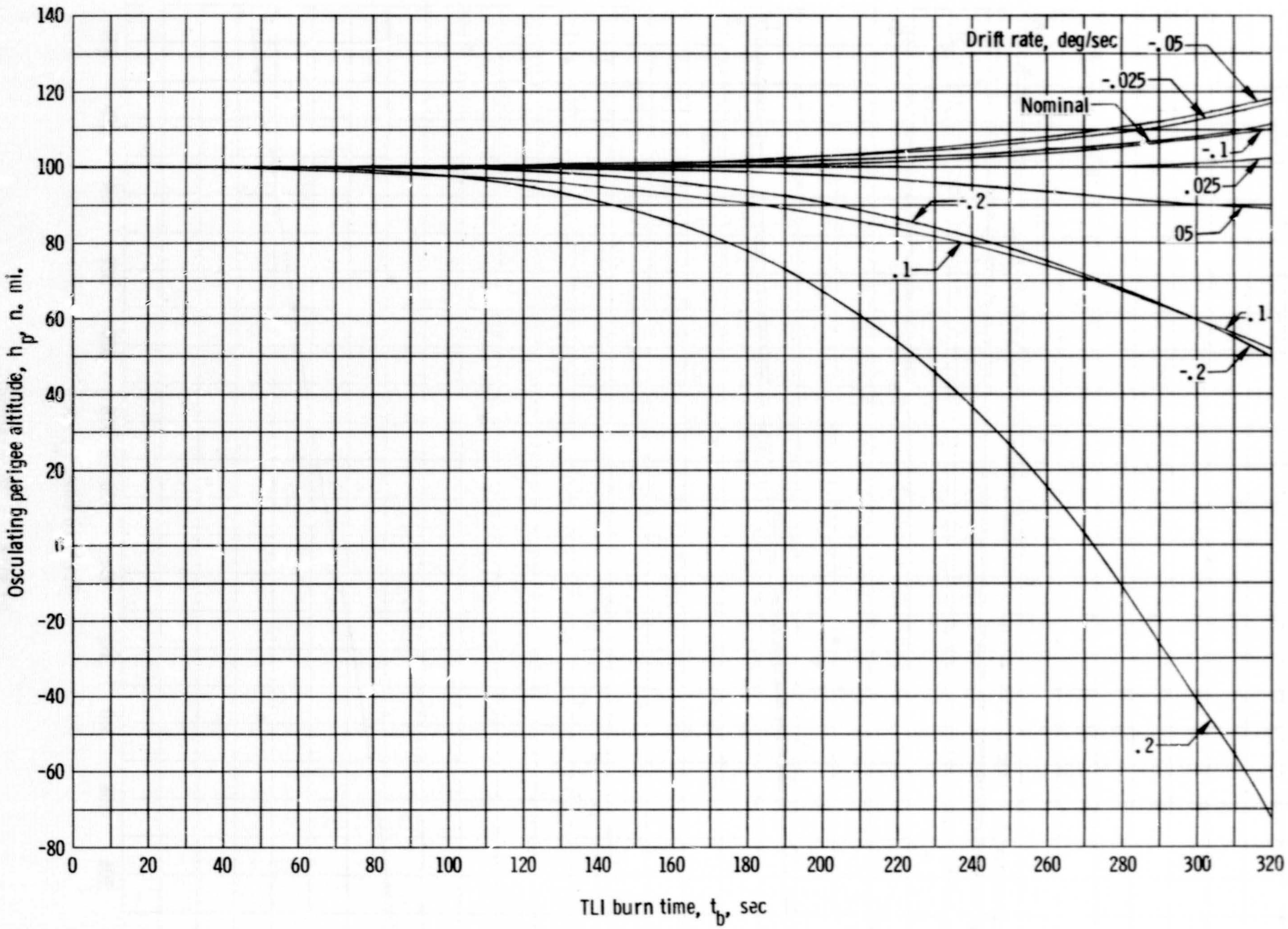
The time histories of h_p and h_a for various IU platform pitch misalignments are shown in figures 9 and 10, respectively. Again the (b) parts show an expanded view from 304 seconds to the nominal cutoff time. It can be seen from the plots that a small misalignment (1° to 3°) does not greatly affect the h_p and h_a profile from the nominal. The line of apsides would be slightly rotated. The direction of rotation would be the same as a drift rate having the sign of the misalignment. The $\pm$14.5° case represents situation where a large constant attitude deviation occurs but does not violate the recommended 15° limits. It can be seen that a perigee problem does not exist. The lowest h_p is around 86 n. mi., and the vehicle is postperigee. The dipping effect is caused by a combination of central angle of travel and a rotation of the line of apsides. The h_a's for the -14.5° and +14.5° are 158 000 and 127 500 n. mi., respectively.

CONCLUSIONS

The study shows that, for the IU platform drifting about its pitch axis for the LLM, (1) a crew safety problem does not exist within the recommended 15° attitude deviation limits, and (2) a postive drift rate produces the worst trajectory effects.

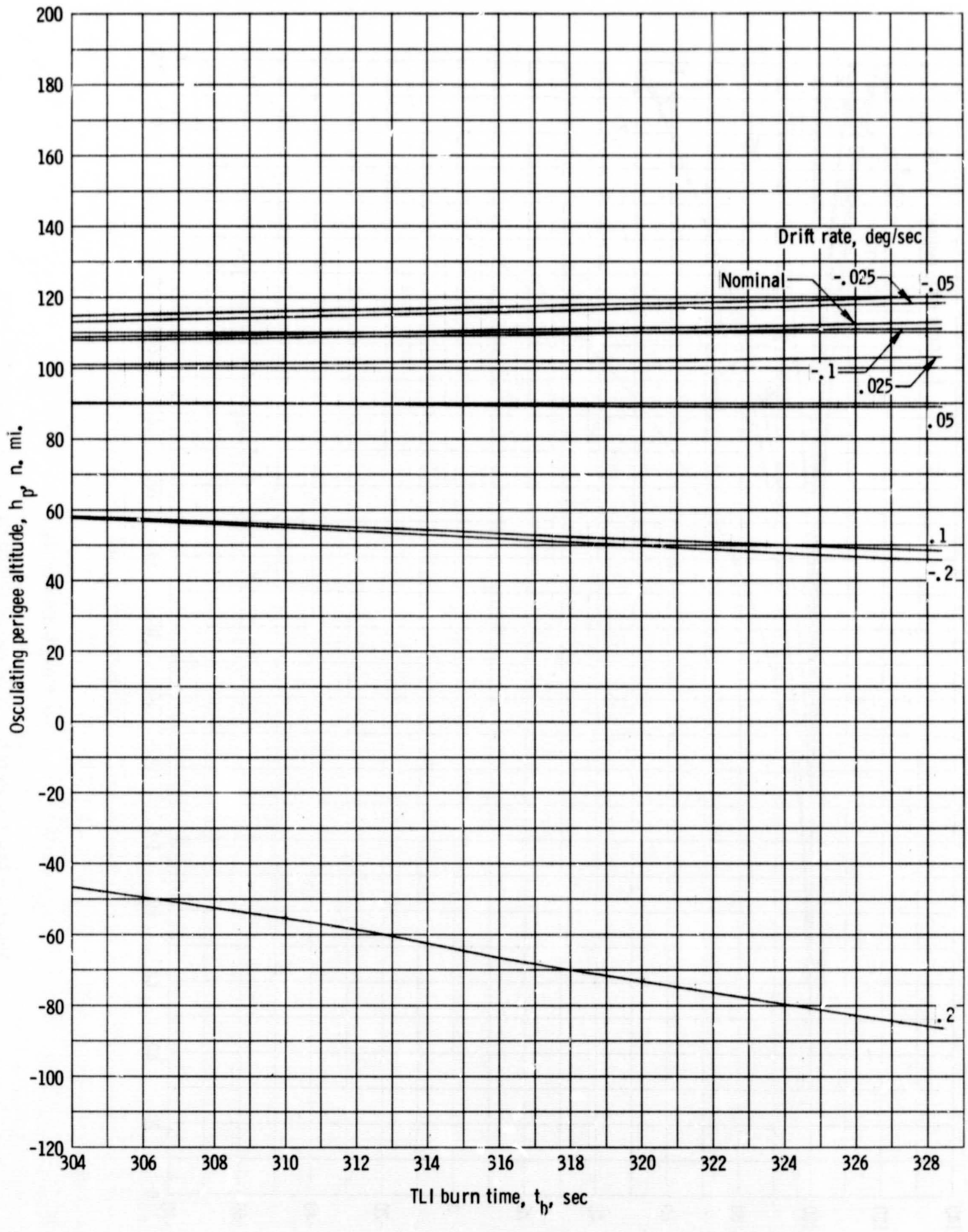
In order to have atmospheric entry, a burn of approximately 310 seconds at a ptich drift rate of -0.2 deg/sec is required. At this rate the recommended 15° attitude deviation limits would be violated after a burn time of only 75 seconds. Within the 15° limits h_p will be greater than 85 n. mi., and the vehicle will be postperigee. This is also true for platform pitch misalignments between ±14.5°.

Of two drift rates with equal magnitude but opposite signs, a positive drift rate causes less of an increase in h_a and more of a decrease in h_p. This is due to the effect of drift rate on the rotation of the line of apsides. If the nominal rotation of the line of apsides is used for a basis, a positive drift rate will rotate the line of apsides in a negative direction, and a negative drift rate will rotate it in a positive direction. Therefore, since a zero drift rate places the vehicle on the correct lunar trajectory, which leads the moon, a positive drift rate will either decrease the lead or result in a trajectory which trails the moon, depending upon its magnitude, and a negative drift rate will increase the lead. Since a trailing trajectory is highly undesirable, the attitude deviation limits for the LLM will have to be defined so as to take this into account. The magnitude of the limits will depend upon how much fuel can be expended to return to an acceptable trajectory.



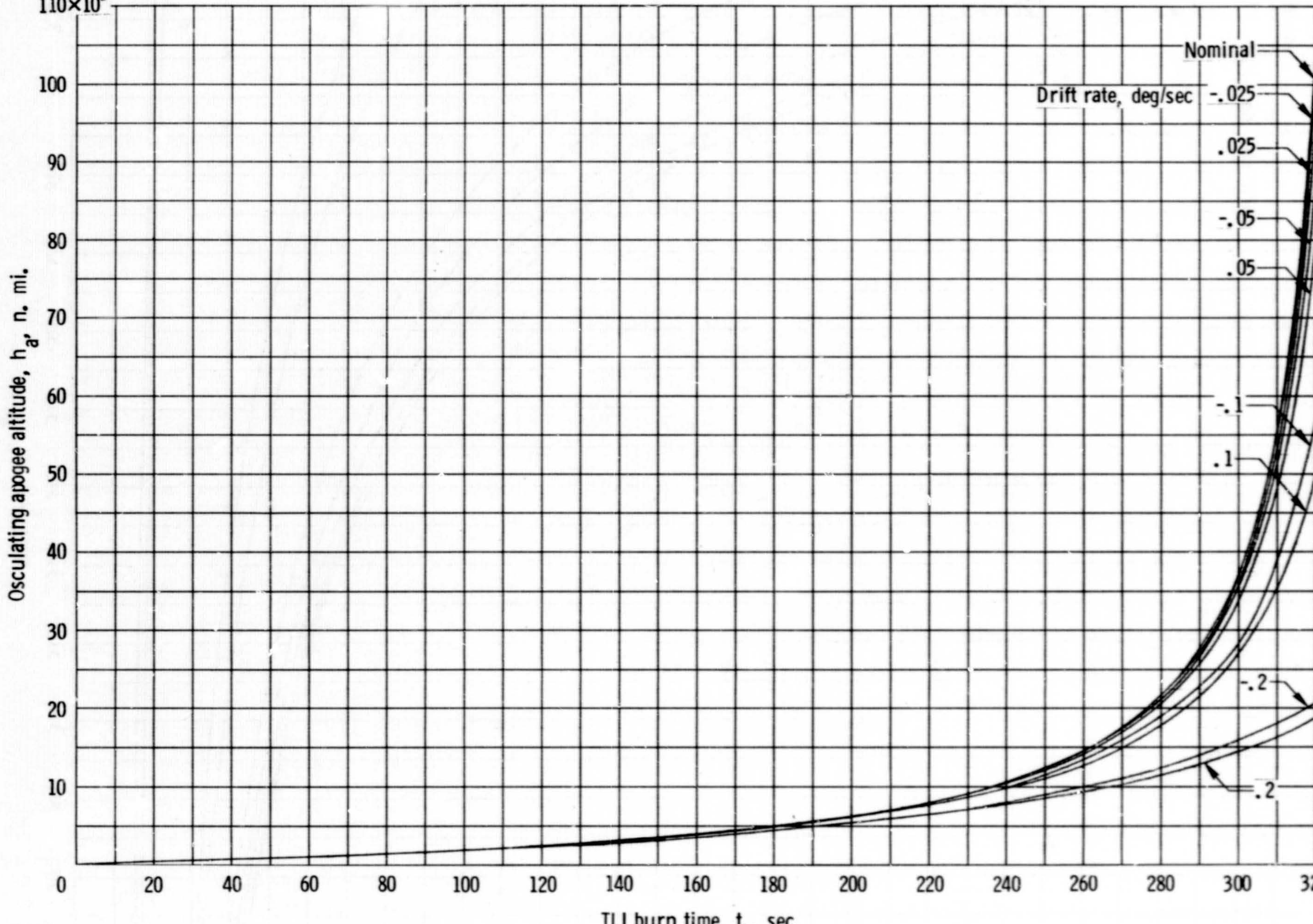
(a) $0 \leq t_b \leq 320$ seconds.

Figure 1. - Time history of osculating perigee altitude for various IU pitch drift rates.



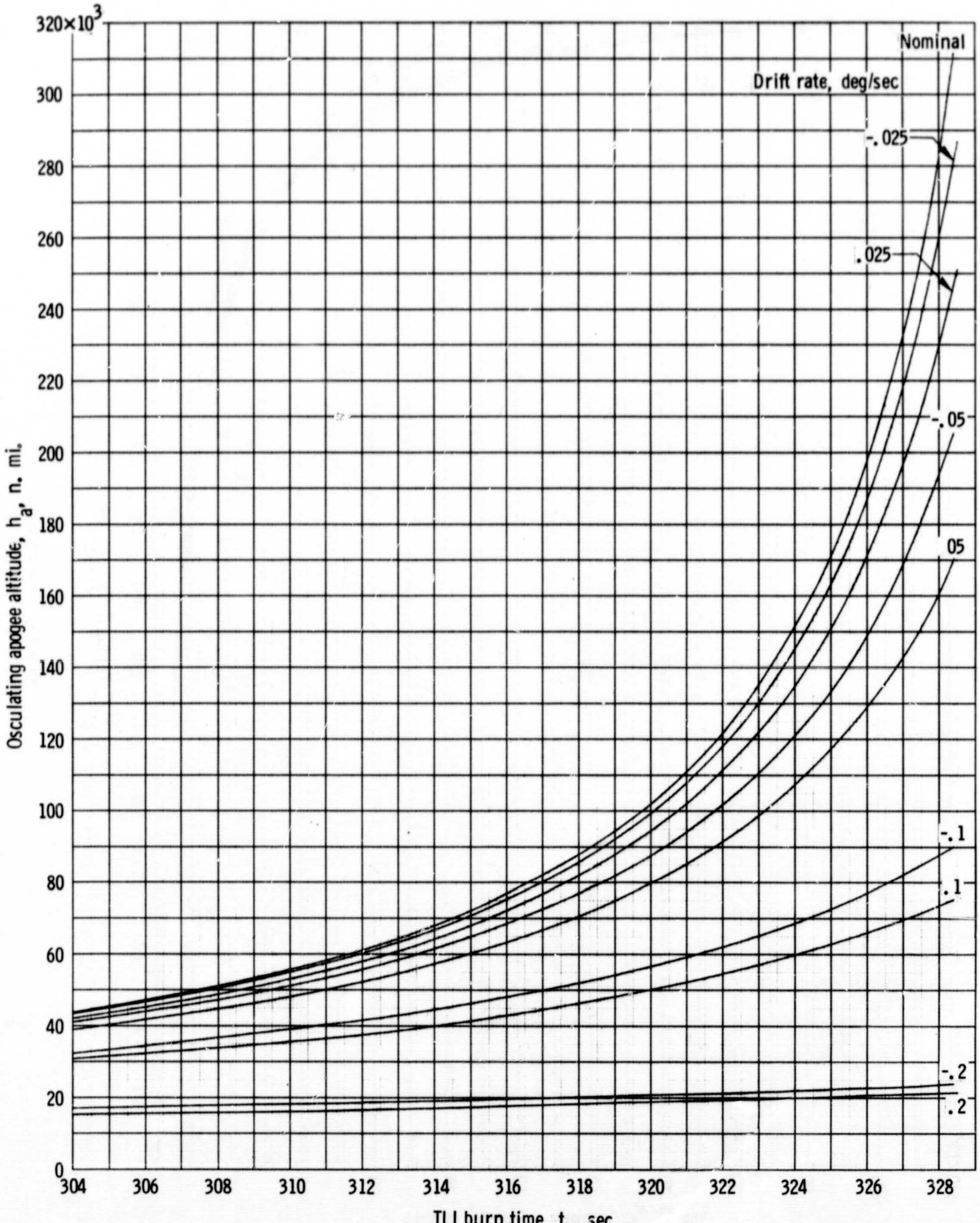
(b) $304 \leqq t_b \leqq 328.4$ seconds.

Figure 1.- Concluded.



(a) $0 \leq t_b \leq 320$ seconds.

Figure 2. - Time history of osculating apogee altitude for various IU pitch drift rates.



(b) $304 \leqq t_b \leqq 328.4$ seconds.

Figure 2.- Concluded.

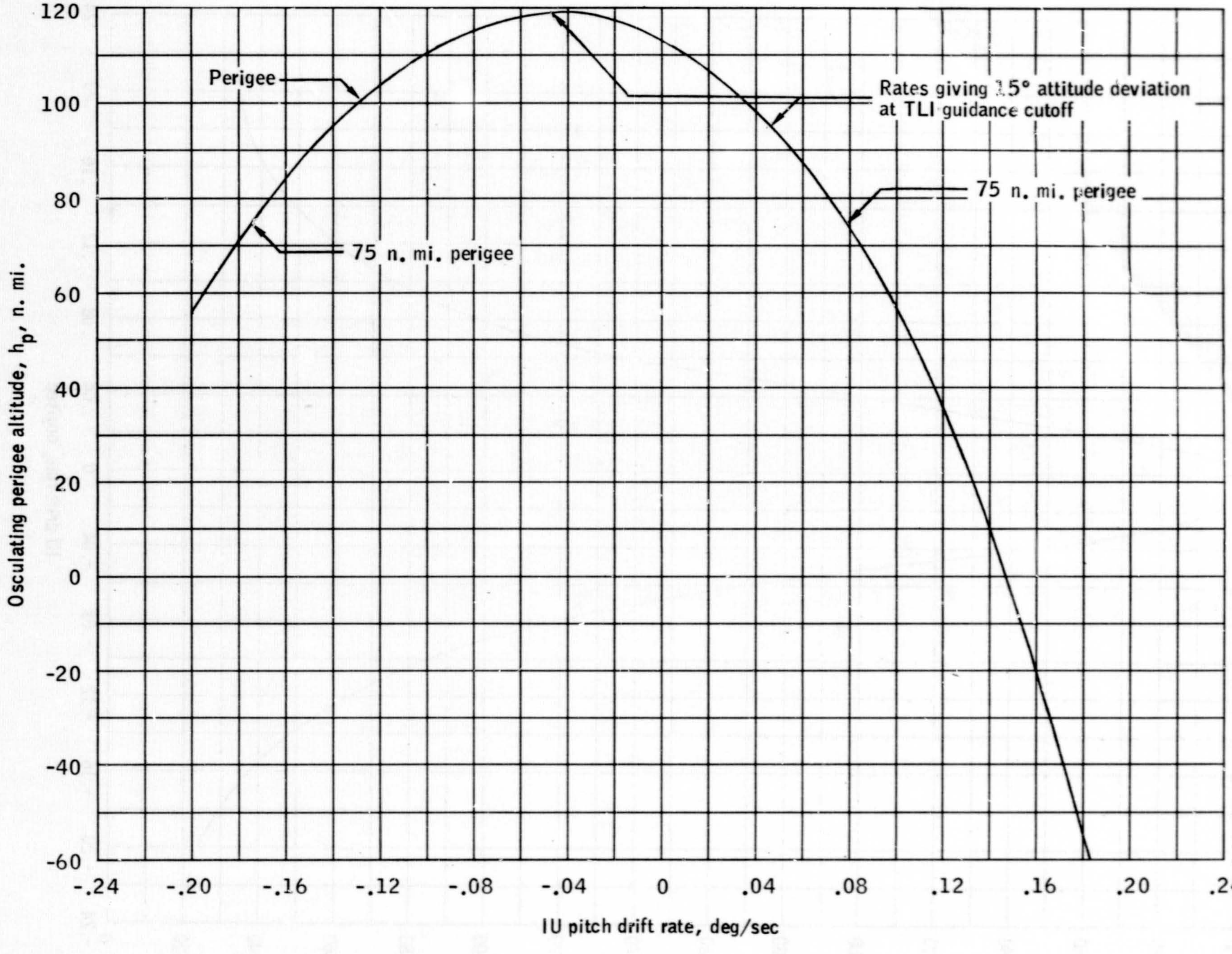


Figure 3.- Osculating perigee altitude at TLI cutoff as a function of IU pitch drift rate.

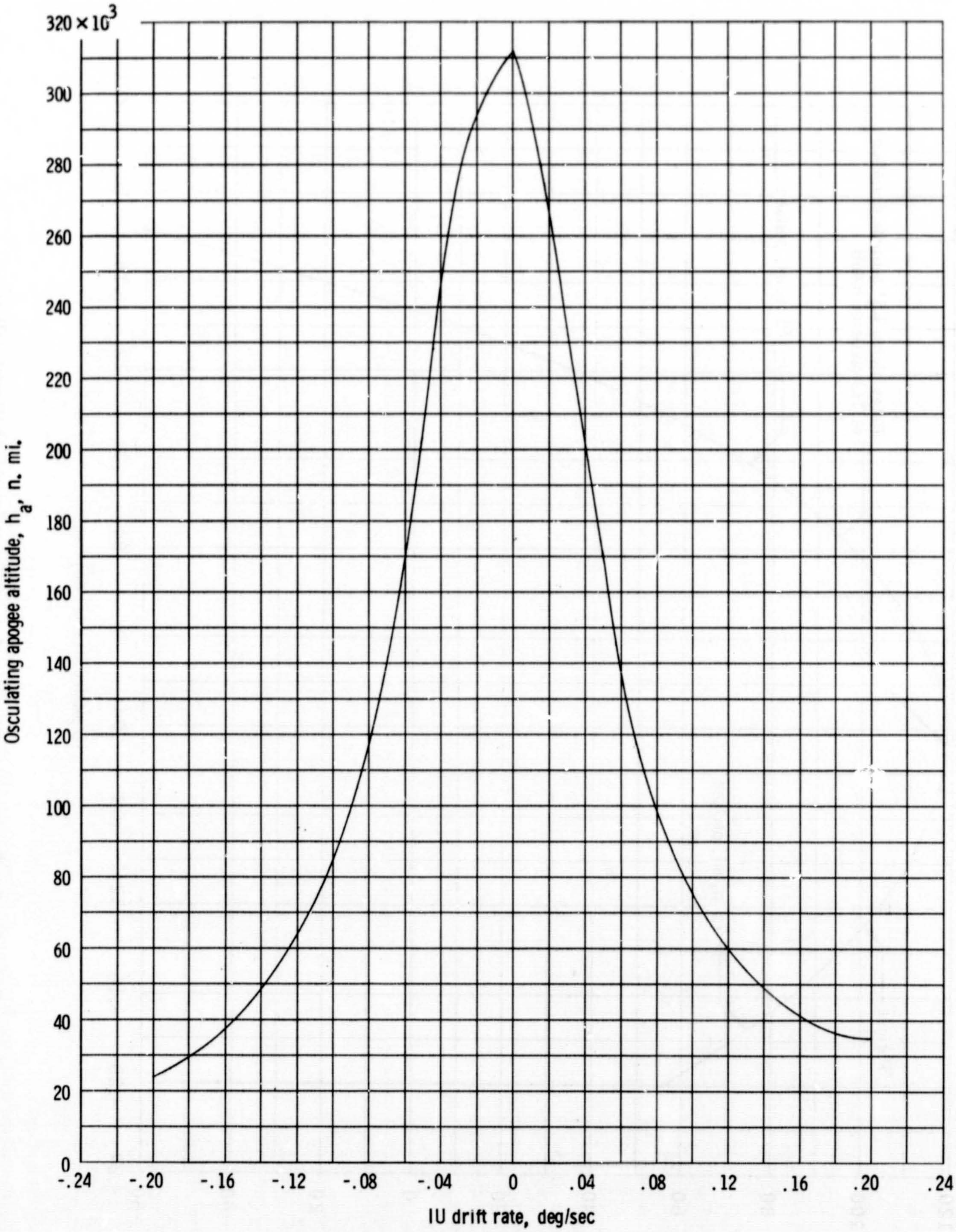


Figure 4. - Osculating apogee altitude at TLI cutoff as a function of IU pitch drift rate.

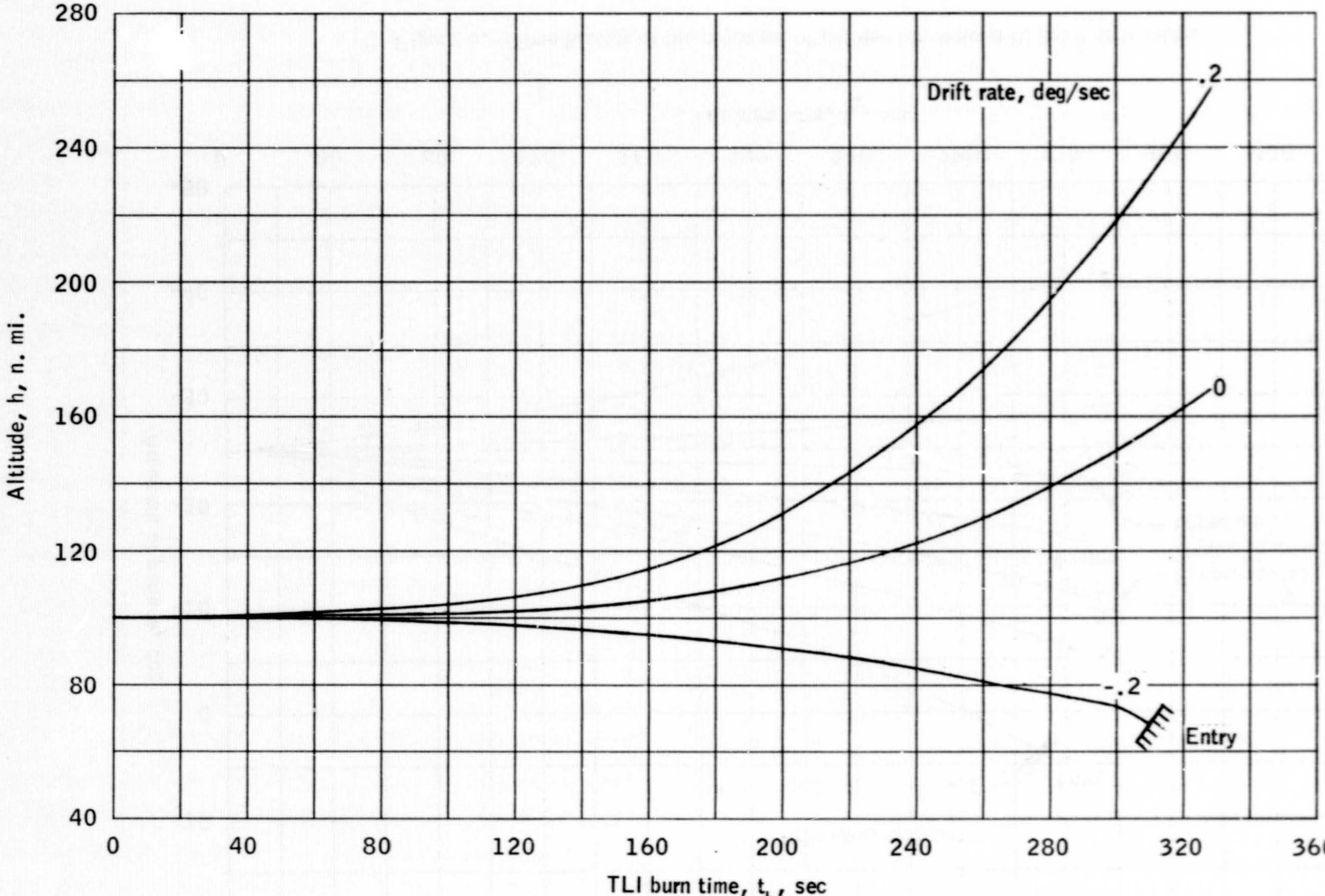


Figure 5.- Time history of altitude for IU drift rates of 0 degrees and ±.2 degrees per second.

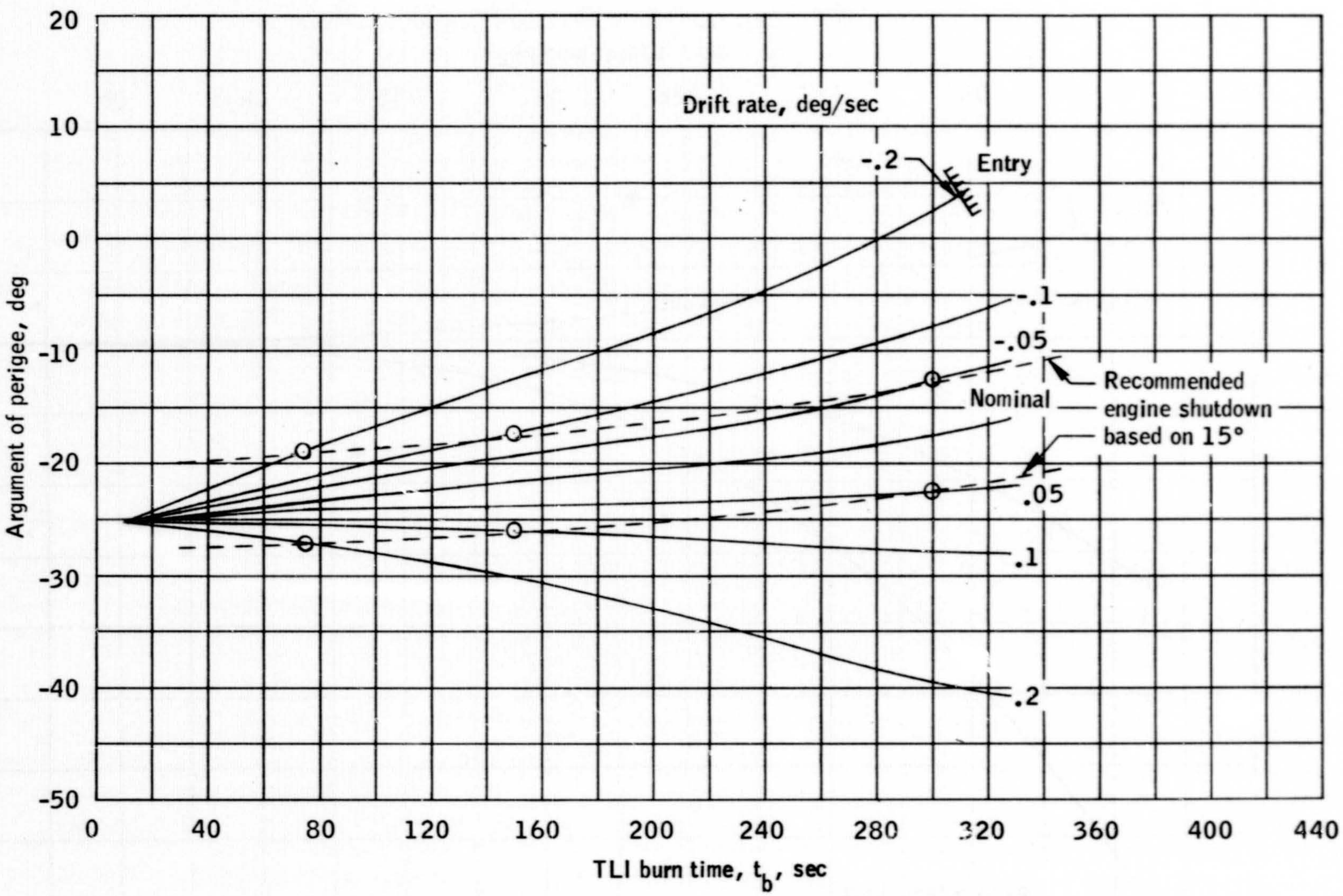


Figure 6.- Time history of the argument of perigee for various IU pitch drift rates.

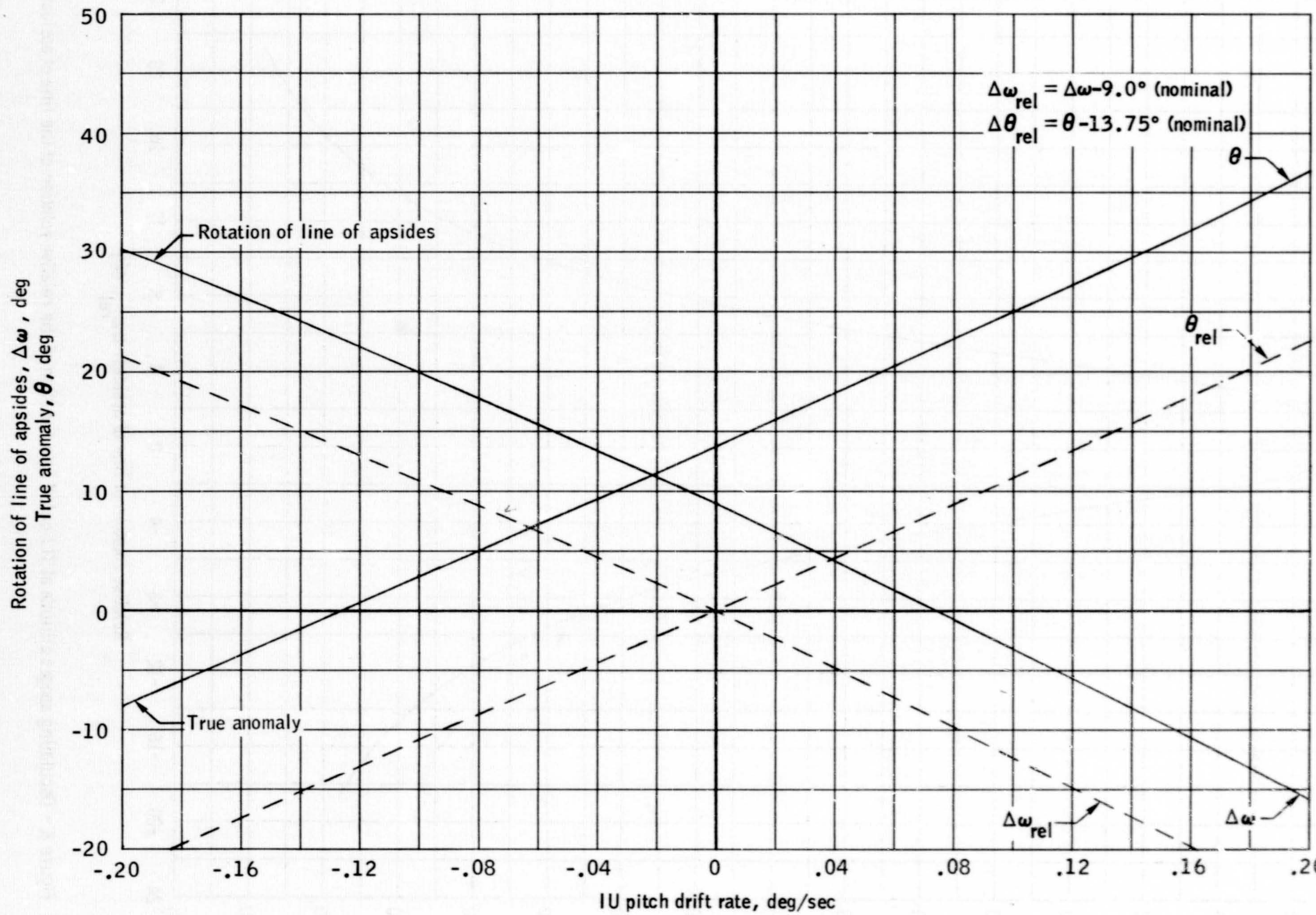


Figure 7.- Rotation of the line of apsides and true anomaly as a function of IU pitch drift rate.

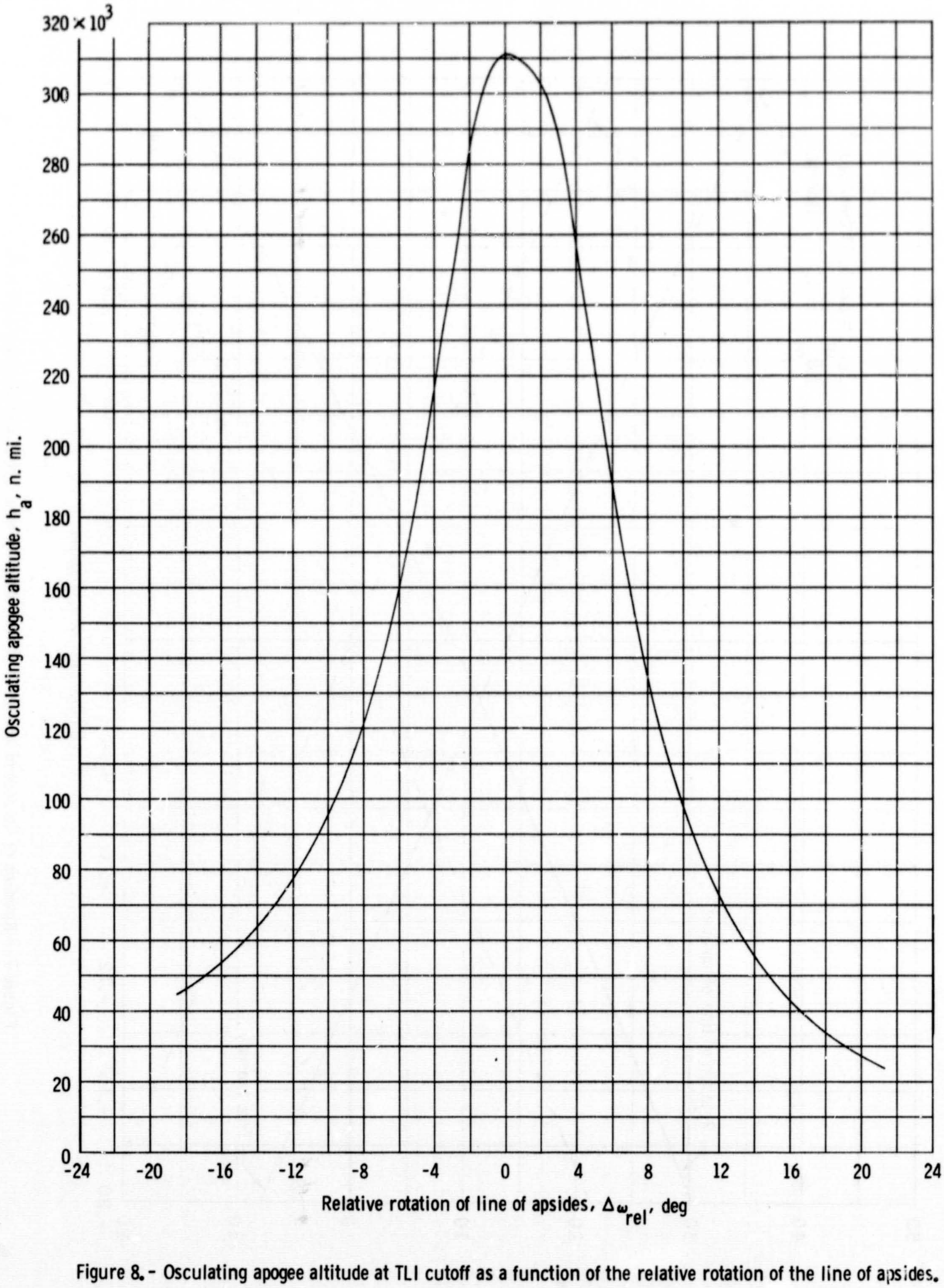
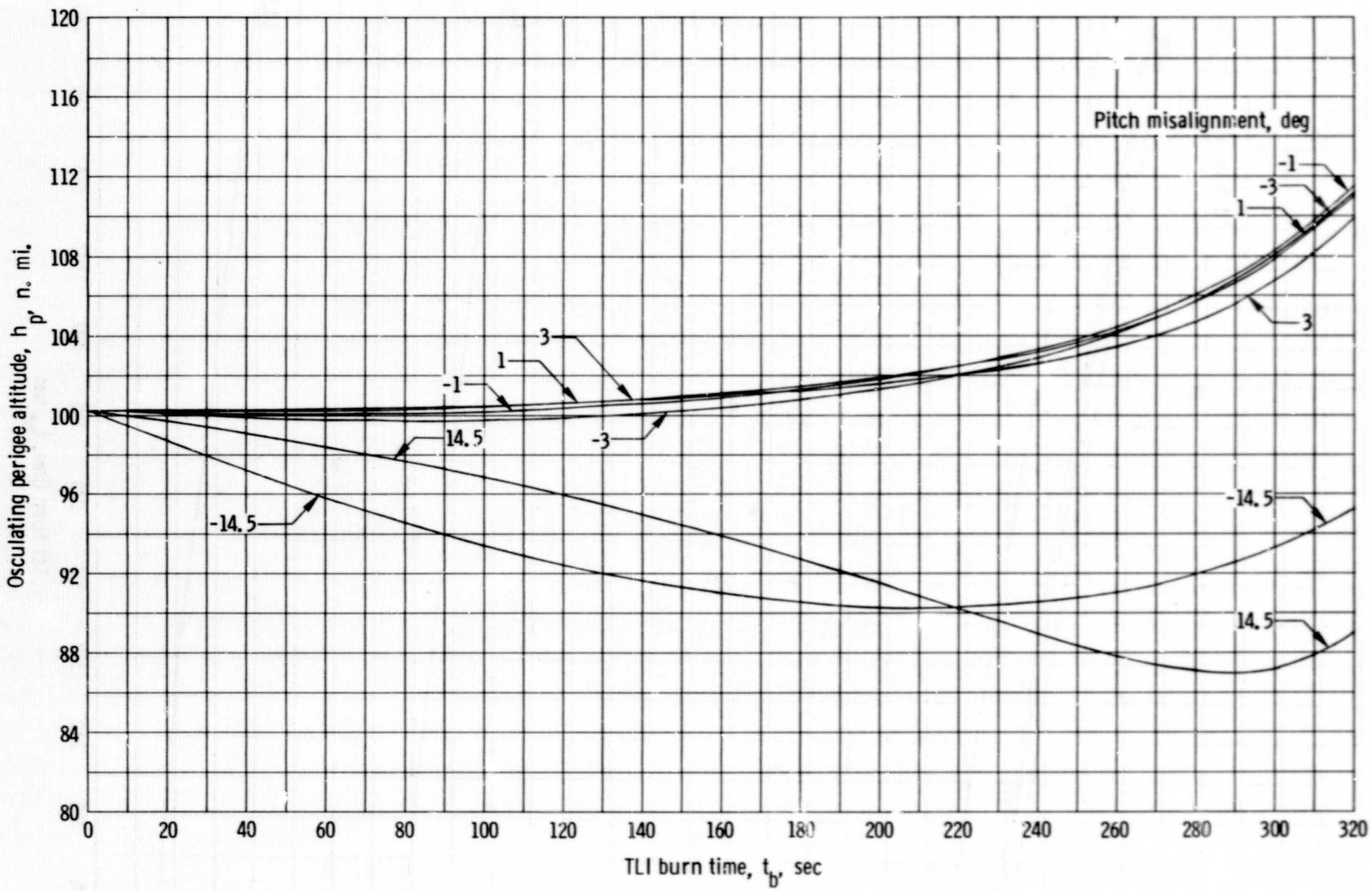
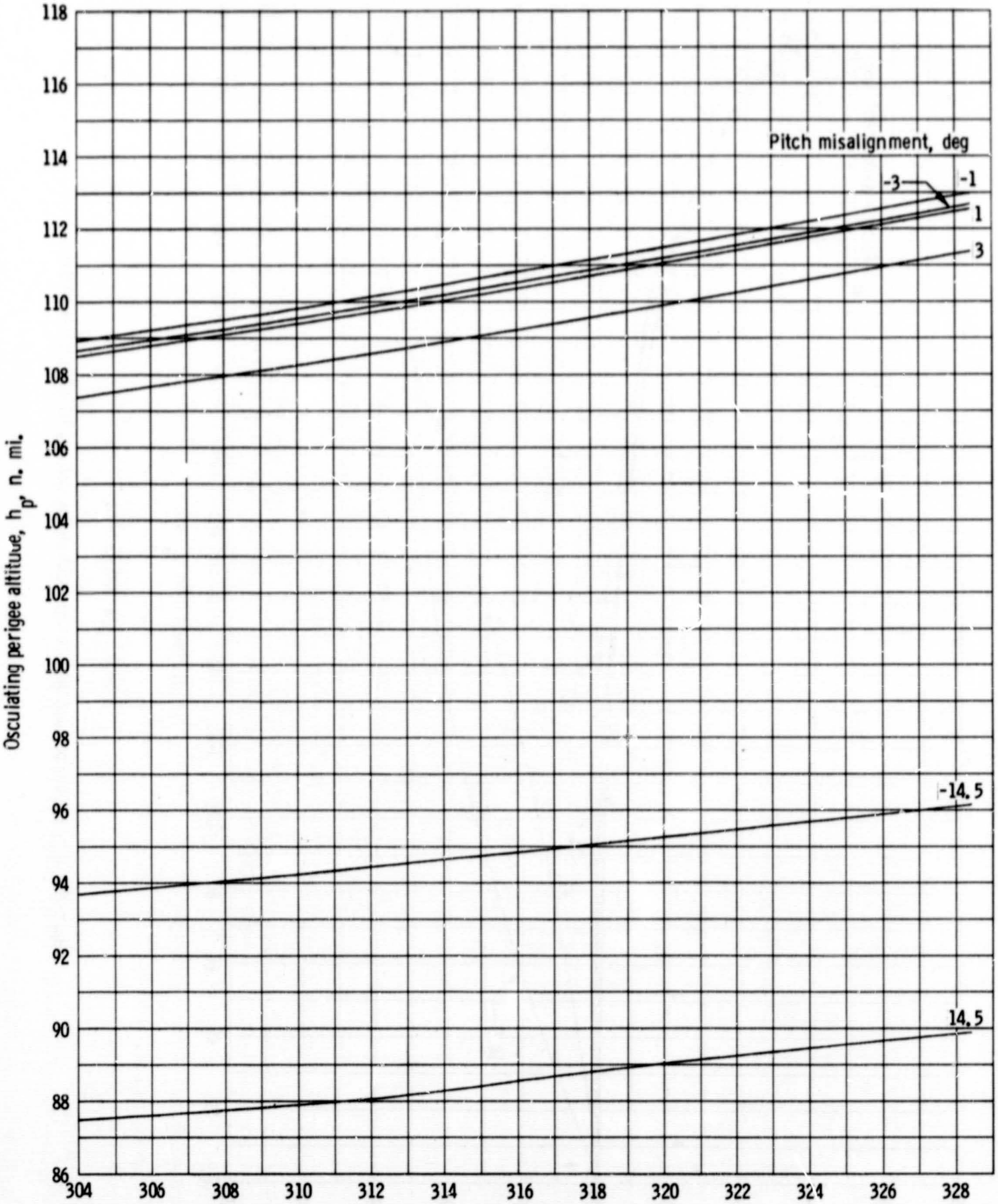


Figure 8. - Osculating apogee altitude at TLI cutoff as a function of the relative rotation of the line of apsides.



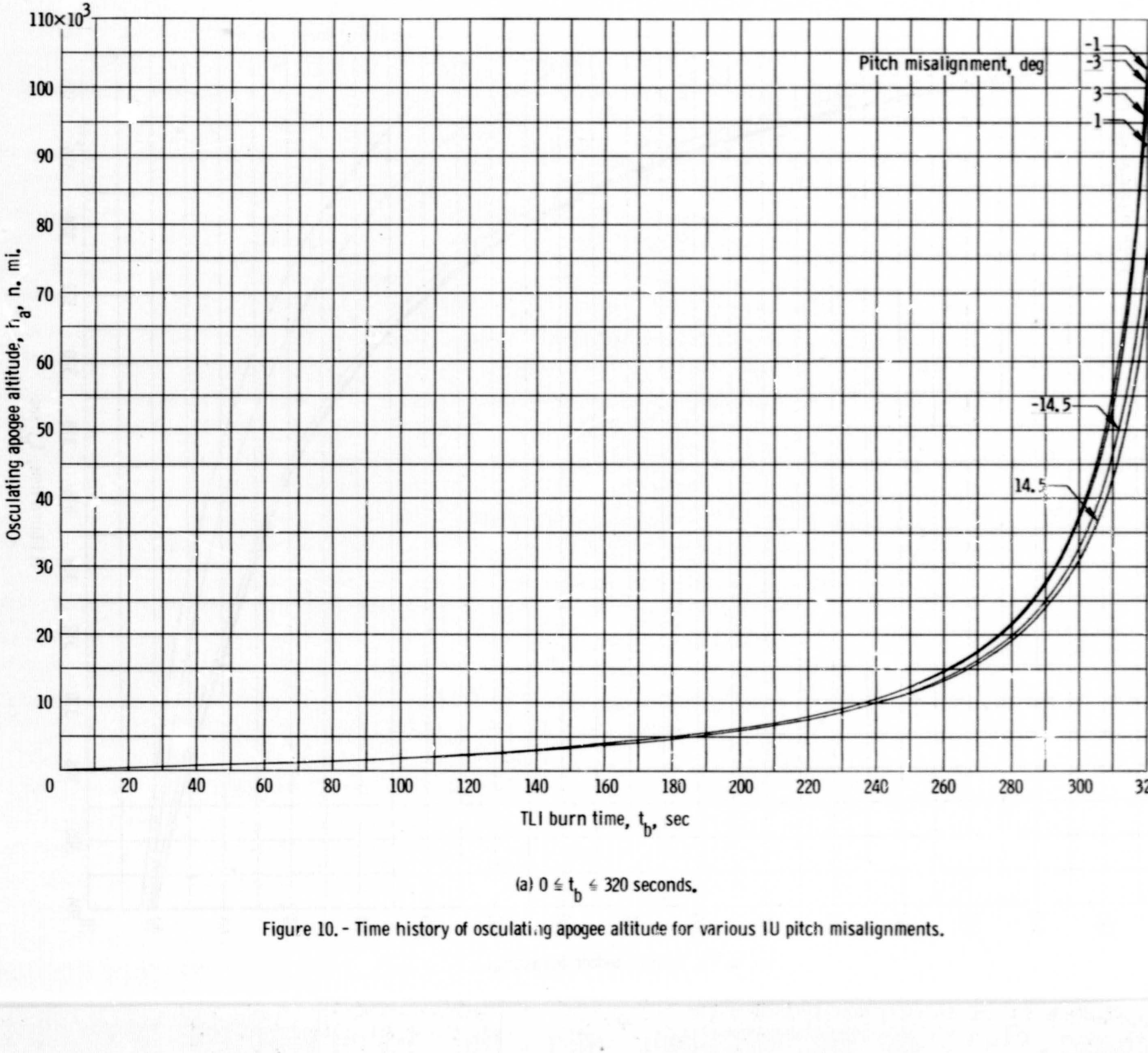
(a) $0 \leq t_b \leq 320$ seconds.

Figure 9. - Time history of osculating perigee altitude for various IU pitch misalignments.



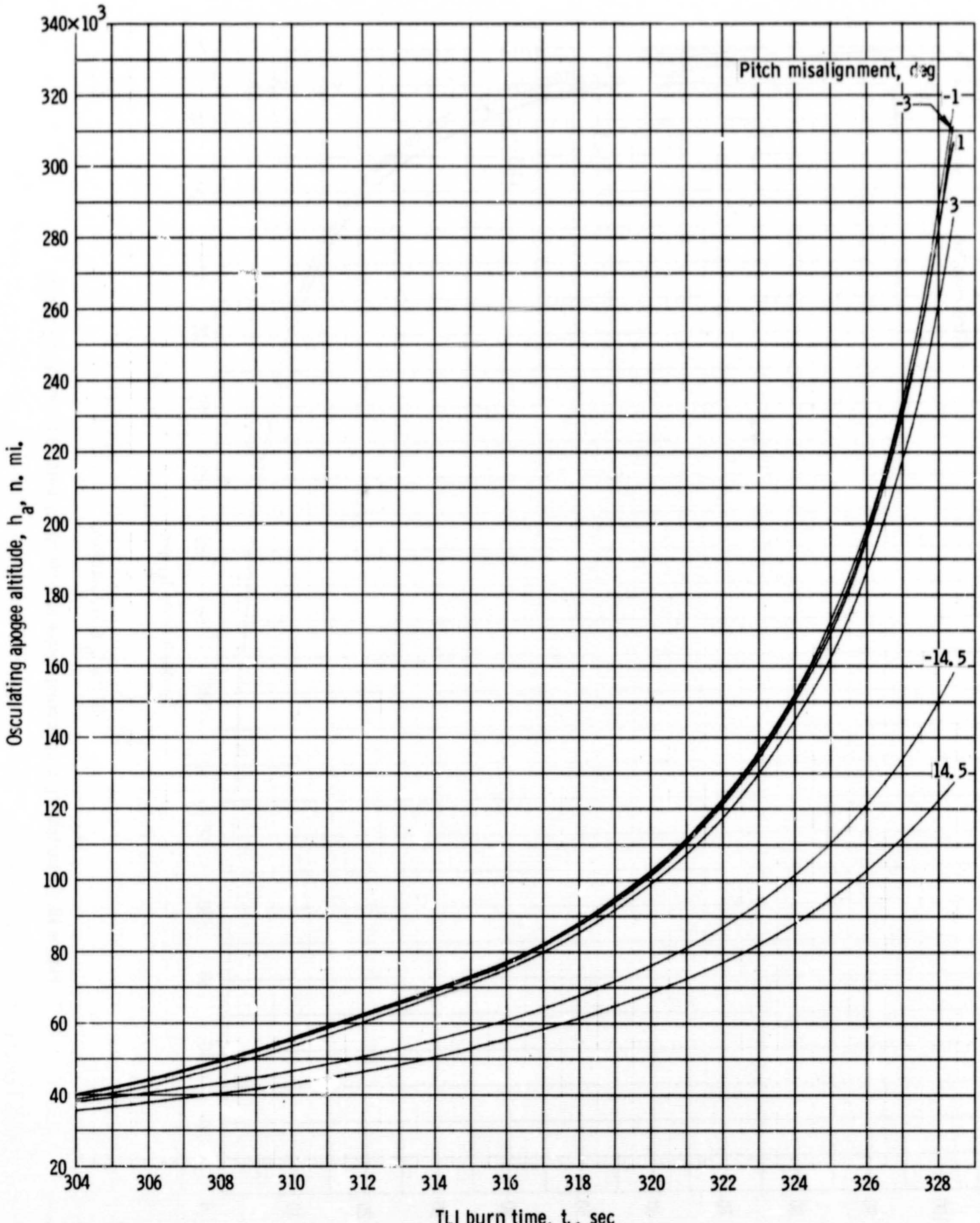
(b) $304 \leq t_b \leq 328.4$ seconds.

Figure 9.- Concluded.



(a) $0 \leq t_b \leq 320$ seconds.

Figure 10. - Time history of osculating apogee altitude for various IU pitch misalignments.



(b) $304 \leq t_b \leq 328.4$ seconds.

Figure 10. - Concluded.

REFERENCES

1. Hyle, Charles T.: Preliminary Display Limits and Crew Monitoring Considerations for TLI, LOI, and TEI. MSC IN 67-FM-138, September 27, 1967.

2. Boeing: AS-504 Preliminary Launch Vehicle Reference Trajectory. Boeing Company Document D5-15481, July 13, 1966.