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NASA PROGRAM APOLLO WORKING PAPER NO. 1180

INVESTIGATION OF LANDING SITE REDESIGNATION DURING PHASE II OF THE LEM POWERED DESCENT USING PRIMARY GUIDANCE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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INVESTIGATION OF LANDING SITE REDESIGNATION DURING PHASE II OF THE LEM POWERED DESCENT USING PRIMARY GUIDANCE

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SUMMARY

A study is presented of the required guidance commands and available footprint for landing site redesignation during the final approach phase (Phase II) of the LEM powered descent. Redesignations are initiated between 11 000 and 5000 feet altitude off a nominal descent trajectory. This study, based on a fixed time-to-go, indicates that a nearly circular footprint of about 10 000 to 20 000 ft radius is available for a ΔV penalty of 100 fps. Since the time-to-go is held constant at the value predicted by the guidance logic for the nominal trajectory, the alternate site selection destroys the constancy of the guidance commands for the nominal Phase II flight. These command variations, in some instances, cause interruptions in the visibility of the landing area and also produce command rates near design control limits.

INTRODUCTION

The LEM powered descent is divided into three phases (see fig. 1); an initial braking phase (Phase I), final approach (Phase II), and the landing phase (Phase III). Phases I and II of the LEM powered descent are guided by a set of equations which are reported in reference 1. The landing approach flight is a constant thrust and constant attitude trajectory designed to allow adequate fuel economy, pilot control and pilot visibility of the landing area, as presented in reference 2. The initial and final conditions and the time of flight of Phase II are predetermined to yield this constant attitude and constant thrust phase of flight. In the event that the predetermined landing site is deemed unsatisfactory by the pilot, he then has the capability for redesignating the landing area during Phase II. However, since the time of flight (time-to-go) was specified in order to yield a constant thrust profile (attitude and magnitude) for guiding to the preselected site, the time-to-go must also be redesignated or variations in the thrust profile must be accepted. It is the purpose of this study to investigate the variations in the thrust profile induced by redesignating the landing site without recalculating the time-to-go. A landing footprint or area available for alternate site selection is determined based on this concept of a fixed time-to-go.

SCOPE OF CALCULATIONS

The nominal powered descent trajectory used for this study is initiated at an altitude of 50 000 feet with a zero flight path angle and a velocity of 5583 fps, which define the state vector at pericynthion for a Hohmann descent transfer from an 80-n.m. orbit. A time history of Phase I is presented in figure 2(a). Phase II is assumed to begin at an altitude of 11 069 feet and incorporates a constant attitude of 47° from the negative horizontal axis (see fig. 3 for axis system) and a thrust level of 4874 lbs., as compared to a full throttle thrust of 10 500 lbs. A time history of Phase II is shown in figure 2(b). The terminal conditions are 10 fps velocity and -10° flight path angle at an altitude of 200 feet. Although this trajectory is only one of a number of possible nominal powered descent trajectories, it is believed that the data acquired is representative of data which would be derived from other nominal trajectories.

The primary guidance equations reported in reference 1 are used to calculate the required guidance commands to approach the terminal conditions at the alternate landing site selected. The equations of motion are based on a point mass. The guidance constants are updated every second and there is no updating less than 10 seconds prior to termination.

Changes in the landing site are initiated at three different altitudes; 11 069 feet, 7812 feet, and 5078 feet with downrange nominal distances of 43 730 feet, 30 210 feet, and 19 110 feet, respectively. The time-to-go is held constant at the value predicted by the guidance logic for the nominal trajectory from each altitude and are, in order of the altitudes given, 115 sec, 95 sec, and 75 sec, respectively. Changes in downrange distances of up to ±40 000 feet and crossrange distances to about 30 000 feet were considered.

RESULTS AND DISCUSSION

Area Available.- The preselected landing area first becomes visible after the pitch-up maneuver at the 11 069-foot altitude (beginning of Phase II). The maximum landing area footprint would arise from an alternate site selection being made immediately, (see fig. 4). It should be noted that this footprint and all others presented herein are symmetrical about the downrange axis. For convenience only half of the footprint is shown. This maximum or ideal footprint shows that for a ΔV penalty of 100 fps from 11 069 feet the range may be lengthened or shortened by about 20 000 feet and a crossrange distance of over 15 000 feet may be reached. The shaded area of figure 4 is not available because the maximum thrust of 10 500 lbs is exceeded.

To allow adequate time to assess the landing area it is assumed that the alternate landing site selection should be initiated at some altitude between 8000 feet and 5000 feet. The landing area will then have been visible from 20 to 40 seconds. After 20 seconds of Phase II flight an altitude of 7812 feet has been reached and the footprint from this altitude is presented in figure 5. This more realistic altitude for a landing site change permits a long range or short range from the nominal of approximately 15 000 feet and a cross range of about 12 000 feet for a ΔV penalty of 100 fps. As in figure 4, the shaded area may not be obtained because the maximum thrust is exceeded.

The resulting altitude after a 40-second assessment is 5078 feet. The area available from this altitude is depicted in figure 6. For a ΔV penalty of 100 fps from a 5078-ft altitude the available range is an additional 10 000 ft and a short range from the nominal landing point of 10 000 feet with a cross range of about 9000 feet. Again the shaded area is not available because of the maximum thrust limitations. The variations of the guidance commands associated with these footprints and landing site visibility are discussed in the following two sections.

Guidance Command Variations.- Since the constant attitude and constant thrust of the Phase II flight are obtained (using the primary guidance equations reported in ref. 1) by predesignating the initial and final conditions and the time of flight, a change in any one of these characteristics would necessarily destroy this constancy, therefore violating the nominal design criteria of this portion of the LEM powered descent. This situation occurs when an alternate site selection (a change in the final conditions) is made. To present the variations in guidance commands after the alternate site selection has been made, the following three typical off-nominal trajectories are calculated from each of the initial altitudes: (a) a 10 000-ft range extension, (b) a 10 000-ft short range, and (c) an out-of-plane case that is a 10 000-ft range extension with a final azimuth of about 80°.

Time histories of the pitch angle for the trajectories (a), (b), and (c) together with the nominal from an altitude of 11 069 feet are shown in figure 7(a). The figure shows a maximum pitch angle rate (nearly a constant rate for the coplanar cases) of about .5 deg/sec from this altitude. Figure 7 is continued by portraying the thrust magni ude in figure 7(b) which indicates a maximum thrust rate (as with the pitch rate, nearly a constant for the coplanar cases) of about 30 lbs/sec. The yaw angle, which is measured from the north as shown in figure 3, is presented in figure 7(c), but is -90° for all coplanar cases. For the out-of-plane case, the yaw angle rate is about one deg/sec. These variations do not seem to be operationally severe, but do become larger, for redesignations at the two lower altitudes investigated.

The pitch angle, thrust magnitude and yaw angle from an altitude of 7812 feet are shown in figures 8(a), 8(b), and 8(c), respectively. For an alternate site selection made at this altitude, the pitch angle rate increases to .7 deg/sec, the thrust magnitude rate to over 40 lbs/sec and the yaw angle rate to about 1.2 deg/sec.

From the lowest altitude of 5078 feet, the pitch angle, thrust magnitude and yaw angle time histories are presented in figures 9(a), 9(b), and 9(c). These trajectories result in the highest guidance command rates, since the alternate site selection was delayed until a later time. The maximum pitch angle rate for these trajectories is about 1.25 deg/sec with a maximum thrust magnitude rate of approximately 80 lbs/sec. Also the yaw angle rate is about 7 deg/sec, the maximum value occurring from initiation to about 25 seconds.

These guidance command variations still do not seem to be operationally severe but may result in spacecraft attitudes that prevent visibility of the landing site, which is discussed in the next session.

Visibility of the Landing Site.- One of the design constraints of the Phase II flight is adequate visibility of the landing area. The lower window limit of visibility is 25 deg above the -x body axis (negative thrust vector) of the LEM (see fig. 3). Time histories of the look angle or line-of-sight angle to the landing site, which is assumed to be 1000 feet downrange from termination of Phase II, are presented in figures 10(a), 10(b), and 10(c) for each of the altitudes investigated. These figures show, that for a short range landing area, visibility of the landing area is lost immediately but regained later in the descent trajectory. The reverse is true for a range extension; i.e., visibility is improved initially but is lost at a later time. This is also the case for an out-of-plane trajectory. However, based upon the ΔV limitations, only one gross change in the landing area may be permitted, thus landing area visibility, immediately after the change is accomplished, may not be a severe limitation. Also, a pitch-up to a vertical attitude occurs at the termination of Phase II, again allowing visibility of the new landing area. Refinements and final selection of the touchdown point could then be made during Phase III, which should allow approximately one-quarter of a mile radius available after termination of Phase II flight. But, if visibility at all times is a requirement, either the area available must be reduced or a new calculation for time-to-go in the guidance logic must be incorporated.

CONCLUDING REMARKS

A study has been presented of the required guidance commands and available footprint for alternate landing site selection during the final approach phase (Phase II) of the LEM powered descent. Redesignations were initiated between 11 000 and 5000 feet altitude off a nominal descent trajectory. It was found that a nearly circular area of about 10 000 to 20 000 feet radius could be reached for a ΔV penalty of 100 fps. Since the time-to-go was held constant at the value predicted by the guidance logic for the nominal trajectory, the alternate site selection destroyed the constancy of the thrust profile (attitude and magnitude) for the nominal Phase II flight. These command variations, in some instances, interrupted the visibility of the landing area and also produced command rates near design control limits.

It is recommended that a similar study on alternate landing site selection be undertaken based on variable time-to-go logic to investigate alleviation of the wide variations in guidance commands and determine the associated footprint.

REFERENCES

1. Cherry, George W., A Class of Unified Explicit Methods for Steering Throttleable and Fixed-Thrust Rockets, MIT/IL, Report R-417 (Rev. 1964).

2. Bennett, Floyd V., Price, Thomas G., Study of Powered-Descent Trajectories for Manned Lunar Landings, NASA TN D-2426, 1964.

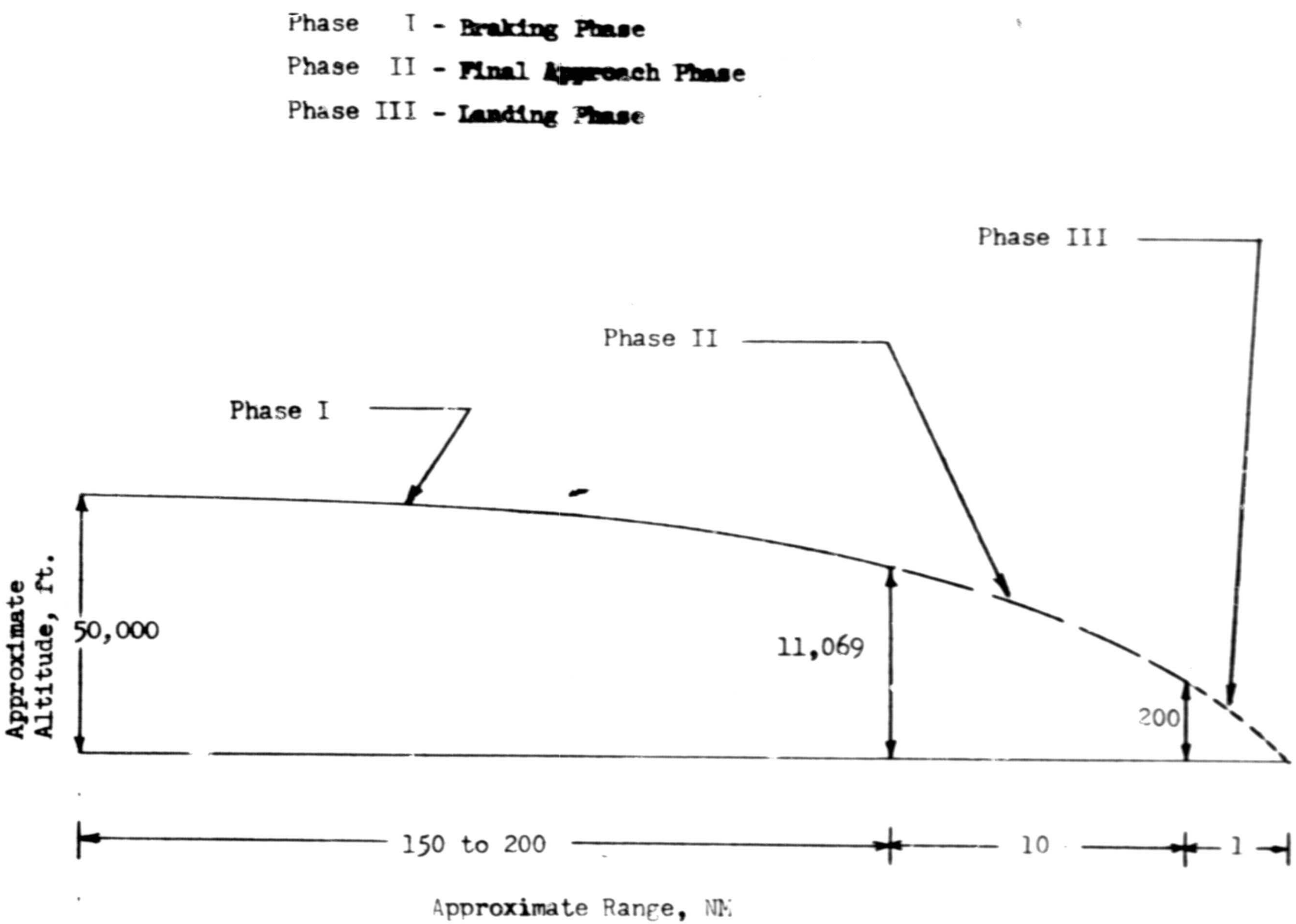
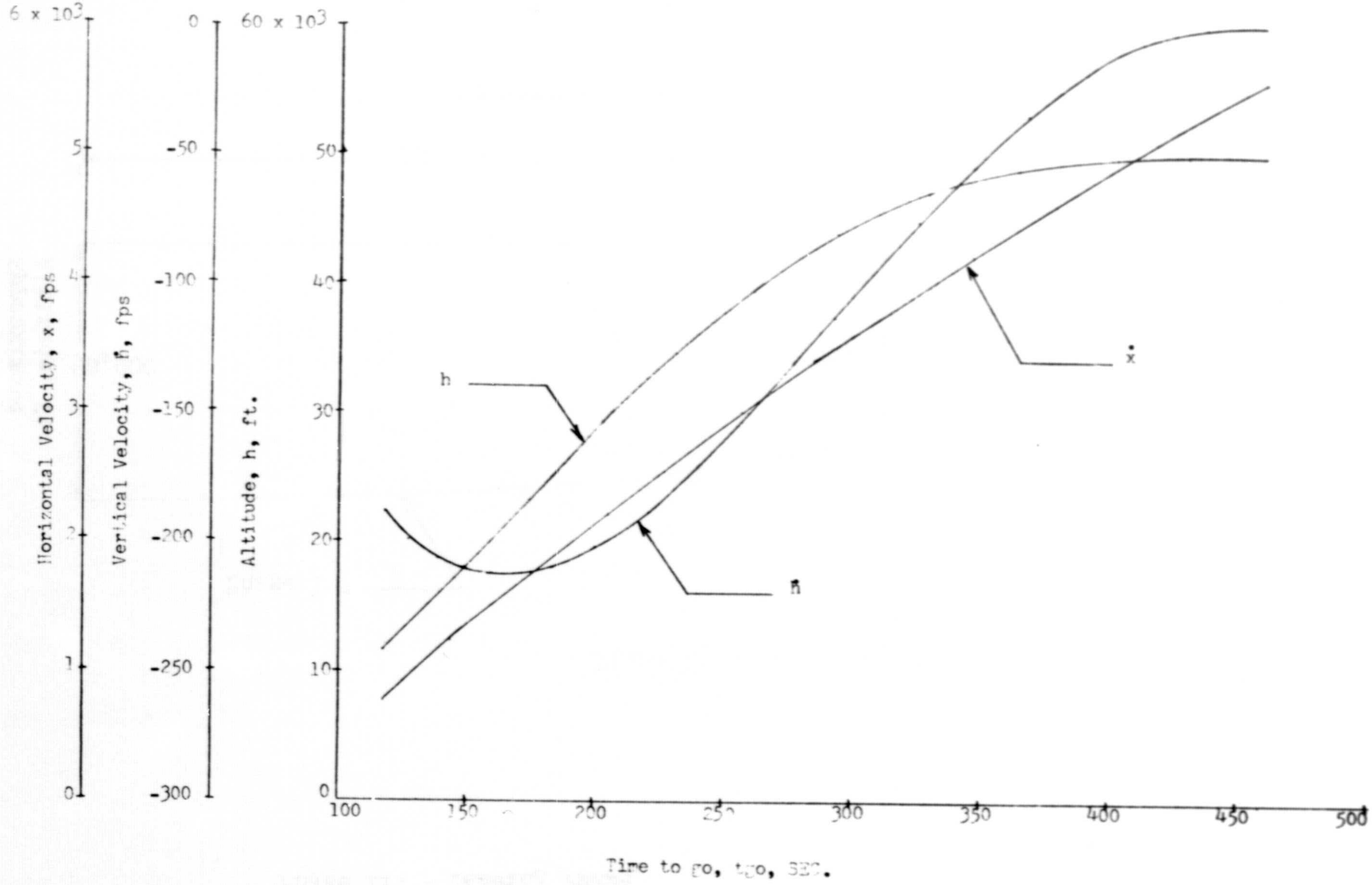
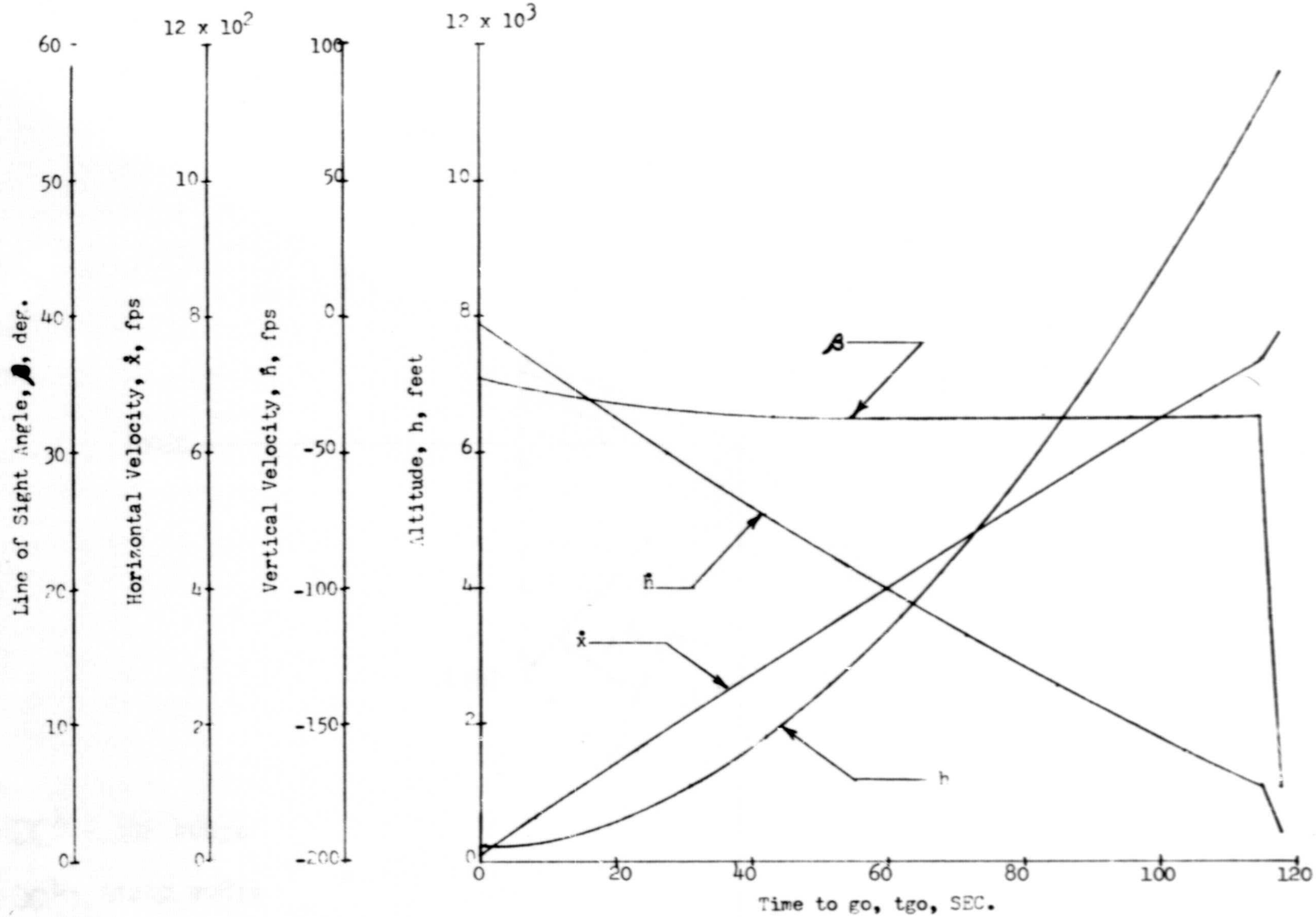


Figure 1.- Three phases of powered descent.



(a) Phase I

Figure 2.- Time history of powered descent.



(b) Phase II

Figure 2.- Time history of powered descent (Concluded).

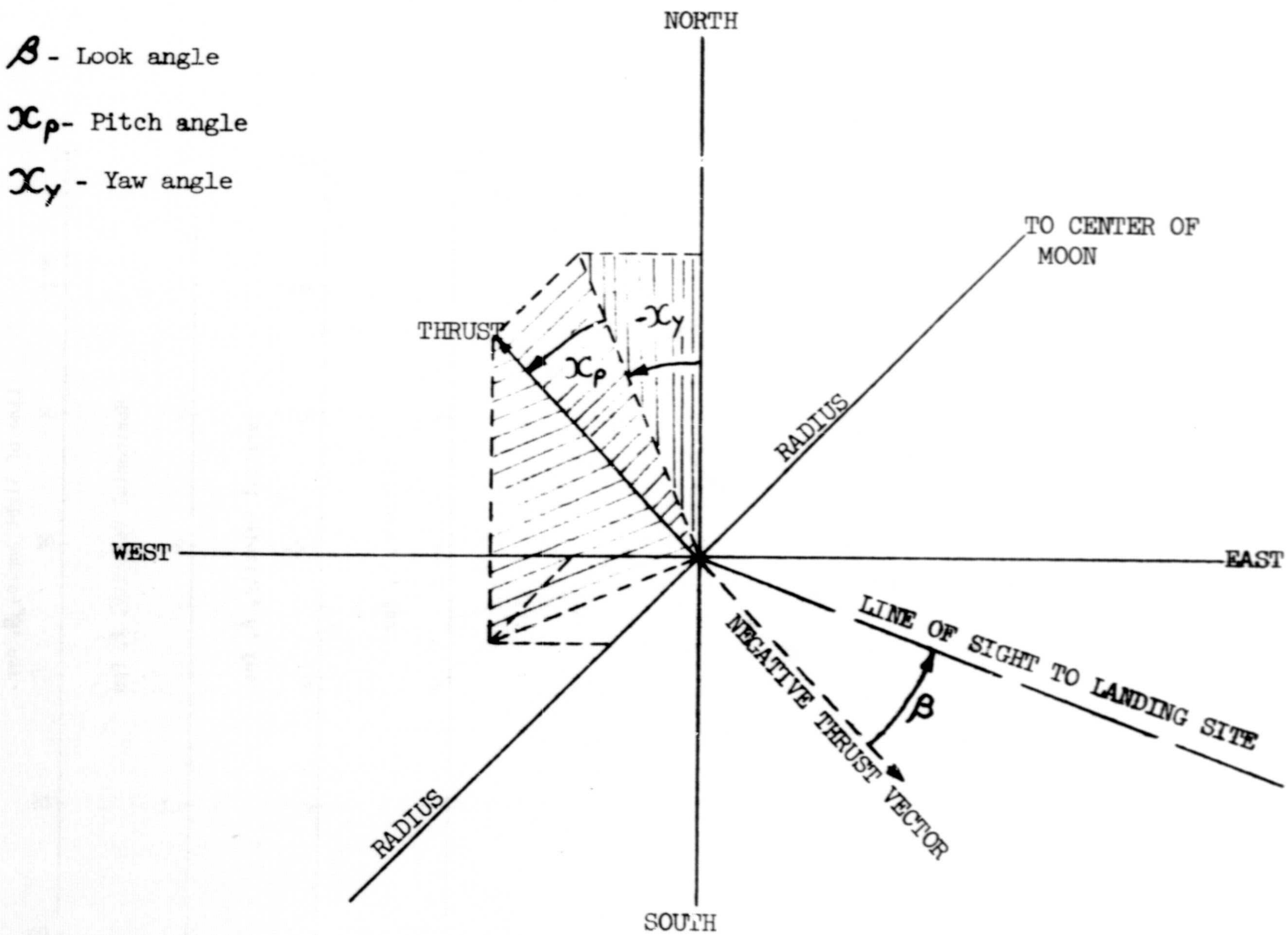


Figure 3.- Sketch of axis system.

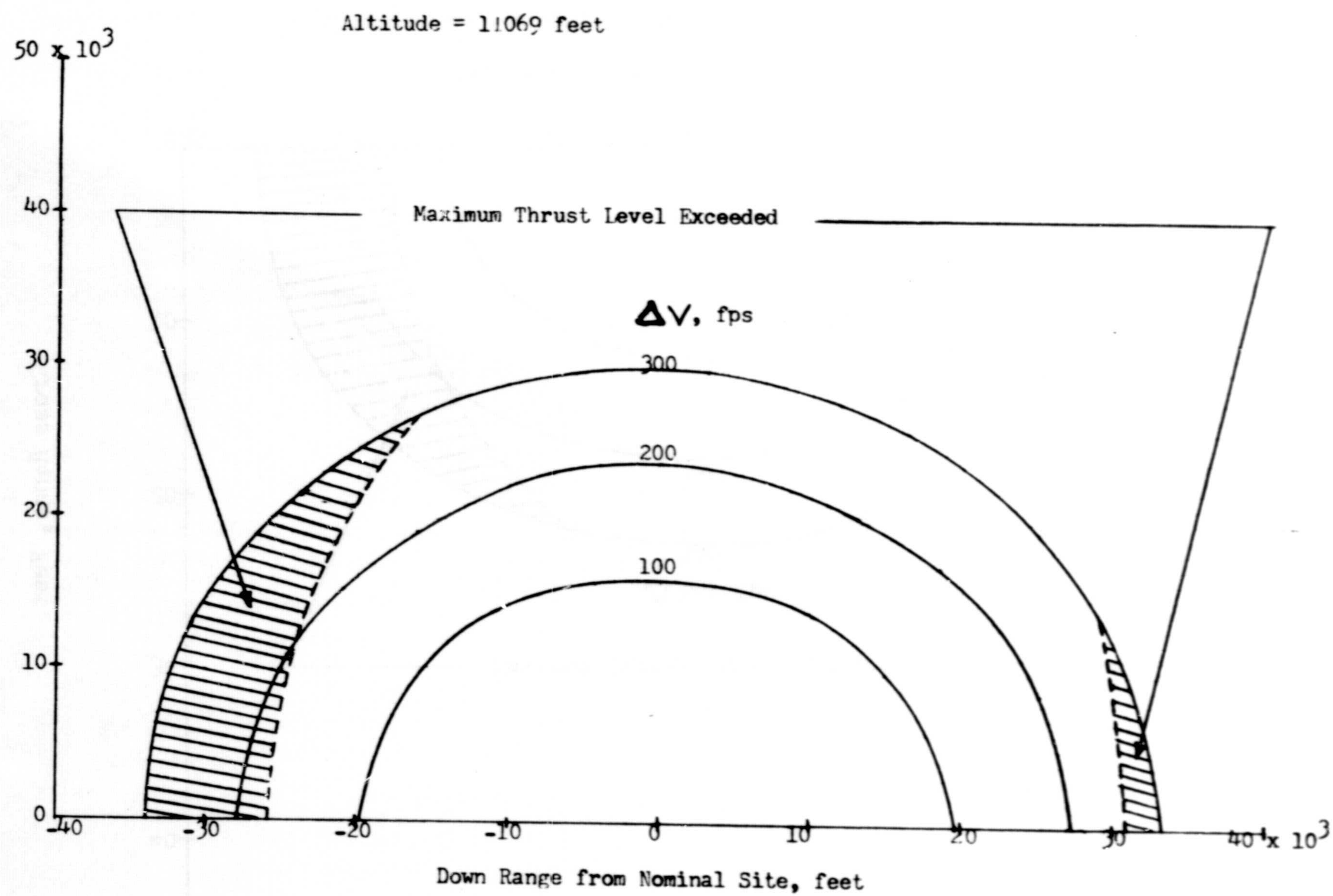


Figure 4.- Footprint from range of 43,730 feet.

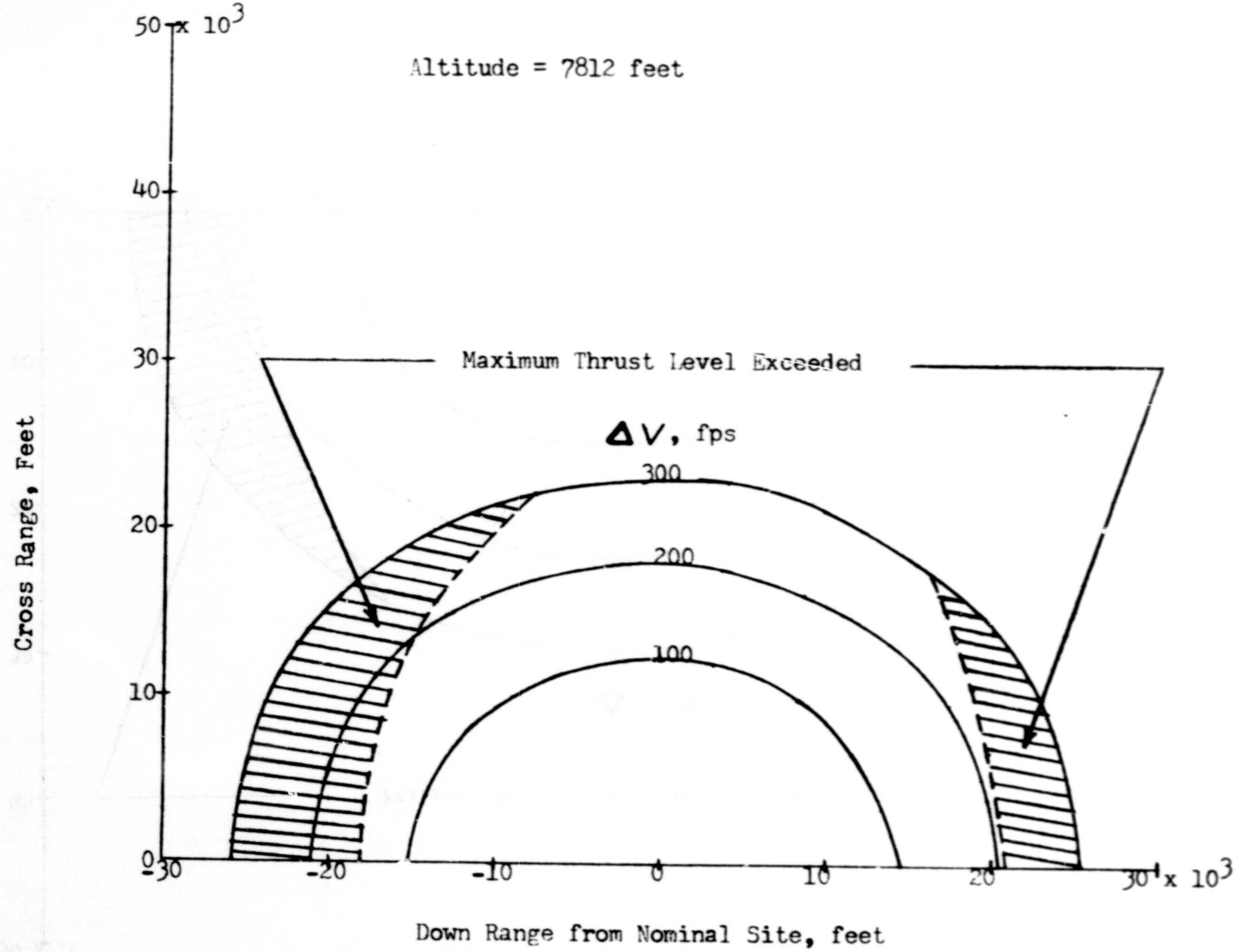


Figure 5.- Footprint from range of 30,210 feet.

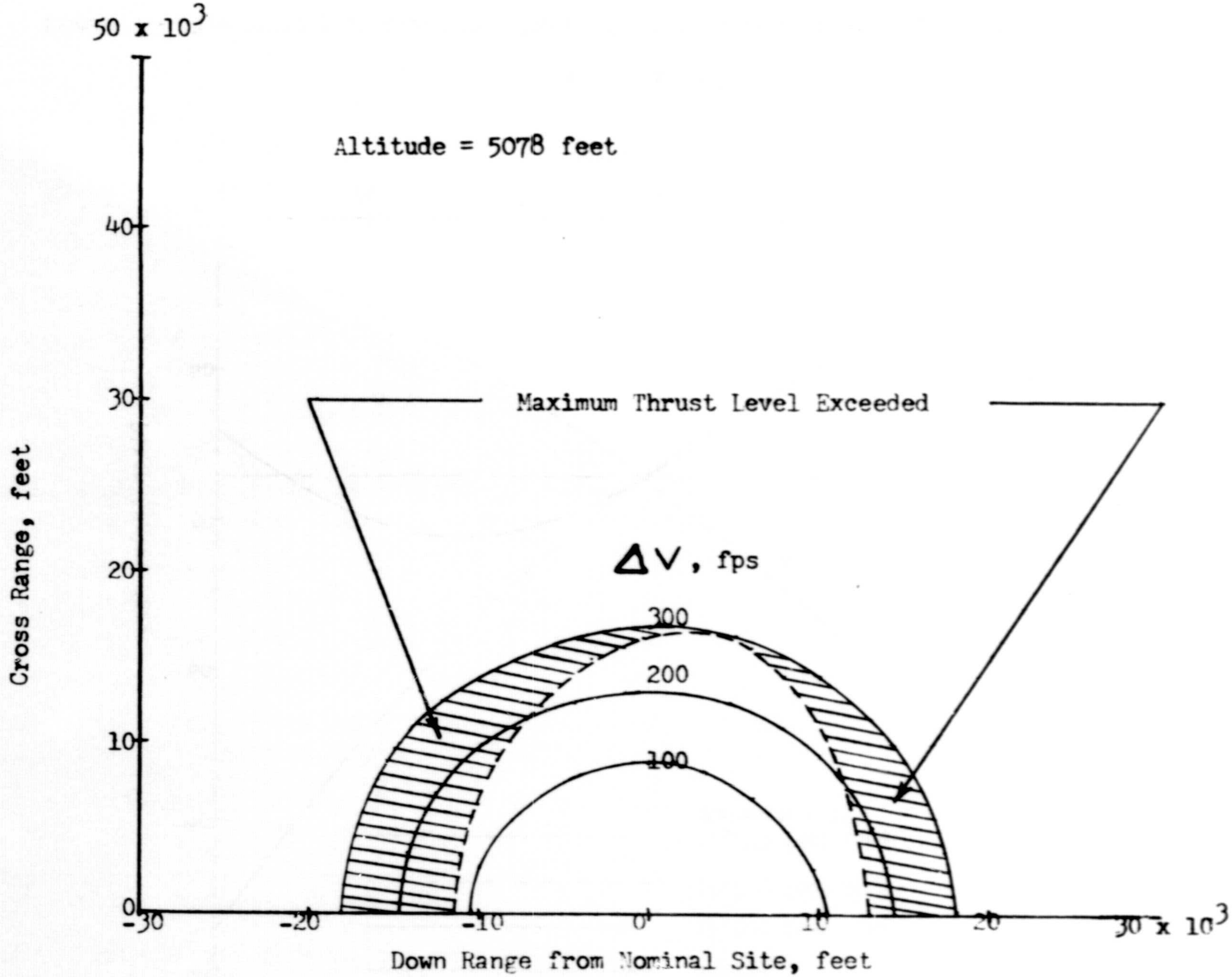
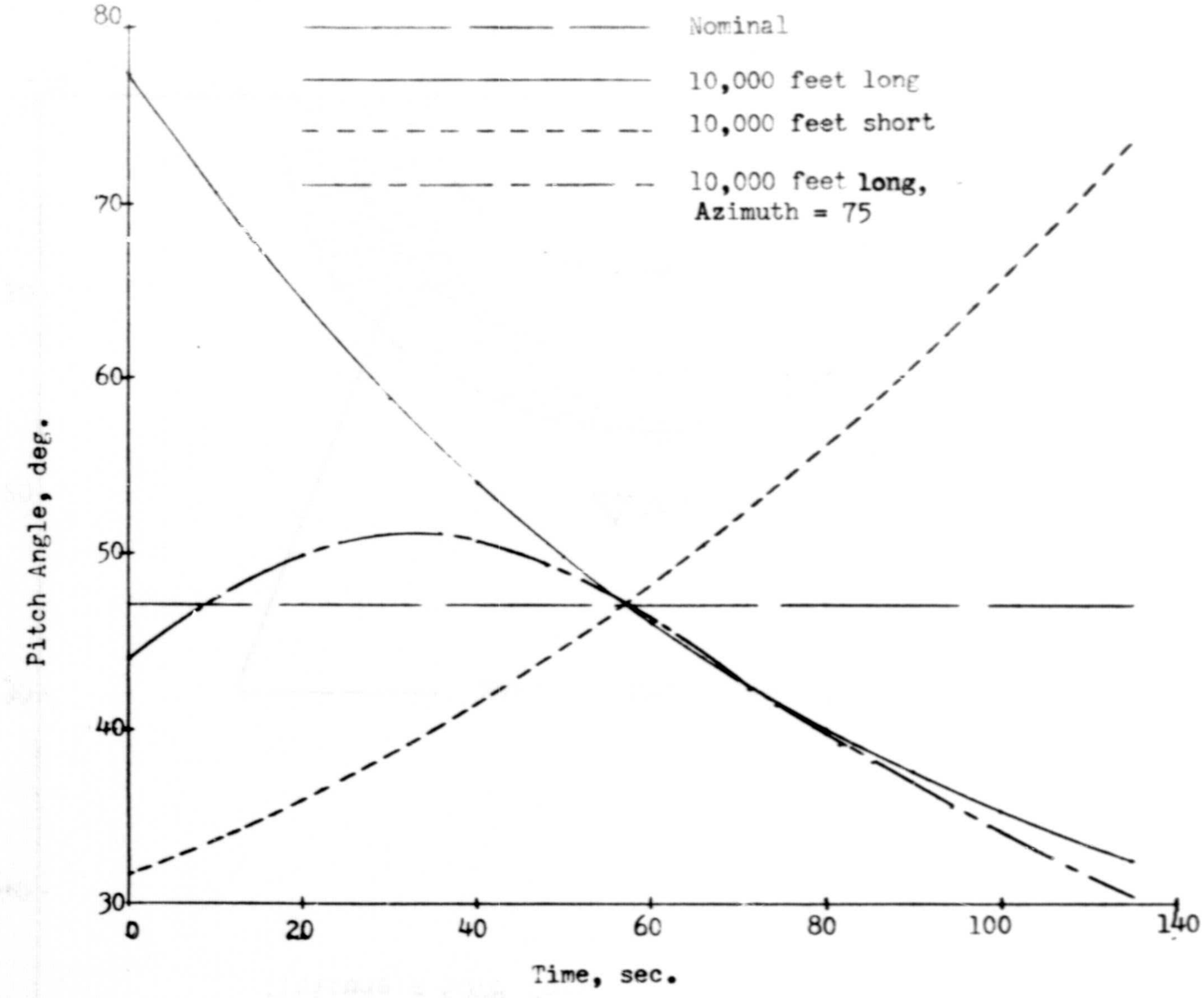
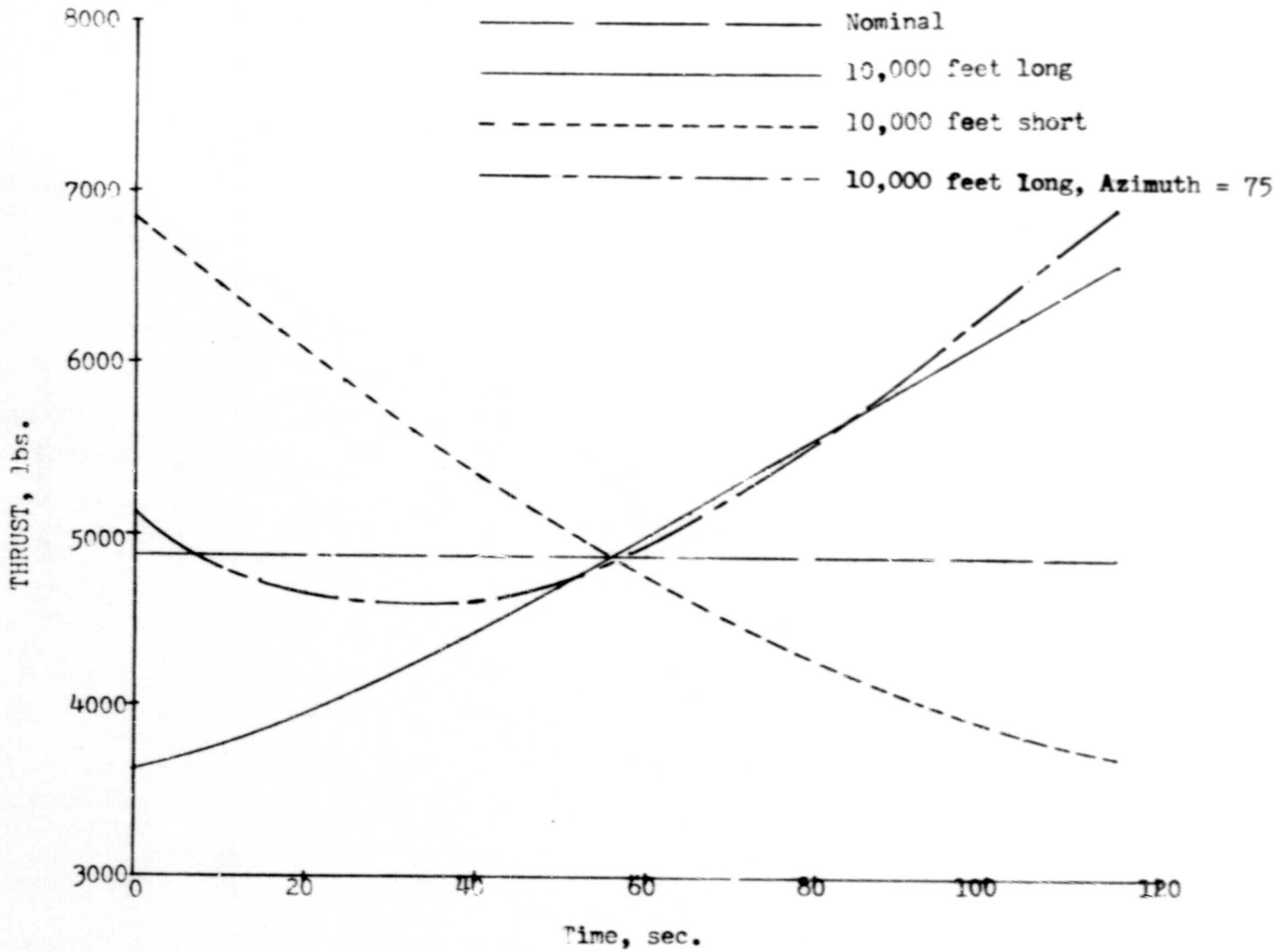


Figure 6.- Footprint from range of 19,110 feet.



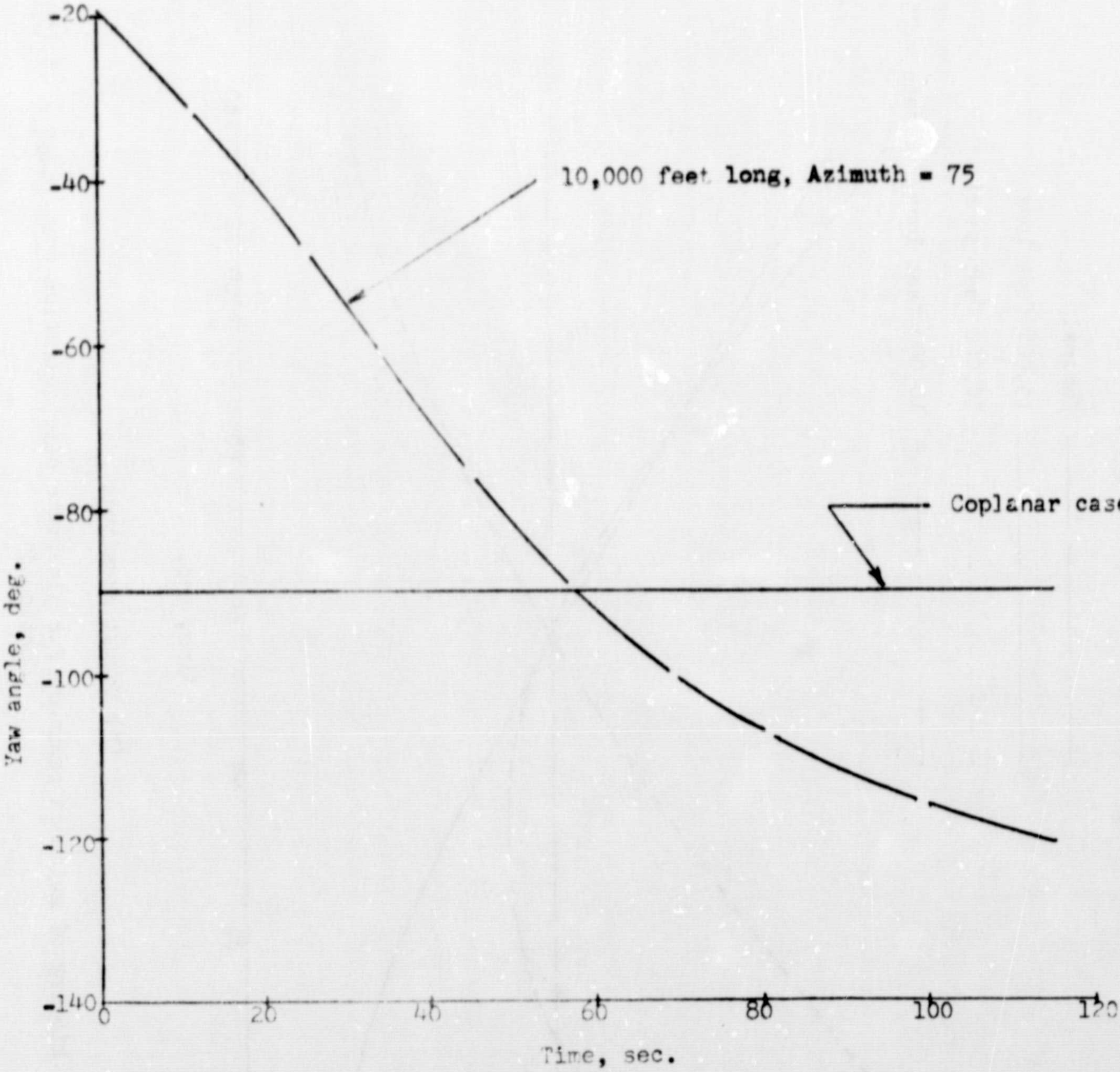
(a) Pitch angle

Figure 7.- Time history of guidance commands for alternate site selection from range = 43,730 feet.



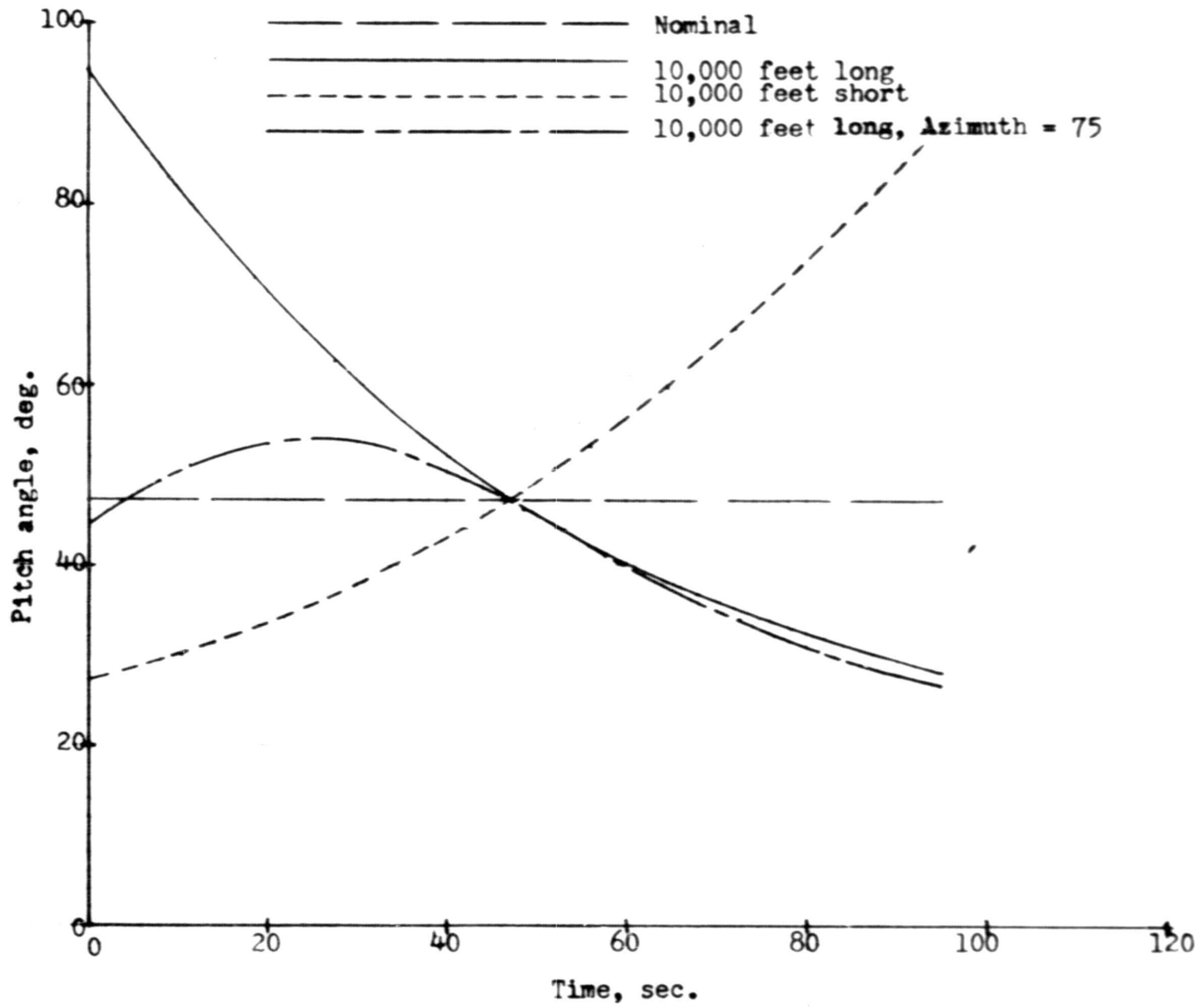
(b) Thrust magnitude

Figure 7.- Time history of guidance commands for alternate site selection from range = 43,730 (Continued).



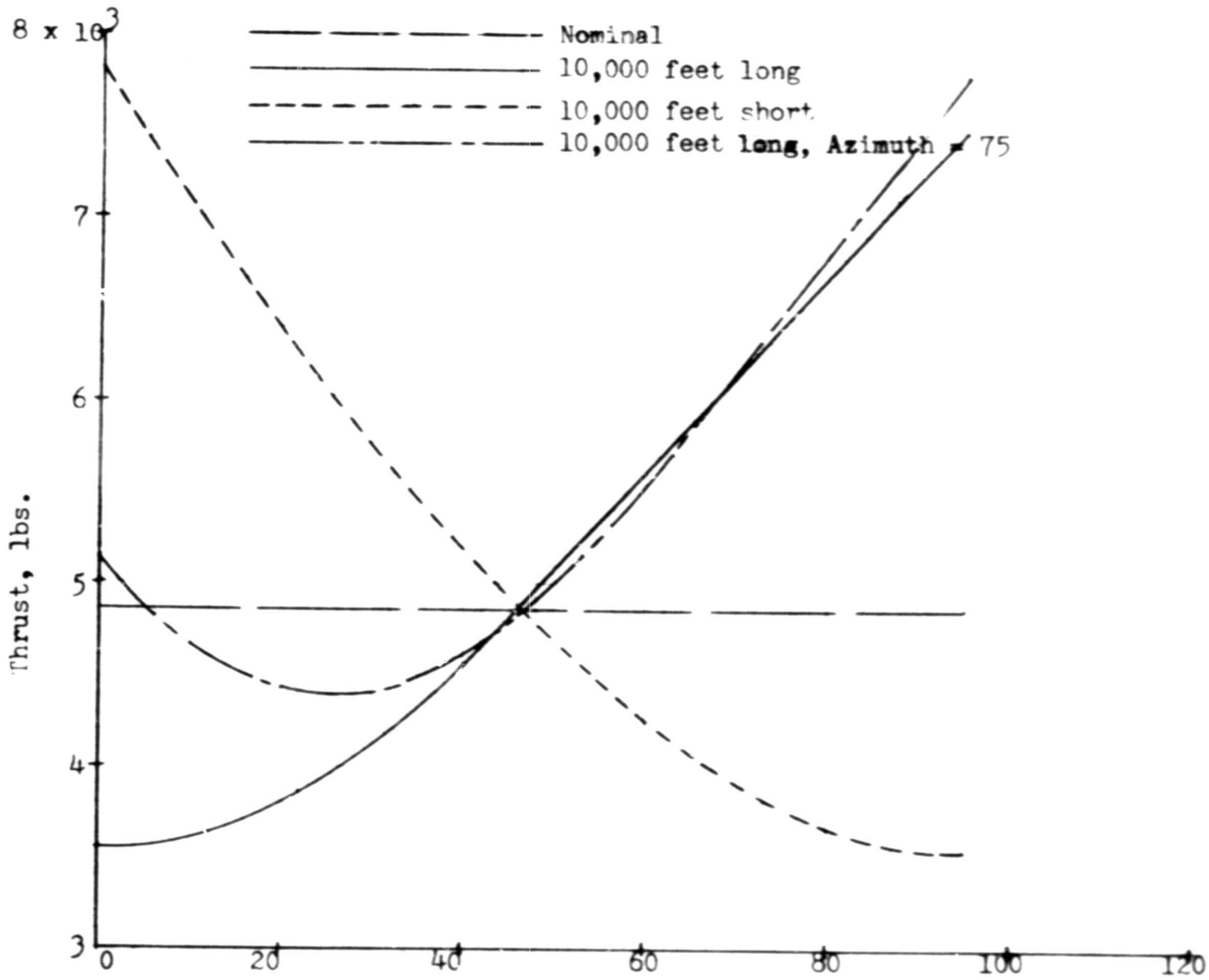
(c) Yaw angle

Figure 7.- Time history of guidance commands for alternate site selection from range = 43,730 feet (Concluded).



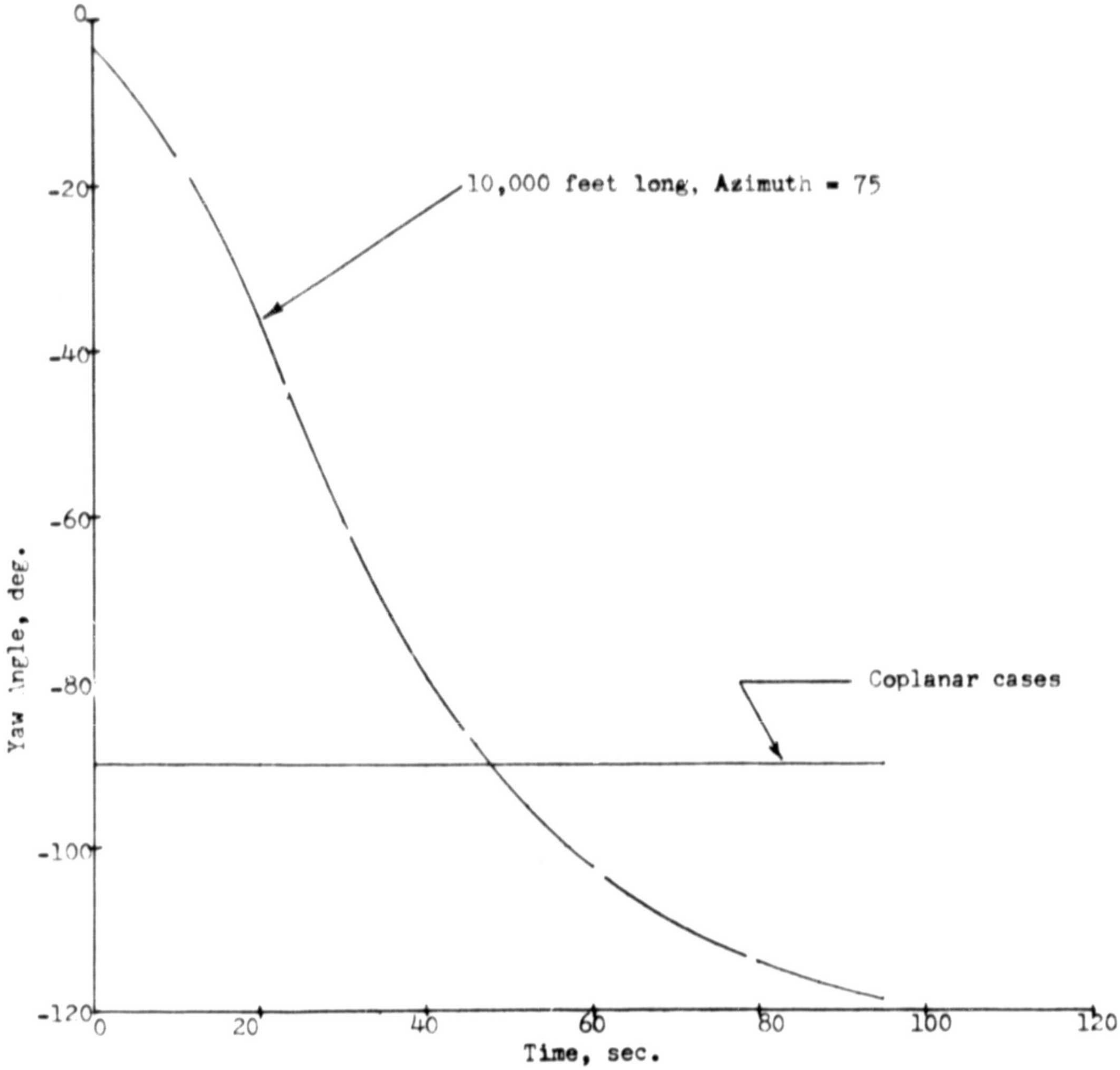
(a) Pitch angle

Figure 8.- Time history of guidance commands for alternate site selection from range = 30,210 feet.



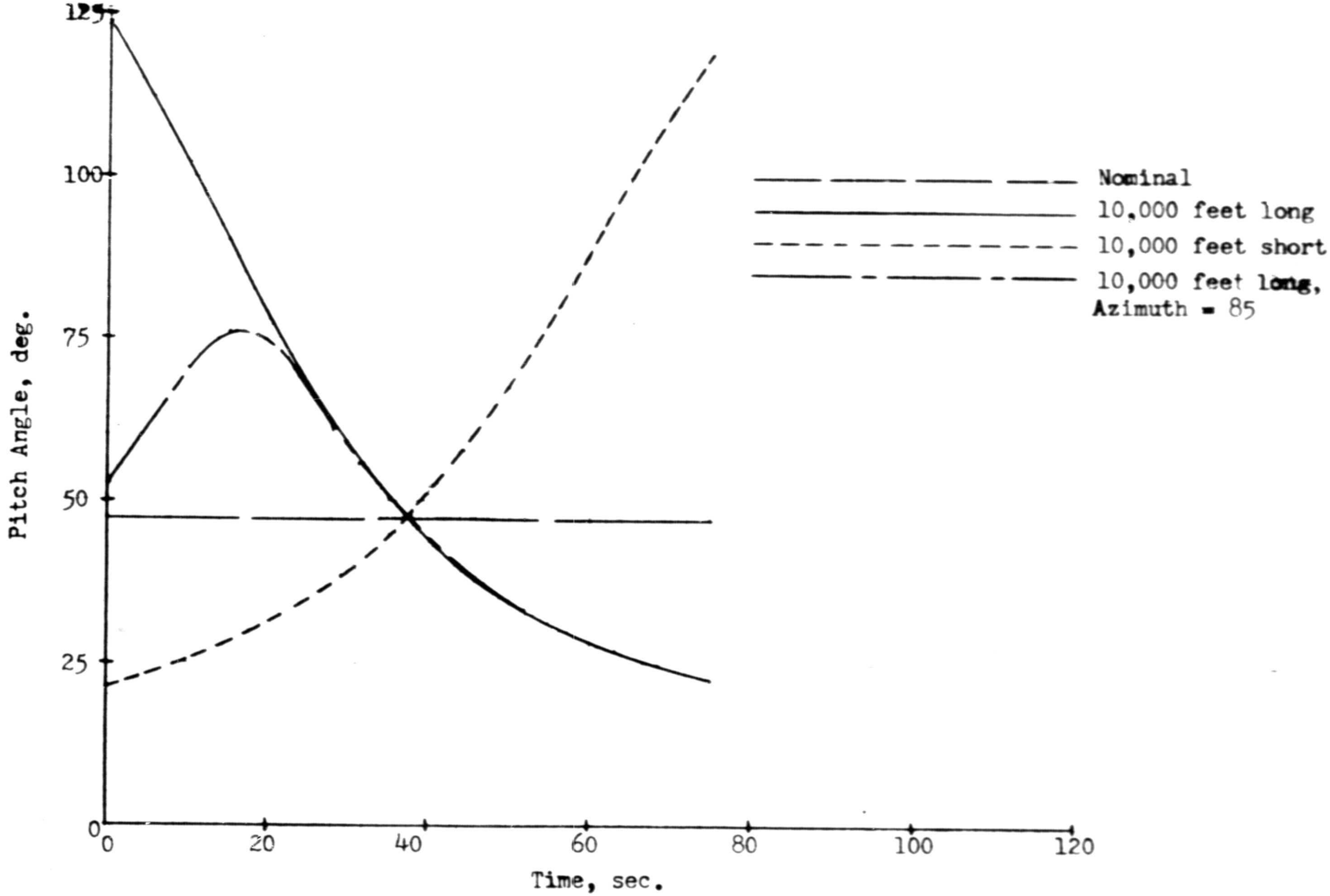
(b) Thrust magnitude

Figure 8.- Time history of guidance commands for alternate site selection from range = 30,210 feet (Continued).



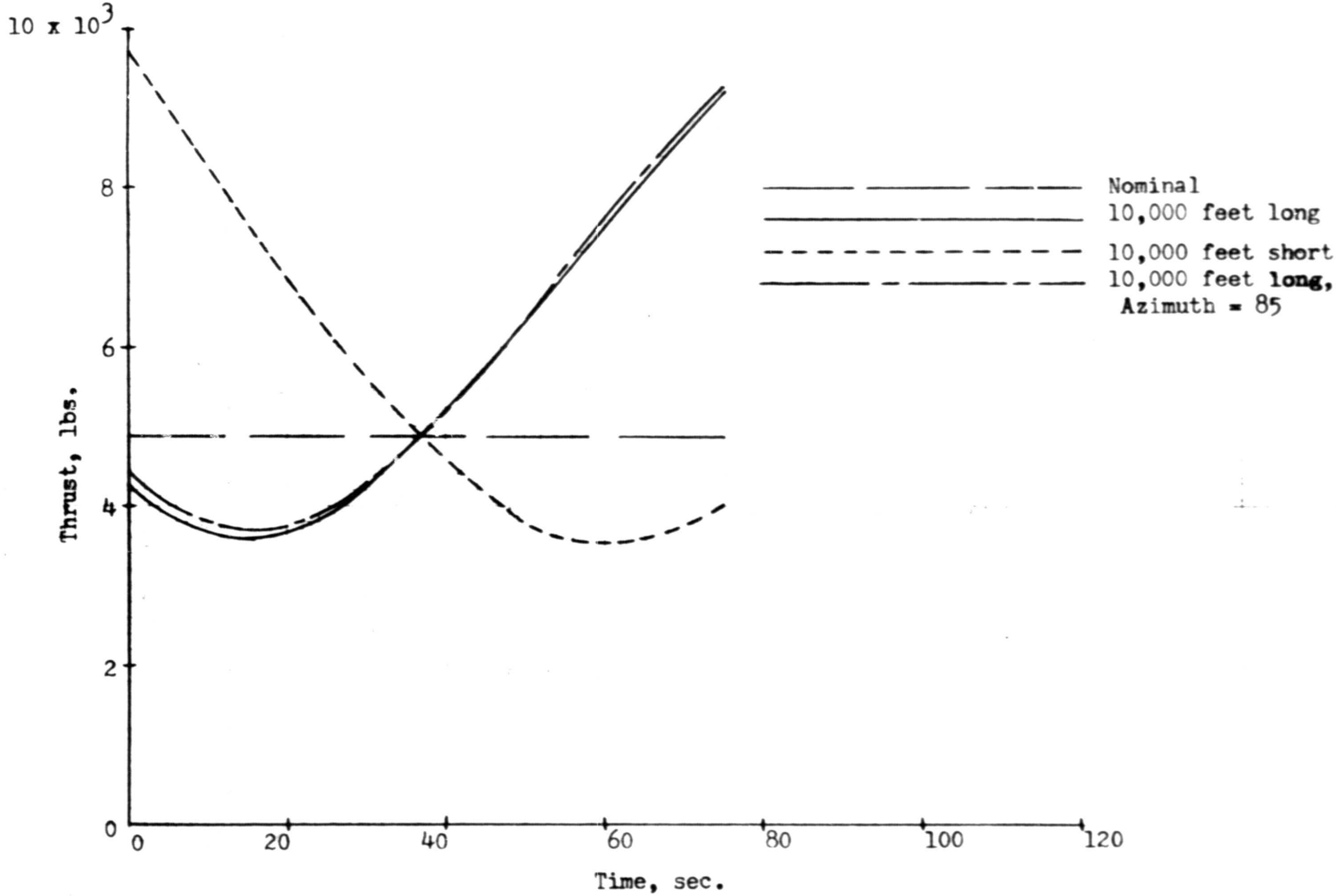
(c) Yaw angle

Figure 8.- Time history of guidance commands for alternate site selection from range = 30,210 feet (Concluded).



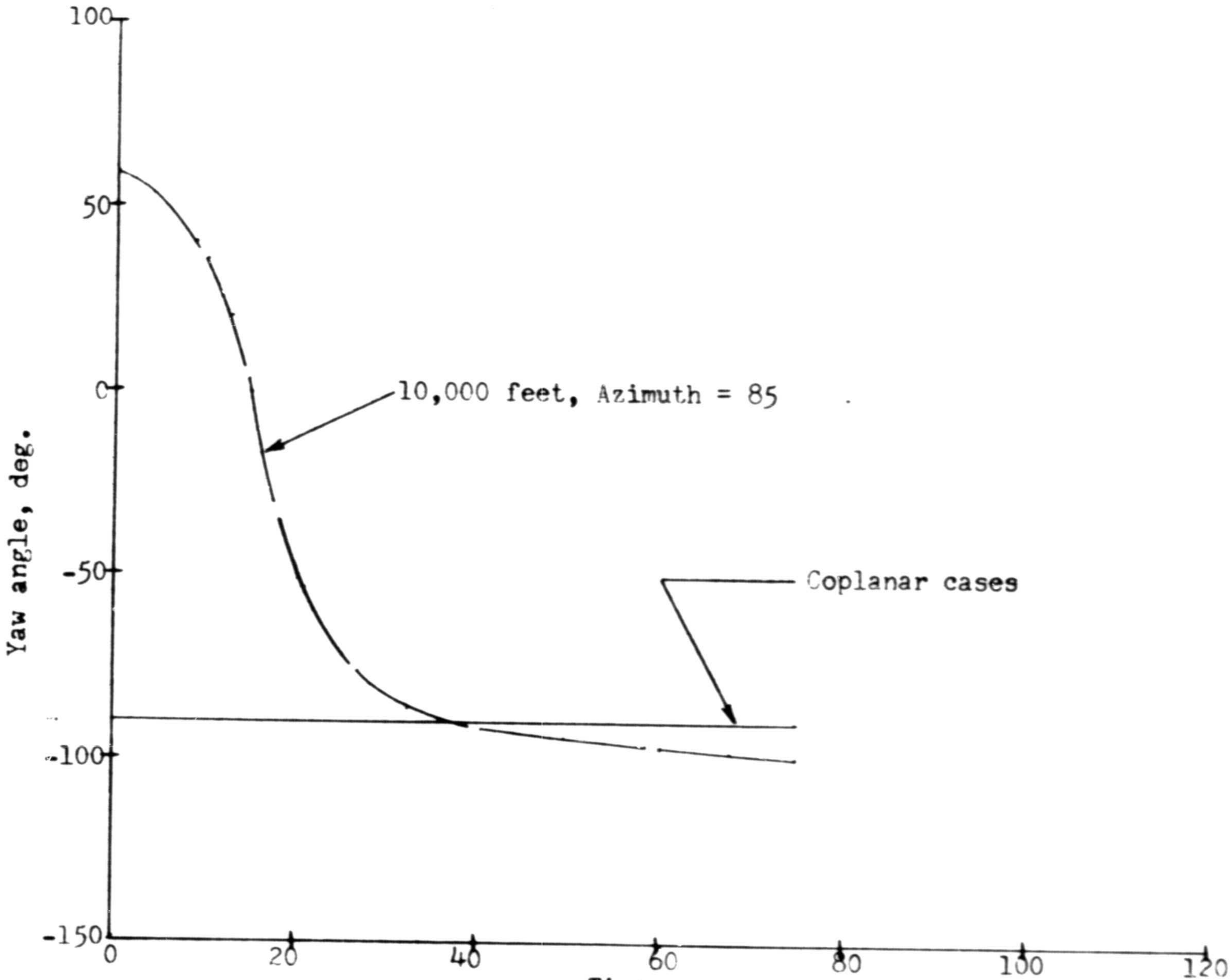
(a) Pitch angle

Figure 9.- Time history of guidance commands for alternate site selection from range = 19,110 feet.



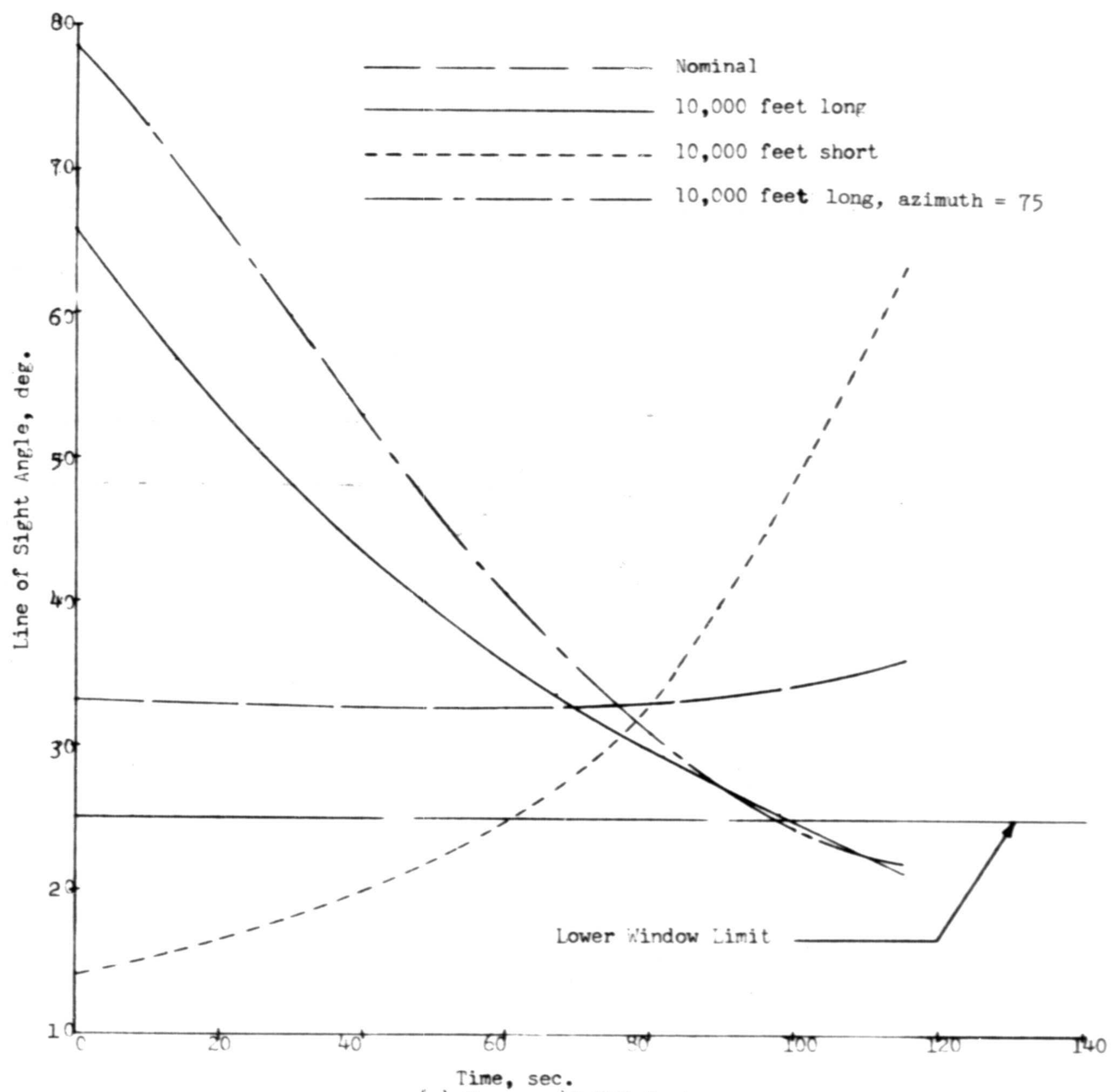
(b) Thrust magnitude

Figure 9.- Time history of guidance commands for alternate site selection from range = 19,110 feet (Continued).



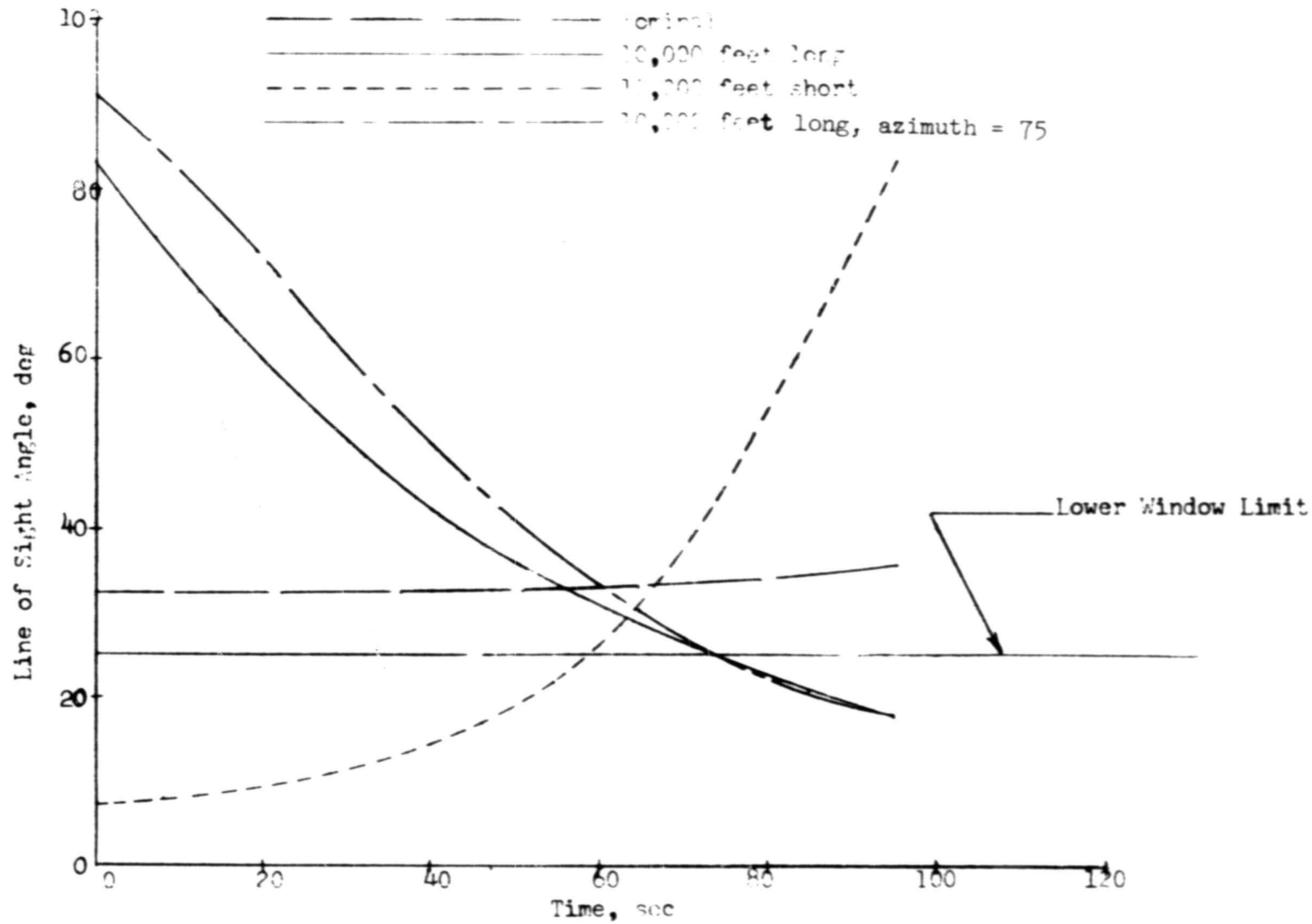
(c) Yaw angle

Figure 9.- Time history of guidance commands for alternate site selection from range = 19,110 feet (Concluded).



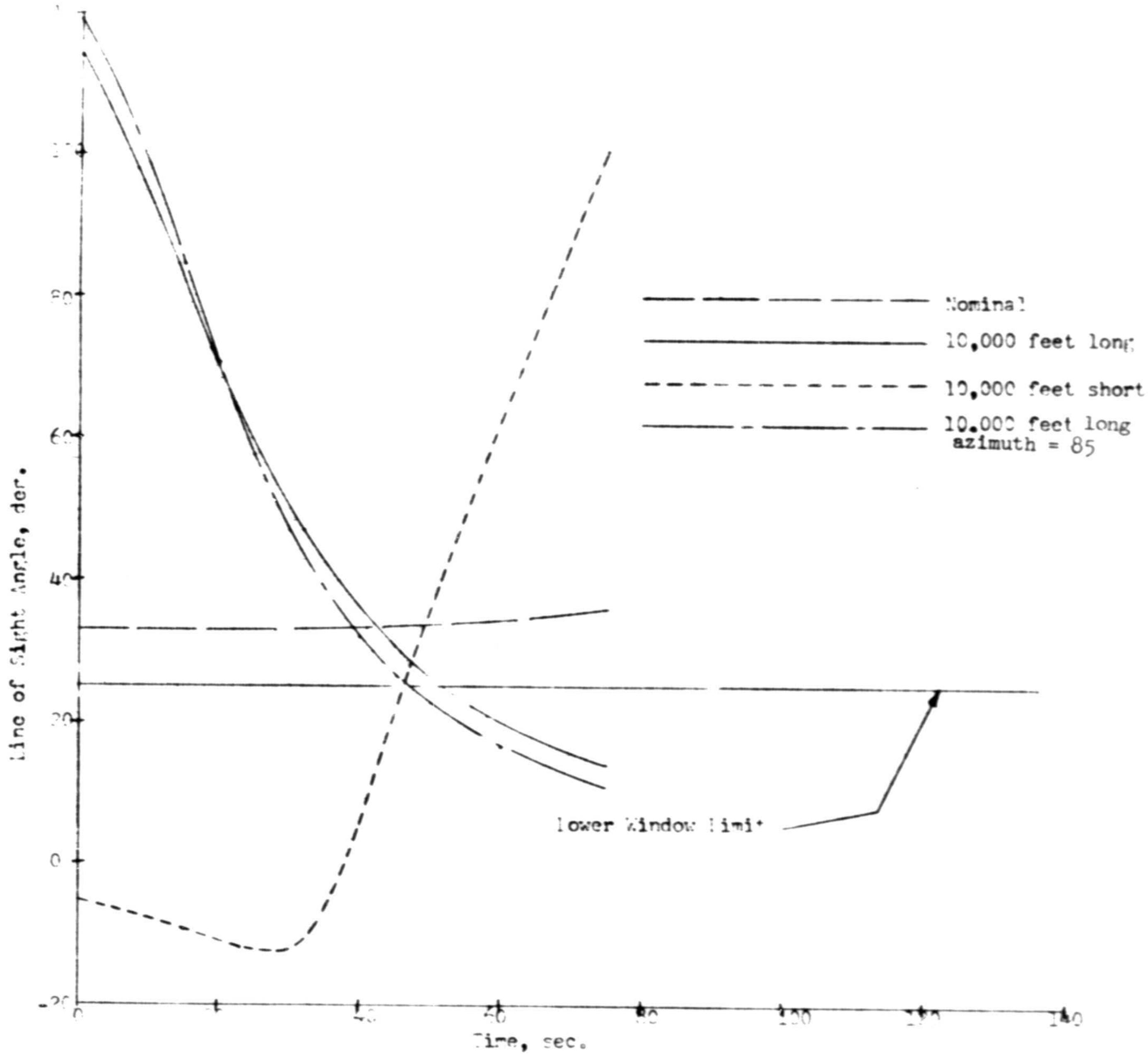
(a) Range = 43,730 feet

Figure 10.- Time history of line of sight angle for alternate site selection.



(b) Range = 30,210 feet

Figure 10.- Time history of line of sight angle for alternate site selection (Continued).



(c) Range = 19,110 feet

Figure 10.- Time history of line of sight angle for alternate site selection (Concluded).