NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 68-FM-232

December 4, 1968

GENERAL APOLLO SATURN V CSM LAUNCH ABORT ANALYSIS

Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

MSC INTERNAL NOTE NO. 68-FM-232

PROJECT APOLLO

GENERAL APOLLO SATURN V CSM LAUNCH ABORT ANALYSIS

By Edward M. Henderson
Flight Analysis Branch

December 4, 1968

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

Approved: Charlie C. Allen
Charlie C. Allen, Acting Chief
Flight Analysis Branch

Approved: J P Mayer
John P. Mayer, Chief
Mission Planning and Analysis Division

CONTENTS

TABLES

FIGURES

Figure		Page

Figure		Page

GENERAL APOLLO SATURN V CSM LAUNCH ABORT ANALYSIS

By Edward M. Henderson

1.0 SUMMARY

The abort studies contained in this document were conducted for a typical Apollo spacecraft and a typical Saturn V launch vehicle. These data will be representative for launch abort planning for any of the planned Apollo Saturn V launches that insert into a near-100-n. mi. altitude circular orbit. This document contains launch abort trajectories for the command and service modules (CSM). Specific trajectory data resulting from a launch escape vehicle abort, mode I, are not presented. The data presented shows the effects of variable launch azimuth, corresponding to the lunar launch window, on the various launch abort parameters. The only significant effect of the variable azimuth on the launch aborts are the landing coordinates. The abort trajectory data presented provides information on abort monitoring, abort maneuver requirements, and abort results.

2.0 INTRODUCTION

The abort studies contained in this document were conducted for a typical Apollo spacecraft (CSM-103) and a typical Saturn V launch vehicle (503). These data will be representative for launch abort planning for any of the planned Apollo Saturn V launches that insert into a near-100-n. mi. altitude circular orbit.

These trajectory studies were conducted by TRW Systems Group, Houston Operations, under MSC/TRW Task A-162, reference 1. The data were presented to MSC in reference 2.

The primary requirement for this launch abort analysis is to provide supporting trajectory data to qualify that the current techniques insure safe recovery of the crew and spacecraft for contingencies that could occur during the launch phase. The launch abort trajectory data shown is to provide information on abort monitoring, abort maneuver requirement, and abort result. It is assumed that the launch vehicle performance can vary over a wide range of conditions during launch. Therefore, these conditions must be bounded by limits that would allow sufficient reaction time by the crew and SC systems operations to perform a safe abort. Abort action would be initiated, if the LV violates these limits, to prevent flight with unsafe conditions. To avoid aborting a successful launch, the limit lines are defined for the least restrictive conditions which will allow a safe abort.

During launch the velocity, altitude, atmosphere, and launch configuration change greatly; therefore, several abort modes, each adaped to a portion of the launch trajectory, are required. Mode I aborts protect the spacecraft and crew while the launch vehicle is on the pad and during atmospheric flight. The procedure utilizes the launch escape system for safe separation, and these aborts result in suborbital trajectories with landings in the Atlantic Continuous Recovery Area (ACRA). The ACRA extends from the launch pad out to a full-lift landing range of 3200 n. mi.

Mode II abort capability begins once the launch escape tower (LET) has been jettisoned and continues until the contingency orbit insertion capability is obtained or until the resulting landings threaten the African coast. Mode II aborts consist of a manual CSM/S-IVB separation from the launch vehicle, CM/SM separation, an entry orientation maneuver, and an open-loop, full-lift entry. These aborts result in a suborbital trajectory with landings in the ACRA.

The mode III abort capability begins once the mode II landings threaten the African coast and continues until nominal insertion. The mode III aborts consist of a manual CSM/S-IVB separation, a fixed-attitude, retrograde service propulsion system (SPS) burn, CM/SM separation, an entry orientation maneuver, and an open-loop, bank-south-55°-entry.[a] These abort maneuvers result in suborbital trajectories with landings at the Atlantic Discrete Recovery Area (ADRA). The ADRA is currently defined by a half-lift (bank angle equals 55°) landing range, 3350 n. mi. from the launch pad.

The mode IV, or contingency orbit insertion (COI) capability, begins once the SPS can be used to insert the CSM into a safe orbit and continues until the launch vehicle has obtained a safe orbit. This COI maneuver consists of a manual CSM/S-IVB separation, a fixed-attitude, posigrade SPS burn that results in at least a 75-n. mi. perigee altitude, and subsequent SPS deorbit to a planned landing area. These maneuvers result in a safe orbital trajectory from which an alternate mission or an immediate deorbit can be planned.

---

[a]Bank-south-55°-entry is flow full-lift up to 0.2g then bank south 55°.

The apogee kick is also a COI procedure designed for nontime-critical contingency situations in the positive flight-path angle region near insertion. This maneuver consists of a manual CSM/S-IVB separation and coast to apogee. At apogee, a fixed-attitude SPS burn is initiated to raise perigee altitude to at least 75 n. mi. Like the mode IV maneuver, the apogee kick procedure results in a safe orbit, and an alternate mission or subsequent deorbit can be planned.

The following lists the basic abort requirements for each mode:

1. Mode I aborts are required to provide rapid separation from the launch vehicle during atmospheric flight.

2. Mode II aborts are required to assure sufficient entry sequencing time prior to atmospheric capture and/or to avoid excessive entry loads.

3. Mode III aborts are required to provide safe water landings for spacecraft systems malfunctions and extremely dispersed cutoff conditions near insertion.

4. Mode IV, or COI, is required to achieve a safe orbit following premature S-IVB cutoff.

5. Apogee kick, rather than the mode IV procedure, is prime in the positive flight-path angle region near insertion and allows the crew to attain a safe orbit following a premature S-IVB cutoff.

The data presented in this report are used to determine when the limiting flight dynamic conditions for a safe abort are reached, to determine which abort mode is required, and to provide the basic information needed to perform an abort and information concerning the abort result.

An important aspect of this analysis is the added consideration which must be due to the possible variations in launch azimuth. Since numerous variables determine the launch window and actual ascent azimuth, a comprehensive abort study must evaluate existing launch abort techniques and procedures as to their adequacy over the range of azimuths possible. Therefore, in addition to presenting an abort analysis for a typical Saturn V mission on a specified azimuth, this study also shows the effects of variable flight azimuths on the overall trajectory data and major abort limit and decision lines. It includes representative tracking information for each abort regime and contains typical flight dynamics display facsimiles and crew charts for monitoring the launch phase of the mission.

Reference 3 is a recent comprehensive study of the effects of dispersions on launch phase aborts. This reference can be used to supplement this document for dispersion type information. The sensitivities of the various abort parameters for variations in weight, altitude, burn attitude, and other parameters are discussed and graphically displayed. Although the trajectories considered in reference 3 were all S-IB trajectories, the conclusions are directly applicable to the S-V trajectories.

Other trajectory studies have been conducted on launch aborts for the Saturn V manned missions and are presented in references 4 and 5. These studies show representative abort trajectory trends that can be used to supplement the enclosed data. Another document that describes the current launch abort techniques in detail for the Apollo Saturn V launches is reference 6. This reference contains the flow charts and accompanying rationale for the abort cues, decisions, and data flow for each of the abort modes.

Spacecraft tumbling could occur for aborts in which the launch vehicle failures result in high rates. Typically, this type of abort could require an SPS burn to damp the rates; however, this additional sequence has a negligible effect on the resulting abort procedures and trajectories. Therefore, the tumbling abort simulations have not been included in these studies.

3.0 INPUT DATA

The input data was as follows:

1. Aerodynamic data - Tables of drag coefficient (C_D) versus Mach number and lift-to-drag ratio (L/D) versus Mach number for CM-103 were based on SC c.g. and weights for the beginning of mission taken from reference 7. These data are presented in tables I and II of this report. They are typical of the beginning-of-mission aerodynamics for current Block II spacecraft. A corresponding beginning-of-mission CM entry weight of 12 153 lb was used as a representative value.

2. Central body constants - Earth model constants were taken from reference 8. The launch pad location was taken from reference 9. The entry interface altitude is 400 000 ft, and the reference altitude for the time-of-free-fall (T_{ff}) calculation is 300 000 ft.

3. Thrust axis - During an SPS burn the thrust axis is aligned through the center of gravity to eliminate rotational moments. Because of the locations of the engine and center of gravity, this thrust axis is set prior to launch through the CSM center of gravity. This offset was simulated to be 2.15° from the X-body, corresponding to the null offset position (ref. 7). The thrust error due to the offset in the Y and Z components is negligible for this analysis.

4. Horizon monitor attitudes - A scribe mark has been positioned on the command pilot's window where the angle between the command pilot's line of sight and the CSM X-body axis is 0.553 radian, or 31.7° (ref. 10). By maneuvering the CSM to superimpose this scribe mark on the horizon of the earth, the command pilot obtains the attitudes illustrated in figure 21 for a mode III abort and in figure 38 for the mode IV and apogee kick maneuvers.

5. Nominal launch trajectories - The launch trajectory computer printout, obtained from reference 11, was used as the basis for the specific detailed analysis of a Saturn V launch on a 72° azimuth. Reference 12 contains five trajectories which were used to study the effects of variable azimuth on current launch abort procedures.

6. S-II and S-IVB tailoffs - S-II and S-IVB thrust and weight flow tailoffs were taken from reference 13. Tailoff is complete at 0.90 seconds after S-IVB cutoff and 0.56 seconds after S-II cutoff.

7. Tracking site locations - Reference 9 defines the S-band tracking station locations for manned Apollo missions. These sites along with the insertion ship location, described in reference 14, were used to provide a typical tracking summary for variable azimuth launches.

8. Trajectory simulation - The computer program documented in reference 15 was used to simulate flights. The multi-vehicle N-stage (MVNS) program has the capability to simulate both powered and coasting flight in a vacuum and in an atmosphere. For these studies vehicle rotational dynamics do not have any significant consequences and were not investigated.

The CSM/S-IVB (S-II) separation burn during an abort was simulated at the same inertial attitude as the vehicle has on the nominal trajectory at the time of abort initiation. If an abort is necessary during the mission, the separation burn will be performed at whatever attitude the vehicle has when separation occurs. The change in flight dynamic parameters due to the reaction control system (RCS) separation burn is so small that even a retrograde separation burn would have only a small effect on the accuracy of the data presented in this report.

All of the data, except where indicated, were generated under the assumption that the altitude at abort equals the altitude on the nominal trajectory at the time of abort. Certain plotboard data are calculated using the current vehicle altitude; therefore, deviations from nominal altitude can be considered by flight controllers during the mission. Digital readout data calculated on the basis of current altitude are also available to flight controllers during the mission.

9. CSM weights, weight flow rates, thrust - A typical SPS thrust and weight flow rate of 20 500 lb and 65.6 lb/sec, respectively, were obtained from reference 16. The resultant +X RCS thrust using four jets is 393.8 lb, and the corresponding weight flow rate is 1.444 lb/sec. The four-jet +X RCS ullage value used for this study is less than the total four-jet thrust deliverable due to the 10° nozzle mounting offset. Typical CSM and CM weights used were 63 471 and 12 153 lb, respectively (ref. 16).

10. Inertial measurement unit (IMU) reference system - The IMU reference system used in this report to define the attitude angles is a right-handed orthogonal coordinate system centered at the launch site. The positive X-axis extends down range along the flight azimuth and lies in the horizontal plane. The positive Z-axis is directed downward along the astronomical vertical at lift-off. The positive Y-axis completes the right-handed system. Figure 1 shows this orientation.

4.0 DISCUSSION OF LAUNCH ABORT TRAJECTORY DATA

4.1 General Trajectory Data

Figures 2, 3, 4, and 5 show typical trajectory parameters for a Saturn V mission. These particular curves were generated for Mission D; however, they are representative of nominal Saturn V launches. Thrust and weight flow termination occurs at guidance cutoff, and nominal insertion occurs 10 seconds later. Figure 4 shows typical gimbal angle readouts of the spacecraft onboard inertial measurement unit (IMU) for the nominal trajectory. These attitudes are referenced to figure 1. Figure 5 includes a bar graph showing the typical regions of contingency capability corresponding to each abort mode along the nominal launch trajectory.

Figures 6 and 7 show five typical ground tracks for the flight azimuths throughout the lunar launch window. These traces are similar to the locus of points describing the full-lift landing range, and are used to depict the same in portions of this document. The range of possible ascent azimuths extends from 72° to 108°. Included on figures 6 and 7 are constant range lines showing down-range distances from the launch pad along each flight azimuth.

Figure 6 shows the typical tracking site acquisition circles associated with the stations listed in reference 9. These ellipses are based on a 100-n. mi. altitude and a 0° elevation angle at acquisition. The insertion ship location shown on figure 6 was obtained from reference 14 and is positioned for optimal tracking coverage over the indicated range of azimuths. The dotted lines on figure 7 depict the landing ranges corresponding to the end of the mode II region (3200 n. mi.) and the ADRA (3350 n. mi.). Also shown on figure 7 are three landing footprints showing the relative landing range control at the indicated positions along the ground tracks. These footprint lengths remain relatively constant along the range of ascent azimuths at similar down-range distances.

If a contingency develops during the ascent phase and requires an abort, yet is not time-critical, then the abort action will be delayed until one of the fixed times of abort. These are defined as ground elapsed times of 2^m00^s, 3^m00^s, 4^m30^s, and 9^m00^s. Figure 8 shows the African continent on a plot having launch azimuth as ordinate and down-range distance from the launch pad as abscissa. Note that for flight azimuths greater than 92°, the land mass shrinks from approximately 4600 n. mi. to between 16-0 and 1200 n. mi., substantially decreasing the possibility of land landings.

Figure 9 shows a plot of down-range distance from the Cape as a function of inertial velocity. Scale 1 depicts conditions during the entire ascent phase, and scale 2 shows the region near insertion. This plot is representative for all launch azimuths and can be used in conjunction with other figures in this document to relate conditions at abort initiation to distances from the Cape.

4.2 Mode II Abort Data

The sequence of events for typical mode II aborts is listed in table III. Mode II coverage begins when the LET is jettisoned and ends when the landing range, resulting from the sequence listed in table III, is greater than 3200 n. mi. down range of the launch pad (end of ACRA). For nominal Saturn V missions, tower jettison occurs approximately 3 minutes after lift-off. The duration of mode II capability displayed on figure 10 is representative of the length of coverage for Saturn V missions.

Figures 11, 12, 13, 14, and 15 show S-band tracking coverage during nominal mode II aborts for flight azimuths of 72°, 81°, 90°, 99°, and 108°. Lines showing acquisition of signal (AOS) and loss (LOS) for nominal altitude and 0° elevation angle, are presented in terms of ground elapsed time from lift-off and ground elapsed time of abort. The cross-hatched regions depict regimes having no tracking coverage, and the communication blackout regions have been included to show the times when ionization precludes S-band communication. Ground elapsed time at 23 500 ft (drogue chute deployment) is also included to show the termination of the abort simulations.

During the entry portion of an abort, the maximum acceptable g-load is considered to be 16g. Figure 16 shows the movement of the 16g full-lift entry limit line and the minimum entry sequence line (T_{ff} equals 100 seconds to 300 000 ft) as functions of flight azimuth. Notice that the 72° flight azimuth is most constraining for the entry load factor limit lines, whereas the 108° azimuth restricts free fall time the most. The relative movement of these major abort limit lines with launch azimuth is so small that the 72° limit can be used in each case for all azimuths with negligible effect on abort capability in the mode II region. These abort limits, as displayed in real time (discussed in Section 5.2), will account for the variations in azimuth.

Figure 17 presents typical 16g and time-of-free-fall limit lines which were generated for Mission D. Also included in this plot are constant full-lift landing range lines showing the variation in landing range capability throughout the mode II regime. Constant entry load factor lines showing full-lift entry decelerations from 10g to 20g are presented as functions of inertial velocity and inertial flight-path angle at entry interface altitude (400 000 ft) in figure 18. This figure provides a quick means of estimating entry decelerations when the anticipated trajectory conditions at 400 000 ft are known. These g-curves are invariant with respect to ascent azimuth and were generated for a lift-to-drag ratio of 0.29.

The major effect of variable azimuth launches on mode II aborts is that the actual full-lift landing points (geodetic latitude and longitude) will move south with southerly launch azimuths. Figure 19 shows the maximum deviation in full-lift landing range as a function of inertial velocity of abort. It can be used in conjunction with either figure 6 or 7 to obtain landing point locations for mode II aborts on azimuths between 72° and 108°. Knowing the acsent azimuth and inertial velocity at abort, one can obtain a full-lift landing range from figure 19. This landing range can then be transferred to the corresponding flight azimuth or ground track in either figure 6 or 7, and the geodetic latitude and longitude of landing can be read off the scales. Tables IV and V list pertinent characteristics for typical nominal mode II aborts for a launch azimuth of 72°.

Figure 20 shows a plot of the typical differences between the predicted time of free fall to 300 000 ft above a spherical earth with the launch pad radius and actual free-fall time above the ellipsoid as functions of abort velocity. All mode II data were generated under the assumption that the altitude at abort equals the altitude on the nominal trajectory at the time of abort. Also shown in figure 20 is the variation in the maximum entry load factor following nominal mode II aborts on flight azimuths between 72° and 108°. Notice that the variation in load factor is relatively small, approximately 0.1g; however, variations in free-fall time may be as great as 12 to 15 seconds for the more southerly ascent azimuths.

4.3 Mode III Abort Data

The sequence of events for mode III aborts for Saturn V missions is listed in table VI. The RCS plus X translation burn begins 3 seconds after abort initiation and is performed at the same inertial attitude that the vehicle has on the nominal trajectory at the time of abort initiation. The retrograde horizon monitor attitude simulated, illustrated in figure 21, is altitude dependent, as shown in figure 22. During the SPS burn the stabilization and control system (SCS) will maintain the CSM in the inertial attitude which corresponds to its horizon monitor attitude at SPS ignition. The bank angle used from 0.2g deceleration to drogue deployment is 55° south to be consisten with the end-of-mission backup entry procedure. Also, 55° bank maximizes cross-range travel, which further reduces a low CM/SM recontact probability.

Mode III abort capability begins when the full-lift landing range exceeds 3200 n. mi. Mode III ends once time-of-free-fall restrictions will not allow sufficient SPS burn time to assure a safe water landing. The landing location for mode III aborts is in the ADRA, 3350-n. mi. down range of the launch site. Figure 23 shows the movement of the ADRA target as a function of launch azimuth.

Figure 24 shows typical CM landing range as a function of ground elapsed time of abort for the mode II, mode III interface region. Note that the crew would orient the CM for a full-lift entry until the landing range exceeded 3200 n. mi. from the launch pad. When the landing range exceeds 3200 n. mi., the spacecraft crew would perform a mode III abort and roll the CM 55° south during entry. As is indicated by figure 24, early mode III aborts require no SPS retrograde burn and will land short of the 3350-n. mi. ADRA. SPS burn times less than 2 seconds will not be considered for nominal mode III aborts.

Figure 25 presents a typical mode III abort region which was generated for Mission D. Shown are constant time-of-free-fall lines to 300 000 ft after SPS cutoff, constant SPS ΔV lines, the 16g entry-load-factor line, and a line depicting an apogee altitude of 500 n. mi. The mode III ΔV lines will shift approximately 100 fps over a range of azimuths from 72° to 108°. Figure 26 shows the total variation in selected mode III ΔV lines over this range of flight azimuths. The circled points shown on figure 26 are data taken from the previous figure (fig. 25) and represent constant ΔV lines for a Saturn V mission on a 72° azimuth. For variable azimuth missions, then, it is necessary to present only mode III ΔV lines for the 72° flight azimuth since they will be the most constraining. Should delays in lift-off necessitate launching further south, the same plot could be used to estimate mode III SPS ΔV on any azimuth and it would be known that the resulting landings will be slightly west of the ADRA. Figures 27 and 28 show typical mode III abort regions for plus and minus 10-n. mi. altitude dispersions at abort. Again, lines depicting constant SPS ΔV for off-nominal altitudes at abort need only be shown for the 72° flight azimuth as these are the most restrictive.

SPS burn duration and typical CSM weight loss are shown as functions of sensed velocity change in figure 29. This SPS burn relationship is independent of burn attitude and, therefore, is also valid for mode IV and apogee kick burns. CSM weight is shown for more accurate interpretation of burn history, and the curves must be adjusted to conform with proper weight.

Figure 30 shows the time of free fall to 300 000 ft after SPS cutoff and the maximum entry load factor following nominal mode III aborts for a typical Saturn V ascent on a 72° flight azimuth. Note that these data are representative of conditions following nominal mode III aborts and are well within the abort limits established for Saturn V missions. Reentry decelerations following both mode II and mode III aborts are relatively insensitive to azimuth variations; however, the difference between predicted and actual free-fall time to entry interface does increase along more southerly azimuths. Figure 31 presents the differences between predicted and actual free-fall time for a nominal mode III abort as functions of flight azimuth. For example, figure 31 indicates that for mode III aborts on a 108° flight azimuth, the actual free-fall time to entry interface (300 000 ft) will be 10 to 12 seconds less than the predicted time.

Figures 32 through 36 present the tracking coverage analysis for nominal mode III aborts on flight azimuths between 72° and 108°. Also included in each figure is the S-band communication blackout region, which is depicted by the cross-hatched area. Note that the blackout duration is relatively insensitive to azimuth and lasts approximately 1 minute 40 seconds. Loss of tracking coverage during nominal mode III aborts is shown by the shaded regions in figures 32 through 36. Notice that of the five flight azimuths investigated, the 108° ascent has the least coverage duration. SPS mode III burn duration is shown to estimate tracking during and after the burn for each azimuth.

Figure 37 shows the retrograde SPS burn required to land at the ADRA as a function of ground elapsed time of abort for a typical mode III abort on a 72° flight azimuth. Note that this curve was generated assuming a hypersonic L/D equal to 0.267. For larger L/D's, this curve will shift slightly to the left, since the increased range capability due to the higher L/D ratio will increase the SPS burn required to assure an ADRA landing for a given time of abort. Table VII presents typical characteristics for nominal mode III aborts on a 72° flight azimuth.

4.4 Mode IV COI Data

The sequence of events for a mode IV abort is given in table VIII, and the posigrade attitude simulated is shown in figure 38. A mode IV abort is a COI maneuver using the SPS. The resulting perigee attitude must be at least 75-n. mi., and the apogee must be low enough to permit a deorbit from any point in the orbit. In real time during an actual mission, the Real-Time Computing Complex (RTCC) generates an SPS ΔV such that the resulting perigee altitude is at least 75 n. mi. at SPS cutoff. Flight control then adds an additional 100 fps to the RTCC-computed burn magnitude and transmits this "padded" value to the spacecraft crew. Currently planned SPS propellant loadings for Saturn V missions allow for a total sensed velocity change of approximately 10 000 fps. Since the typical maximum ΔV need for the COI is less than 4000 fps, the remaining 6000 fps is more than sufficient to arrest any rates and deorbit to a planned recovery area. The fixed ignition time and fixed attitude during the burn are instrumental in the relative low ΔV orbital capability.

A COI capability analysis was investigated for Mission D and is presented in figure 39. This figure shows typical abort envelopes in the COI region and is representative of the type of limits placed on the COI maneuver for Saturn V missions. The theoretical COI regime was generated assuming nominal conditions at abort, the correct pitch attitude at SPS ignition, and an unlimited amount of available SPS ΔV. The effects of a plus and minus 5° pitch error and a plus and minus 5-n. mi. attitude error on the COI envelope are also included in this figure. During a typical Saturn V mission, the RTCC will know the actual altitude at abort, but will not be able to account for the pitch attitude errors during the burn. Therefore, the value of the posigrade burn sent up to the crew will not consider any attitude variation. The COI regions contained in the succeeding figures are composites of the plus 5° pitch error line in the positive flight-path angle region and the minus 5° pitch error line in the negative flight-path angle region. A mode IV procedure will be performed only if orbital conditions are in this region. Mode IV maneuvers performed outside this region could, with errors greater than those shown, result in a maximum perigee altitude of less than 75-n. mi. - an unsafe orbit.

Figure 40 presents a nominal COI region with constant SPS ΔV lines from 0 to 2200 fps at 200 fps intervals on a plot of inertial flight-path angle versus inertial velocity. These constant ΔV lines indicate the sensed velocity change necessary to achieve an orbit with a 75-n. mi. perigee.

Constant apogee lines displayed on figure 40 show the dimensions of the orbit (perigee equals 75 n. mi.) which can be expected as a result of the COI. However, these ΔV quantities will be padded an additional

100 fps in real time to assure a safe orbit, and the orbital parameters will vary accordingly. (See table IX.) The GO - NO-GO line ($\Delta V = 0$) indicates conditions at abort resulting in an orbit with a 75 n. mi. perigee. On or to the right of this line, the mode IV ΔV is zero. Figures 41 and 42 show the effects of a plus and minus 10-n. mi. altitude deviation at abort on the COI regions and burn ΔV's. The COI regions presented in the preceding three figures were generated for Mission D; however, they do represent typical COI capabilities for Saturn V missions and the effects of pitch and altitude errors on this capability. Should the RTCC be unable to provide a SPS ΔV for a mode IV abort during an actual mission, flight control would use updated curves similar to figures 34, 35, and 36 to pass to the crew a SPS ΔV magnitude.

Figure 43 presents the variation in the nominal COI boundary for flight azimuths between 72° and 108°. The total shift in the COI envelope over the range of azimuths investigated is approximately 50 fps. This indicates that for Saturn V missions, the COI region is relatively insensitive to variations in azimuth.

Tracking coverage during COI posigrade burns is presented as a function of ground elapsed time of abort and SPS burn time in figures 44 through 48. For the five azimuths investigated, the CSM was acquired by at least two tracking stations prior to SPS ignition. The cross-hatched regions on these figures show regions which are not covered by tracking during the COI burn. Problem areas exist for large COI burns and vary depending on the ascent azimuth. As is indicated by the preceding five figures, the 108° ascent azimuth is significantly affected by tracking loss during the burn with approximately 3 minutes of tracking coverage for COI burns from the nominal.

Table IX contains typical SPS burn duration, SPS sensed velocity change, and resulting apogee altitudes for nominal mode IV aborts on a 72° flight azimuth. Since flight control will normally request the crew to burn an additional 100 fps more than that required to attain a 75-n. mi. perigee altitude, the resulting SPS burn time, sensed velocity change, and perigee and apogee altitudes for the "padded" burn are also included in this table. The pitch attitude at SPS ignition in the local coordinate system is shown in figure 49. Positive pitch is measured upward from the projection of the velocity vector on the local horizontal plane.

4.5 Apogee Kick Abort Data

A modified mode IV procedure, called apogee kick, is a COI maneuver which can be used to advantage for some positive flight-path angle contingencies near insertion. The SPS burn to raise perigee is delayed until the CSM coasts to apogee. The CSM attitude simulated for the posigrade SPS burn is identical to that used for the mode IV maneuver, figure 38. Compared to the standard mode IV sequence, apogee kick allows the crew more time to prepare for the SPS burn and requires a smaller ΔV to achieve a 75-n. mi. perigee. Apogee kick also has the advantage of a smaller increase in apogee altitude during the SPS burn. This burn will be padded an additional 100 fps similarly to the mode IV maneuvers. A lower apogee requires less retrograde burn for a deorbit maneuver performed near perigee. As a rule the apogee kick technique is less sensitive to trajectory dispersions than the mode IV procedure.

Figure 50 presents a typical apogee kick abort region for a Saturn V mission on a 72° launch azimuth. Shown are coast-time-to-apogee lines in increments of five minutes, constant SPS ΔV's at apogee to raise perigee to 75 n. mi., and resulting apogee altitudes at abort. For a particular launch vehicle-CSM configuration, the apogee kick region is relatively insensitive to variations in flight azimuth. However, booster performance characteristics, CSM thrust, and weight differences may alter the apogee kick capability on a mission-to-mission basis. This sensitivity will require that the apogee kick region be investigated for each individual mission, and once a region of capability has been established for a particular mission, it is very probable that flight azimuth will have little effect on it.

Figure 51 presents a composite plot showing the abort capability overlap for a typical Saturn V launch. Once the S-IVB has crossed the GO - NO-GO line, no abort action will be required unless a necessary spacecraft system malfunctions and precludes continuing the mission.

4.6 SPS Failure Data

As was discussed in the preceding sections, if the SPS is operational, a continuous abort capability does exist throughout the launch phase for Saturn V missions. There are two regions during the launch phase, modes III and IV, where SPS failures could produce unsafe orbital or landing conditions. An unsafe orbit is defined as one with a perigee altitude greater than 40 n. mi., but less than 75 n. mi., and an unsafe landing condition implies a CM landing on the African continent. Because of the variable flight azimuth aspect of Saturn V missions, the African land mass shrinks from approximately 4500 n. mi. on a 72° azimuth to about 1400 n. mi. on a 108° azimuth (fig. 8) and becomes less hazardous.

Figures 52 and 53 present spacecraft landing locations for SPS failures during nominal mode III and mode IV aborts on a 72° flight azimuth. For SPS malfunctions during mode III and mode IV launch aborts on more southerly azimuths (92° to 108°), the possibility of African landings will be significantly reduced since the actual land mass shrinks considerably.

Figure 59 shows typical spacecraft landing traces and maximum entry decelerations for three CM entry lift profiles. Since these particular lines are relatively insensitive to flight azimuth for a particular set of CM characteristics, they can be used effectively to determine limits on abort conditions which will necessarily result in African landings when the SPS is inoperative. Should conditions at abort permit the use of lift vector control to avoid any land landing, the appropriate entry lift profile and resulting maximum entry deceleration can be chosen from figure 54.[a] Full-lift (bank angle equals 0°) range lines at the east coast of Africa and zero-lift (bank angle equals 90°) range lines at the west coast of Africa are shown as functions of inertial velocity and inertial flight-path angle at abort in figure 55 for ascent azimuths of 72°, 81°, 90°, 99°, and 108°. Also included in this figure is a typical near-insertion nominal trajectory trace for a Saturn V mission. Figure 55 can be used to determine if a CM African landing is imminent for any particular velocity - flight-path angle - azimuth combination during the ascent phase of the mission.

As discussed previously, in the event that the SPS fails to ignite during a mode III or mode IV abort procedure and the predicted CM landing point is on the African continent near the east or west coast, CM lift-vector control is the primary tool available to prevent a land landing. A limited amount of SM RCS thrust is also available to supplement entry profile modification. Figures 56 and 57 show the additional landing range control capability using the SM RCS. It was assumed that the SPS failed to ignite 125 seconds after S-IVB cutoff and that 2 minutes were required for malfunction diagnosis and a second SPS ignition attempt. All SM RCS burns were initiated 4^m5^s after S-IVB cutoff and terminated when the time of free fall to 300 000 ft equaled 100 seconds.

Since only a limited amount of additional thrust is available from the SM RCS, only those contingencies which afford an optimum use of the SM RCS were investigated. Figure 56 shows the full-lift and zero-lift CM landing ranges as functions of inertial velocity at abort. Curve 1 depicts the full-lift landing range resulting from the use of four plus-X SM RCS thrusters with the CSM in the mode IV posigrade attitude, and curve 2 shows the zero-lift landing range following the use of four plus-X thrusters with the CSM in the mode III retrograde attitude. The SM RCS plus-X thrusters are most optimally used in the mode IV posigrade attitude to overfly Africa and effect an Indian Ocean landing, and the mode III retrograde orientation to return to the Atlantic.

Figure 57 indicates that using the SM RCS thrusters in the retrograde attitude is equivalent to approximately 1.5 seconds of S-IVB burn time. That is, with the additional SM RCS thrust, a 3200-n. mi. zero-lift landing range can be effected 1.5 seconds later during the nominal ascent

[a]Note the Cape Verde Island could be a problem for landing ranges around 3100 n. mi. along the 85° to 90° launch azimuth traces.

trajectory. Use of SM RCS thrust in the posigrade attitude will allow a CM full-lift landing range 8000 n. mi. from the Cape 3 seconds sooner than would normally be the case.

The results of these studies indicate that the maximum total reduction in dwell-time over Africa resulting from the most optimal use of the SM RCS thrusters is slightly less than 5 seconds. In most cases, a few additional seconds of S-IVB burn time is equivilant to more than 500 seconds of SM RCS thrust.

5.0 LAUNCH TRAJECTORY MONITORING

5.1 Abort Mode Selection

A typical Saturn V launch trajectory is divided into abort mode regions which are selected depending upon

1. Spacecraft propulsion and performance capabilities.

2. Trajectory conditions at abort initiation.

3. Status of life support systems.

Consequently, abort modes are defined to protect for the following contingencies:

1. Mode I - The mode I abort procedures are designed to protect the crew for contingencies that could occur while the launch vehicle is on the pad, in the sensible atmosphere, at S-IC/S-II staging, and during the first portion of S-II powered flight. Contingencies occurring in this region of flight require an escape system that will insure rapid detection of the malfunction, provide adequate separation from the launch vehicle in the event of an impending catastrophe, and to provide sufficient activation of the spacecraft's earth landing systems. Therefore, a mode I abort is selected when the launch escape vehicle is required to insure a safe procedure.

2. Mode II - The mode II abort procedures are designed for contingencies occurring after the launch escape tower jettison either until a safe orbit can be achieved with the SPS or until the resulting landings threaten the west coast of Africa. Because the aborts initiated in this region can result in very high entry loads (g's) and/or time-critical entries, no range control maneuvers are considered. A full-lift entry is used to minimize g's, and a simple separation technique is established for rapid entry orientation. The mode II procedure requires at least 100 seconds of coast from S-IVB or S-II cutoff to 300 000 ft

altitude to orientate the CM to proper atmospheric capture attitude. For low launch trajectories, this sometimes requires extending the mode I region or delaying tower jettison until sufficient free-fall time is available to perform the mode II abort. If a nontime-critical contingency develops in the mode II region, then the abort will be delayed until one of the fixed abort times. These are presently defined as ground elapsed time of 4^m30^s and 9^m00^s for mode II.

3. Mode III - The mode III abort procedures are for contingencies occurring beyond mode II when a safe orbit cannot be achieved or when spacecraft systems malfunctions require immediate landings. The first mode III requirement is unlikely because of the large region of available COI capability, and S-IVB cutoff conditions would have to be greatly dispersed from the nominal launch trajectory to necessitate initiating a mode III abort. Since no time-critical systems malfunction has been identified that would require an immediate landing, the probability of employing a mode III abort procedure is very small.

4. Mode IV - This COI procedure is selected for contingencies occurring once the SPS can insert the spacecraft into a safe orbit (perigee altitude $\geq$ 75 n. mi.) and deorbit from any place in the resulting orbit. This technique is the prime selection because it is safest. It allows the ground and crew ample time in earth orbit to determine the spacecraft's trajectory and system status, and the ground can compute a precise deorbit maneuver for a planned landing area. Depending on the propellant available after executing the COI maneuver, an alternate mission may be persued, fulfilling some of the originally planned test objectives. This COI maneuver will be performed at a fixed time after S-IVB cutoff, or, if possible, delayed until an apogee kick maneuver can be performed.

5. Apogee kick - This procedure is a COI similar to mode IV, in that it uses the SPS to insert the spacecraft into a safe orbit. Should the S-IVB shut down prematurely in the positive flight-path angle region near insertion, the spacecraft crew would separate the CSM from the S-IVB and coast to apogee. At apogee, they would perform a posigrade SPS burn in the mode IV attitude to raise their perigee altitude to at least 75 n. mi. The apogee kick maneuver has the following advantages:

1. Requires less ΔV than the mode IV maneuver.

2. Results in smaller apogees.

3. Gives the spacecraft crew additional time to prepare for the SPS burn.

4. Is less sensitive to trajectory or execution errors.

Therefore, the apogee kick maneuver should be selected whenever the apogee is located favorably for the mode IV procedure.

To summarize, the abort mode selection criterion is based on the safest procedure available. Mode I, mode II, or deorbiting at a planned landing area would be the best procedure for spacecraft systems malfunctions that require terminating the mission. The COI procedures, mode IV and apogee kick, would be used whenever possible for adverse trajectory conditions at S-IVB cutoff.

5.2 Ground Monitoring

The ground flight controllers at the Mission Control Center in Houston (MCC-H) have the primary responsibility of monitoring the trajectory during the launch phase. The ground is prime for determining abort trajectory limit violations, abort mode decisions, and GO - NO-GO orbit insertion status. To aid the ground's trajectory monitoring are the flight dynamics displays.

The flight dynamics displays are the visual aids which are available for the Flight Dynamics, Retrofire, and Guidance Officers for trajectory monitoring during the launch. There are launch digitals and projection plots displayed on cathode ray tubes and analog plotboards to be used to determine the trajectory status and to command abort action if necessary. The displays are driven by real-time computer computations based on the actual flight data received from the Manned Space Flight Network (MSFN).

Figures 58 through 65 present the background plots currently proposed to monitor the trajectory traces for manned Saturn V missions. These figures are similar to those used for S-IB launches, and, in addition, they reflect variable azimuth constraints. It should be noted here that these plotboards will be updated with specific mission data for each launch.

Figure 58 is the primary display for monitoring the launch trajectory. The lines shown on this display, except for the structural breakup line, were computed assuming that the altitudes corresponding to the inertial velocities along the nominal launch trajectory remain constant for the flight-path angles investigated. The nominal launch profile is shown for easy detection of launch deviations.

The structural breakup line defines the region where structural failure is assured. Structural failures above this line are protected by the emergency detection system (EDS). This line is used to protect against slow drifting trajectories which will not be covered by the EDS, and it is the only line on this display that will be used to command abort action. It is biased 8.5 seconds for data and reaction delays. The line is only valid when all five engines are thrusting during S-IC flight. The maximum load factor line is used only to indicate an impending abort. The actual abort action will be taken on figure 59. The time-of-free-fall line is also used only as an indication, and abort action will be taken when the time-of-free-fall digital equals 100 seconds and is decreasing.

The mode IV capability line is an unbiased line based on the region defined by the most restrictive combination of the pitch error regions that were shown in figures 39 and 40. When the trajectory trace reaches this line, the spacecraft has achieved COI capability, and the ground will inform the crew that mode IV status has been achieved. This line will be erroneous if the trajectory is off-nominal in altitude. The S-IVB early staging line is included in figure 58 and represents the first time trajectory conditions will permit an S-IVB/S-II early staging and still result in near 100-n. mi. orbital insertion.

The apogee kick line indicates when, after S-IVB shutdown, there would remain 5 minutes until apogee. The GO - NO-GO line is determined by trajectory parameters which define a 75-n. mi. perigee altitude for S-IVB shutdowns occurring with the nominal insertion altitude. The GO - NO-GO decision will be based on the digital displays for the selected tracking source after S-IVB cutoff. The 500-n. mi. apogee line is an unbiased line indicating the trajectory conditions that define an instantaneous 500-n. mi. apogee.

A potential abort limit that may be added to this display is an exit heating limit. This limit will protect against flight conditions which would cause heating damage to the spacecraft during launch. This limit is currently under investigation by North American Rockwell, and its exact use will depend upon the results of these studies.

The time-of-free-fall and the maximum-entry-load-factor limit lines in figure 58 were generated using the altitude on the nominal trajectory corresponding to the velocity at abort initiation. These lines will be inaccurate at off-nominal altitudes. To avoid making an abort decision on an inaccurate boundary, the flight controllers will switch to one of the plotboards shown in figures 59 and 60 if the maximum entry load factor or time-of-free-fall limits in figure 58 are approached. The plotboard on figure 59 displays the trace of the actual entry conditions at 400 000-ft altitude, and the one on figure 60 displays the trace of free-fall time and full-lift landing range. These parameters are computed almost instantaneously by the real-time program from the actual position and velocity vectors extracted from the flight data. Therefore, the lines shown on these displays are not subjected to altitude assumptions as are the one of figure 58. The S-II performance boundary is also included in figures 59 and 60 to show the limiting conditions on S-II performance degradation which would still allow an S-IVB early staging and insertion into a near-nominal orbit.

Figure 59 will be used to initiate abort action for trajectory violations that result in excessive maximum entry load factors. Figure 60 illustrates the nominal full-lift landing range variation with free-fall time. This plot shows the free-fall-time abort limit, but abort action will be taken on the digital value of free-fall time of 100 seconds and decreasing. Full-lift landing range at the ADRA has also been included in figure 60 to show where the mode II abort region ends.

Figure 61 shows the geodetic latitude versus longitude plotboard, which is used to record the predicted mode II landing point of the CM. Since these plotboards were designed to be used over a wide range of ascent azimuths, the full-lift-landing-range traces along five selected azimuths (72°, 81°, 90°, 99°, and 108°) are shown on scale I. Three of these traces (72°, 90°, and 108°) are continued on scale II. When the full-lift-landing-range trajectory trace crosses the "Full-Lift Line for 3200 Nautical Miles", mode II capability ends. Acquisition ellipses for the Canary Island, Bermuda, Antigua, the Insertion ship, Grand Bahama, and Ascension Island tracking stations are shown for a 100-n. mi. altitude and 0° elevation angle tracking conditions. Full-lift-landing-range lines at abort times of 6^m50^s and 9 minutes are also included in figure 61.

Figure 62 is the Apollo guidance computer (AGC) Dynamic Status display. This display will be used to compare the trajectory from the AGC tracking data with that of other sources. The mode IV capability line is also shown to indicate when the AGC would compute a valid COI maneuver. Also included is the S-IVB early staging line showing the first time the S-IVB is capable of attaining orbital insertion. This display, along with other data, is used to indicate that the AGC is navigating properly.

Figure 63 displays the inertial flight-path angle and velocity-to-go (V_S) to achieve a 75-n. mi. altitude perigee orbit. When the trace crosses the $V_S = 0$ line, a GO orbit is achieved. The primary use of this display will be to monitor the COI maneuver. This display will indicate when the COI burn has achieved a safe orbit. Altitude variations of plus and minus 15 n. mi. are shown for the mode IV capability line. Since the three trajectory parameters of velocity, flight-path angle, and altitude are the quantities that determine mode IV capability, these lines would enable defining COI capability 15 seconds prior to the burn and not just at 125 seconds after S-IVB cutoff. Also for delayed burns, it would show for the altitudes considered when COI capability is lost.

The altitude-versus-range profile is shown on figure 64. This display would show when the altitude history deviates significantly from the planned profile. The display can be used in conjunction with figure 58 to help determine the validity of those altitude-dependent lines. The mode IC mark is a biased 100 000-ft altitude line which defines the first time the crew can perform the high altitude mode I abort procedure. The actual ground report to the crew will be based on the corresponding digital value of altitude. The 75-n. mi. altitude line shows the smallest altitude for which a COI maneuver can be computed.

Figure 65 presents the wedge angle and cross-range velocity versus inertial velocity plotboard. Three wedge angle traces for launch azimuths of 72°, 90°, and 108° are shown. This figure is used to monitor the ascent trajectory and indicates that the launch vehicle is targeting to the correct insertion conditions.

The flight dynamics displays are designed to account for off-nominal flight-path angles and altitudes for abort conditions where possible. However, much of the information data shown on the displays is computed premission, and a nominal altitude history has been assumed. For this reason, to back up the RTCC computations, and to serve as a cross check, the abort burn ΔV parameters will be generated for several different altitudes for each mission. These will be flight controller console plots which can be used in simulations or during the mission to compare with or to replace RTCC solutions.

5.3 Onboard Monitoring

During the launch the crew has program 11 and its corresponding display and keyboard panel (DSKY) displays to facilitate trajectory monitoring (fig. 66). This program is automatically initiated upon lift-off and is available until the ground or crew commands program 00. Normally the Mission Control Center (MCC) will inform the crew of their trajectory status. However, if voice communications were lost during the launch, the crew would have to depend on the DSKY for this information. Table X shows the values of the parameters for a nominal launch, which were computed with the COLOSSUS guidance equations (ref. 17) for a typical Saturn V mission. During the launch, these parameters are updated every two seconds and displayed to the crew. Any time the MCC would rule the spacecraft guidance NO GO from the displays like figure 59, the computer will be commanded to program 00, and these DSKY displays would no longer be available.

In conjunction with the DSKY displays in program 11, two onboard charts are proposed for use in the event of voice communications loss during the launch (figs. 67 and 68).

The basic displays for launch monitoring are the inertial velocity, altitude rate, and altitude parameters. Therefore, these are the parameters used to govern the charts. The charts with the DSKY are to be used to help determine when abort action is necessary and what action is required. These functions would normally be conducted by the MCC when voice communications exist. Once the abort decision has been made, the crew would use the DSKY parameters to monitor the abort burn. The following list defines the action required for each mode:

1. Mode I - Mode I aborts use the launch escape vehicle, and no DSKY parameters will be required.

2. Mode II - Mode II aborts require no SPS burns, and entering V82E and then N50E to get the display is recommended. This display would give ΔR[a], free-fall time (T_{ff}), and perigee altitude (HP). These parameters will indicate the T_{ff} remaining for entry orientation and can be used to estimate their landing range by adjusting ΔR for the appropriate entry profile.

3. Mode III - Mode III aborts might require an SPS burn, and again V82E and then N50E should be entered to get the necessary display. After achieving the proper burn attitude (fig. 21) the crew would burn the SPS until ΔR is equal to zero. This would satisfy the desired landing coordinates for a mode III entry.

4. Mode IV - Mode IV also requires an SPS burn, and V82E and then N50E are the recommended inputs. After achieving the proper burn attitude (fig. 38) for mode IV, the crew would burn the SPS until perigee altitude is equal to 75 n. mi. plus 10 seconds. This procedure would insure achieving a safe orbit. Caution should be employed here. If at anytime during the burn, the perigee altitude starts decreasing, the burn should be terminated; and, for these terminated burns with perigee altitude less than 75 n. mi., a mode III abort should be initiated when altitude rate is less than zero or apogee altitude less than 75 n. mi. and an apogee kick initiated when altitude rate is positive.

5. Apogee kick - Apogee kick procedures will be to delay the COI burn to apogee (altitude rate equal to zero) and perform the mode IV procedure.

---

[a]ΔR or SPLERROR is the difference between the half-lift landing point as computed by the AGC and the desired ADRA target coordinates. This computation is based on the current position and velocity of the spacecraft.

6. GO orbit - A GO orbit is defined to exist anytime the cutoff conditions result in perigee altitude greater than 75 n. mi., and no other action is required. V82E can be called to display insertion parameters.

Figure 67 shows the nominal altitude rate versus velocity trace and the current abort trajectory limits. Should the actual flight trace violate the booster breakup line or the maximum-entry-load-limit line, an abort is required. If the trace approaches the time-of-free-fall limit line, V82E and then N50E should be called. Abort action is then taken when time of free fall equals 100 seconds and is decreasing. Note that even if voice communications were lost, the MCC might still have command capability; then MCC would light the abort light for trajectory limit violations.

Figure 68 shows the nominal-altitude-rate-versus-velocity trace for approximately the last 2 minutes of the launch. This plot expands the region in which abort capability starts varying rapidly. The primary use of this chart is to show S-IVB cutoff conditions where COI capability exists. Therefore, the COI boundary is defined for different altitudes. Since the altitude is fairly static near insertion, the crew could choose the appropriate COI boundary and determine when the S-IVB trace crosses into the COI capability region. The other abort capabilities can be determined directly from the DSKY. Once tower jettison has occurred, mode II capability extends until SPLERROR (ΔR) becomes greater than -368 n. mi. corresponding to a full-lift landing at 3200 n. mi. Mode III capability extends from ΔR greater than -368 n. mi. until a nominal insertion is achieved. A GO orbit is achieved when perigee altitude is greater than or equal to 75 n. mi.

Note that whenever the time of free fall is pegged at 59^m59^s, the ΔR computation is invalid. This is true once the perigee altitude becomes greater than 300 000 ft. If a mode III burn is required in this region, ΔR will become valid when the burn has progressed enough to decrease perigee below 300 000 ft.

6.0 CONCLUSIONS

The abort studies contained in this document were conducted for a typical Apollo spacecraft and a typical Saturn V launch vehicle. This data will be representative for launch abort planning for any of the planned Apollo Saturn V launches that insert into a near-100-n. mi. altitude circular orbit. The launch abort techniques are well established and should remain consistent for future flights. Therefore, the data enclosed would satisfy the primary requirement of trajectory data with only minor revisions to supply the specific mission-dependent data. These updates would include final plotboards, crew charts, and other pertinent trajectory data used for actual mission support. Launch vehicle performance characteristics, CSM thrust, and weight changes may alter data shown slightly (from mission to mission). Major changes would result in reevaluating this trajectory data.

The data presented shows the effects of variable launch azimuth, corresponding to the lunar launch window, on the various launch abort parameters. The only significant effect of the variable azimuth on the launch aborts are the landing coordinates. These coordinates can be estimated from the maps showing the flight azimuth traces for the different landing ranges.

If the time history of the launch changes, the associated abort times can be correlated to the inertial velocity at abort initiation and the resulting trajectory solutions would still be representative.

The real-time displays are specifically designed for monitoring trajectory deviations during launch. Therefore, the data presented here is primarily used to estimate potential problem areas and to establish trajectory trends premission. During the mission, the ground displays will accurately display the corresponding trajectory parameters. Should malfunctions occur during launch that change the ascent profile, the resulting trajectory will also be monitored as if a normal launch.

The primary objective if contingencies occur during launch is to continue to orbit whenever possible. These studies show that the existing launch abort procedures and techniques used to define, execute, and monitor abort trajectories are adequate for contingency situations which could develop during the launch phase for the planned Apollo Saturn V missions.

TABLE I.- COMMAND MODULE AERODYNAMIC DATA FOR A TYPICAL SATURN V MISSION - L/D = 0.29429

X_{CG} = 1040.83 inches Y_{CG} = -0.20 inches Z_{CG} = 5.86 inches

Weight = 12153.0 lbs

Bank Angle Bias = -1.95 Degrees

Mach Number M (nd)	Trim Angle of Attack α_T (deg)	Lift Coefficient C_L (nd)	Drag Coefficient C_D (nd)	Lift-to-drag Ratio L/D (nd)
0.20	170.88	0.23378	0.82537	0.28324
0.40	167.50	0.23704	0.85430	0.27746
0.70	164.82	0.25831	0.98808	0.26143
0.90	162.14	0.31453	1.06871	0.29430
1.10	155.46	0.48459	1.17674	0.41181
1.20	155.64	0.47056	1.16219	0.40489
1.35	154.51	0.55366	1.28485	0.43091
1.65	153.69	0.54381	1.27166	0.42764
2.00	153.63	0.52800	1.28161	0.41199
2.40	154.16	0.50245	1.25127	0.40155
3.00	154.63	0.47418	1.22719	0.38640
4.00	156.56	0.43658	1.22294	0.35699
10.00	157.20	0.42387	1.23297	0.34378
29.50	160.50	0.38183	1.29745	0.29429

TABLE II.- COMMAND MODULE AERODYNAMIC DATA FOR A TYPICAL SATURN V MISSION

- L/D = 0.26705

X_{CG} = 1042.82 inches Y_{CG} = -0.50 inches Z_{CG} = 5.25 inches

Bank Angle Bias = -5.44 Degrees

Mach Number M (nd)	Trim Angle of Attack α_T (deg)	Lift Coefficient C_L (nd)	Drag Coefficient C_D (nd)	Lift-to-drag Ratio L/D (nd)
0.20	171.71	0.20902	0.83072	0.25161
0.40	169.02	0.20493	0.85898	0.23857
0.70	166.64	0.23833	0.99549	0.23941
0.90	163.93	0.28851	1.08077	0.26695
1.10	158.03	0.44242	1.20470	0.36725
1.20	157.87	0.43606	1.18977	0.36650
1.35	156.69	0.51175	1.30739	0.39143
1.65	155.70	0.51597	1.29642	0.39799
2.00	155.73	0.30591	1.31690	0.38416
2.40	156.33	0.47758	1.28839	0.37099
3.00	156.71	0.45097	1.26788	0.35574
4.00	158.37	0.41452	1.25507	0.33028
10.00	158.89	0.40322	1.26644	0.31839
29.50	162.33	0.35568	1.33188	0.26705

TABLE III.- SEQUENCE OF EVENTS FOR MODE II LAUNCH ABORTS

Controlling Condition	Value of Controlling Condition	Event
Time Since Abort Initiated (sec)	0.0	Tailoff begins.
	0.56 (S-II)	Thrust and weight flow equals zero
	0.90 (S-IVB)	
	3.0	S-II or S-IVB/CSM separation. Service module RCS ullage begins (4 SM RCS jets in plus-X direction).
↓	24.0	Ullage burn terminates. Coast begins. Crew begins maneuvers to separate CM from SM and to orient for entry.
Altitude (ft)	400,000	Atmospheric entry. Bank angle equals zero.
↓	24,000	Apex cover jettison
Time Since Apex Cover Jettison (sec)	2.0	Drogue parachute deploys.
Altitude	10,000	Main parachute deploys.
↓	0	Landing in Atlantic Continuous Recovery Area.

TABLE IV.- HIGH ALTITUDE CHARACTERISTICS OF MODE II ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY FOR A TYPICAL SATURN V MISSION ON A 72-DEGREE FLIGHT AZIMUTH

Ground Elapsed Time of Abort (min:sec)	Predicted Time of Free Fall to 300,000 Feet (min:sec)	Ground Elapsed Time at 400,000 Feet (min:sec)	Inertial Velocity at 400,000 Feet (ft/sec)	Inertial Flight-path Angle at 400,000 Feet (deg)	Ground Elapsed Time at 300,000 Feet (min:sec)	Ground Elapsed Time at S-band Blackout Entry (min:sec)	Ground Elapsed Time at S-band Blackout Exit (min:sec)
2:30.34*	3:27	-	-	-	5:58	-	-
2:40	3:25	5:07	8,436.27	-7.05	6:05	-	-
2:50	3:26	5:27	8,714.14	-8.95	6:16	-	-
3:00	3:26	5:41	8,992.70	-10.27	6:26	-	-
3:05.97**	3:26	5:49	9,160.53	-10.90	6:33	-	-
3:10	3:26	5:55	9,274.97	-11.27	6:37	-	-
3:20	3:27	6:08	9,557.70	-12.10	6:48	-	-
3:30	3:28	6:22	9,841.89	-12.76	6:59	-	-
3:40	3:29	6:34	10,130.74	-13.22	7:10	-	-
3:50	3:29	6:46	10,424.48	-13.53	7:20	8:09	8:09
4:00	3:29	6:57	10,722.89	-13.73	7:30	8:15	8:21
4:10	3:29	7:08	11,026.30	-13.84	7:40	8:22	8:31
4:20	3:29	7:18	11,335.54	-13.88	7:50	8:30	8:41
4:30	3:29	7:29	11,651.40	-13.85	8:00	8:38	8:51
4:40	3:29	7:39	11,974.46	-13.75	8:10	8:47	9:01
4:50	3:28	7:49	12,305.12	-13.61	8:19	8:55	9:11
5:00	3:28	7:59	12,643.88	-13.43	8:29	9:03	9:21
5:10	3:28	8:08	12,991.43	-13.21	8:39	9:11	9:31
5:20	3:27	8:18	13,348.46	-12.95	8:48	9:20	9:41
5:30	3:27	8:28	13,715.73	-12.67	8:58	9:28	9:52
5:40	3:27	8:38	14,093.95	-12.36	9:08	9:37	10:02
5:50	3:27	8:48	14,483.88	-12.02	9:18	9:45	10:13
6:00	3:27	8:58	14,886.37	-11.66	9:28	9:54	10:24
6:10	3:27	9:08	15,302.33	-11.29	9:38	10:04	10:35
6:20	3:26	9:19	15,732.76	-10.90	9:49	10:13	10:47

*S-IC/S-II Staging
**LET Jettison

TABLE IV.- HIGH ALTITUDE CHARACTERISTICS OF MODE II ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY FOR A TYPICAL SATURN V MISSION ON A 72-DEGREE FLIGHT AZIMUTH - Concluded

Ground Elapsed Time of Abort (min:sec)	Predicted Time of Free Fall to 300,000 Feet (min:sec)	Ground Elapsed Time at 400,000 Feet (min:sec)	Inertial Velocity at 400,000 Feet (ft/sec)	Inertial Flight-path Angle at 400,000 Feet (deg)	Ground Elapsed Time at 300,000 Feet (min:sec)	Ground Elapsed Time at S-band Blackout Entry (min:sec)	Ground Elapsed Time at S-band Blackout Exit (min:sec)
6:30	3:29	9:30	16,178.73	-10.49	10:00	10:23	11:00
6:40	3:31	9:41	16,641.43	-10.06	10:12	10:34	11:13
6:50	3:33	9:53	17,121.05	-9.63	10:25	10:45	11:27
7:00	3:36	10:05	17,583.46	-9.21	10:37	10:56	11:41
7:10	3:38	10:16	18,026.30	-8.81	10:49	11:07	11:55
7:20	3:40	10:28	18,473.76	-8.40	11:02	11:18	12:09
7:30	3:43	10:40	18,936.78	-7.99	11:15	11:31	12:25
7:40	3:48	10:54	19,411.98	-7.[illegible]7	11:30	11:44	12:42
7:50	3:55	11:10	19,898.48	-7.14	11:47	12:01	13:03
8:00	4:04	11:28	20,408.69	-6.70	12:06	12:18	13:26
8:10	4:15	11:47	20,945.68	-6.23	12:27	12:38	13:52
8:20	4:30	12:10	21,503.35	-5.75	12:53	13:03	14:23
8:30	4:52	12:39	22,093.39	-5.23	13:24	13:33	15:03
8:40	5:17	13:13	22,660.24	-4.73	14:02	14:10	15:51
8:40.22*	5:20	13:13	22,660.36	-4.73	14:02	14:10	15:51
8:50	5:17	13:19	22,755.83	-4.64	14:09	14:17	16:00
9:00	5:20	13:31	22,961.52	-4.45	14:22	14:29	16:18
9:10	5:24	13:44	23,170.52	-4.25	14:37	14:44	16:37
9:20	5:30	13:57	23,382.95	-4.04	14:53	14:59	17:00
9:30	5:38	14:13	23,599.10	-3.82	15:11	15:17	17:25
9:40	5:48	14:29	23,818.61	-3.60	15:31	15:36	17:54
9:50	6:01	14:49	24,064.82	-3.36	15:54	15:59	18:28
9:55**	6:12	15:02	24,163.54	-3.22	16:03	16:10	18:50

*S-II/IVB Staging

**End Mode II Region

TABLE V.- LOW ALTITUDE CHARACTERISTICS OF MODE II ABORTS FROM THE NOMINAL

LAUNCH TRAJECTORY FOR A TYPICAL SATURN V MISSION

ON A 72-DEGREE FLIGHT AZIMUTH

Ground Elapsed Time of Abort (min:sec)	Ground Elapsed Time at Drogue Chute Deployment (min:sec)	Ground Elapsed Time at Main Chute Deployment (min:sec)	Ground Elapsed Time at Landing (min:sec)	Geodetic Latitude at Landing (deg North)	Longitude at Landing (deg West)	Range at Landing (n mi)	Maximum Entry Load Factor (g's)
2:30.34*	9:02	9:50	14:25	30.28	73.82	369.3	8.5
2:40	9:09	9:57	14:32	30.34	73.56	383.3	8.7
2:50	9:19	10:07	14:42	30.42	73.17	404.0	9.[illegible]
3:00	9:29	10:17	14:52	30.50	72.77	425.3	9.[illegible]
3:05.97**	9:35	10:23	14:58	30.55	72.52	438.4	9.[illegible]
3:10	9:40	10:28	15:03	30.58	72.35	447.4	9.8
3:20	9:51	10.39	15:14	30.67	71.91	470.7	10.2
3:30	10:02	10:50	15:25	30.76	71.46	494.9	10.6
3:40	10:13	11:01	15:36	30.84	70.99	519.6	11.0
3:50	10:24	11:12	15:47	30.93	70.51	544.8	11.3
4:00	10:36	11:24	15:59	31.02	70.02	570.8	11.6
4:10	10:48	11:36	16:11	31.10	69.51	597.5	11.9
4:20	10:59	11:47	16:22	31.19	68.98	625.1	12.2
4:30	11:11	11:59	16:34	31.28	68.44	653.6	12.5
4:40	11:23	12:11	16:46	31.37	67.88	682.9	12.8
4:50	11:35	12:23	16:58	31.46	67.30	713.2	13.0
5:00	11:48	12:36	17:11	31.54	66.69	744.7	13.3
5:10	12:00	12:48	17:23	31.63	66.06	777.4	13.5
5:20	12:13	13:01	17:36	31.72	65.41	811.5	13.7
5:30	12:27	13:15	17:50	31.81	64.72	847.1	13.8
5:40	12:40	13:28	18:03	31.90	64.00	884.3	14.0
5:50	12:55	13:43	18:18	31.98	63.24	923.4	14.1
6:00	13:09	13:57	18:32	32.07	62.43	964.7	14.2
6:10	13:25	14:13	18:48	32.16	61.58	1,008.5	14.2
6:20	13:41	14:29	19:04	32.24	60.67	1,087.2	14.2

*S-IC/S-II Staging

**LET Jettison

TABLE V.- LOW ALTITUDE CHARACTERISTICS OF MODE II ABORTS FROM THE NOMINAL

LAUNCH TRAJECTORY FOR A TYPICAL SATURN V MISSION

ON A 72-DEGREE FLIGHT AZIMUTH - Concluded

Ground Elapsed Time of Abort (min:sec)	Ground Elapsed Time at Drogue Chute Deployment (min:sec)	Ground Elapsed Time at Main Chute Deployment (min:sec)	Ground Elapsed Time at Landing (min:sec)	Geodetic Latitude at Landing (deg North)	Longitude at Landing (deg West)	Range at Landing (n mi)	Maximum Entry Load Factor (g's)
6:30	13:58	14:46	19:21	32.32	59.60	1,105.1	14.2
6:40	14:16	15:04	19:39	32.40	58.64	1,159.0	14.1
6:50	14:36	15:24	19:59	32.47	57.49	1,217.5	13.9
7:00	14:55	15:43	20:18	32.54	56.32	1,276.8	13.8
7:10	15:14	16:02	20:37	32.59	55.14	1,336.6	13.5
7:20	15:35	16:23	20:58	32.63	53.89	1,400.2	13.2
7:30	15:56	16:44	21:19	32.66	52.51	1,470.3	12.9
7:40	16:20	17:08	21:43	32.68	50.98	1,547.8	12.5
7:50	16:48	17:36	22:11	32.67	49.20	1,637.9	12.0
8:00	17:18	18:06	22:41	32.62	47.20	1,739.2	11.5
8:10	17:53	18:41	23:16	32.53	44.87	1,857.4	10.8
8:20	18:33	19:21	23:56	32.35	42.11	1,998.2	10.1
8:30	19:23	20:11	24:46	32.03	38.66	2,174.6	9.2
8:40	20:20	21:08	25:43	31.53	34.65	2,382.1	8.2
8:40.22*	20:20	21:08	25:43	31.53	34.64	2,382.1	8.2
8:50	20:31	21:19	25:54	31.42	33.88	2,421.7	8.0
9:00	20:53	21:41	26:16	31.18	32.35	2,501.9	7.6
9:10	21:16	22:04	26:39	30.89	30.68	2,589.9	7.2
9:20	21:42	22:30	27:05	30.54	28.84	2,687.1	6.8
9:30	22:11	22:59	27:34	30.12	26.81	2,795.2	6.3
9:40	22:43	23:31	28:06	29.61	24.54	2,917.6	5.8
9:50	23:22	24:10	28:45	28.95	21.92	3,060.4	5.3
9:55**	23:40	24:28	29:03	28.45	19.75	3,200.0	5.0

*S-II/S-IVB Staging

**End Mode II Region

TABLE VI.- SEQUENCE OF EVENTS FOR MODE III LAUNCH ABORTS

Controlling Condition	Value of Controlling Condition	Event
Time Since Abort Initiated (sec)	0.0	Tailoff begins.
↓	0.56 (S-II) 0.90 (S-IVB	Thrust and weight flow equals zero.
↓	3.0	S-IVB and CSM separate (4 SM RCS jets in plus X direction).
↓	24.0	Ullage burn terminates. Crew begins orienting CSM for retrograde horizon monitor burn with heads up.
↓	125.0	RCS ullage terminates. SPS engine ignites.
Predicted Half Lift Landing Range (n mi)	3,350	SPS burn terminates. Crew begins maneuvers to separate CM from SM and orient CM with heat shield forward for entry.
Altitude (ft)	400,000	Atmospheric entry. Bank angle equals zero.
Deceleration (g's)	0.2	Change bank angle to 55 degrees South.
Altitude (ft)	24,000	Apex cover jettison.
Time Since Apex Cover Jettison (sec)	2.0	Drogue parachute deploys.
Altitude (ft)	10,000	Main parachute deploys.
	0	Landing at Atlantic Discrete Recovery Area. (Short of ADRA for early Mode III aborts).

TABLE VII.- CHARACTERISTICS OF MODE III ABORTS FROM THE NOMINAL TRAJECTORY

FOR A TYPICAL SATURN V MISSION ON A 72-DEGREE FLIGHT AZIMUTH

Ground Elapsed Time of Abort (min:sec)	SPS Burn Time (min:sec)	SPS ΔV (ft/sec)	Predicted Time of Free Fall from SPS Cutoff to 300,000 Feet (min:sec)	Ground Elapsed Time at 400,000 Feet (min:sec)	Inertial Velocity at 400,000 Feet (ft/sec)	Inertial Flight-path Angle at 400,000 Feet (deg)	Ground Elapsed Time at 300,000 Feet (min:sec)	Ground Elapsed Time at Drogue Chute Deployment (min:sec)	Ground Elapsed Time at Main Chute Deployment (min:sec)	Ground Elapsed Time at Landing (min:sec)
9:55	0:00.00*	0.00*	3:53.87	15:02.31	24,162	-3.22	16:03.72	21:39.62	22:27.62	27:02.62
10:00	0:00.00	0.00	4:09.10	15:14.20	24,266	-3.10	16:23.01	22:04.23	22:52.23	27:27.23
10:06	0:00.00	0.00	4:29.91	15:29.95	24,403	-2.94	16:42.57	22:33.36	23:21.36	27:56.36
10:16	0:00.00	0.00	5:01.66	16:04.19	24,633	-2.66	17:23.75	23:31.12	24:19.12	28:54.12
10:20	0:08.79	96.14	4:47.95	16:03.98	24,665	-2.68	17:23.06	23:30.81	24:18.81	28:53.81
10:30	0:32.29	357.93	4:13.75	16:05.67	24,736	-2.78	17:22.36	23:28.93	24:16.93	28:51.93
10:40	0:58.73	660.69	3:40.04	16:12.34	24,791	-2.96	17:25.00	23:27.06	24:15.06	28:50.06
10:50	1:29.70	1027.32	3:03.84	16:22.97	24,822	-3.26	17:29.65	[illegible]:22.41	24:10.41	28:45.41
11:00	2:04.98	1461.78	2:27.65	16:38.96	24,836	-3.69	17:38.55	[illegible]	24:05.94	28:40.94
11:05.73**	2:28.12	1757.13	2:05.85	16:50.51	24,831	-4.02	17:45.[illegible]	23:14.86	24:02.86	28:37.86
11:15.73***	2:35.26	1850.02	1:53.64	16:57.62	24,789	-4.21	17:50.34	23:13.64	24:01.64	28:36.64

* Beginning of Mode III Region, Landing Will Be Short of ADRA
** Guidance Cutoff Signal
*** Insertion

TABLE VIII.- SEQUENCE OF EVENTS FOR MODE IV ABORTS

Controlling Condition	Value of Controlling Condition	Event
Time Since Abort Initiated (sec)	0.0	S-IVB thrust tailoff begins.
↓	0.9	Thrust and weight flow equal zero.
	3.0	S-IVB and CSM separate (4 SM RCS jets in plus X direction).
	24.0	Ullage burn terminates.
	125.0	RCS ullage terminates. SPS engine ignites.
Predicted Perigee Altitude (n mi)	75	SPS burn terminates. Orbital coast begins.

TABLE IX.- CHARACTERISTICS OF MODE IV ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY FOR A TYPICAL SATURN V MISSION ON A 72-DEGREE FLIGHT AZIMUTH

Ground Elapsed Time of Abort (min:sec)	Inertial Velocity at Abort (ft/sec)	Inertial Flight-path Angle at Abort (deg)	SPS Burn Time (sec)	Sensed Velocity Change (ft/sec)	Apogee Altitude (n mi)	SPS Burn* Time (sec)	Perigee* Altitude (n mi)	Sensed* Velocity Change (ft/sec)	True* Anamoly (deg)	Apogee* Altitude (n mi)
9:32	23,600	0.02	182.0	2105.2	87	190.5	84.87	2215.3	7.62	124
9:55	24,078	-0.07	139.0	1559.9	93	147.2	90.69	1659.9	4.07	125
10:05	24,304	-0.09	117.8	1306.1	95	126.2	93.11	1406.1	3.15	126
10:15	24,533	-0.10	96.0	1050.9	97	104.6	95.33	1150.9	2.71	126
10:35	25,004	-0.09	50.2	536.4	100	59.3	99.18	636.4	3.93	127
10:45	25,246	-0.06	26.3	276.9	101	35.6	100.70	376.9	5.86	127
10:55	25,491	-0.02	2.0	20.8	103	11.5	102.00	120.8	8.68	130

*Data shown for a nominal SPS burn plus 100 ft/sec

TABLE X.- TYPICAL DSKY PARAMETER VALUES DURING LAUNCH

Ground Elapsed Time (min:sec)	Inertial Velocity (ft/sec)	Altitude (n mi)	Altitude Rate (ft/sec)	SPLERROR (n mi)	Predicted Perigee (n mi)	Predicted Apogee (n mi)	Predicted Time of Free Fall to 300,000 Feet (min:sec)
3:00	9,311	49.8	2796	-2905.9	-3220.8	73.3	-3:26
3:20	9,688	58.5	2510	-2860.5	-3193.6	77.8	-3:27
3:40	10,107	66.4	2254	-2811.6	-3163.2	82.2	-3:29
4:00	10,576	73.4	1997	-2760.5	-3128.2	86.1	-3:29
4:20	11,092	79.5	1751	-2706.2	-3088.3	89.6	-3:29
4:40	11,657	84.9	1513	-2648.7	-3042.3	92.6	-3:29
5:00	12,273	89.5	1285	-2587.3	-2989.3	95.2	-3:28
5:20	12,941	93.4	1070	-2521.0	-2927.8	97.5	-3:27
5:40	13,664	96.6	870	-2448.9	-2856.0	99.4	-3:27
6:00	14,446	99.1	687	-2369.5	-2771.6	101.0	-3:27
6:20	15,291	101.1	525	-2280.4	-2671.4	102.3	-3:28
6:40	16,205	102.6	388	-2178.3	-2551.2	103.3	-3:31
7:00	17,159	103.7	271	-2062.7	-2410.9	104.0	-3:36
7:20	18,062	104.4	155	-1942.2	-2261.7	104.5	-3:40
7:40	19,016	104.7	70	-1798.5	-2084.5	104.8	-3:48
8:00	20,029	104.9	45	-1611.7	-1870.2	104.9	-4:04
8:20	21,140	105.1	43	-1377.3	-1597.6	105.1	-4:30
8:40	22,323	105.3	83	-1041.9	-1254.4	105.3	-5:20
9:00	22,625	105.4	-19	-939.1	-1156.4	105.4	-5:20
9:20	23,054	105.2	-99	-779.2	-1009.5	105.3	-5:30
9:40	23,498	104.7	-159	-578.4	-846.5	105.2	-5:48
10:00	23,958	104.1	-187	-305.7	-665.4	104.9	-6:20
10:20	24,431	103.5	-178	120.4	-463.3	104.5	-7:22
10:40	24,917	103.0	-130	967.7	-236.5	103.9	-9:49
11:00	25,415	102.7	-35	4037.2	19.3	103.0	-24:09
11:05.6	25,561	102.7	-1	-2023.9*	99.1	102.7	-59:59**
11:15.6	25,568	102.7	1	-1985.1*	102.7	102.9	-59:59**

*SPLERROR = R_{TO-GO} (distance from current position to target - perigee greater than 300,000 feet)

**Time of free fall = POSMAX (-59:59) - perigee greater than 300,000 feet

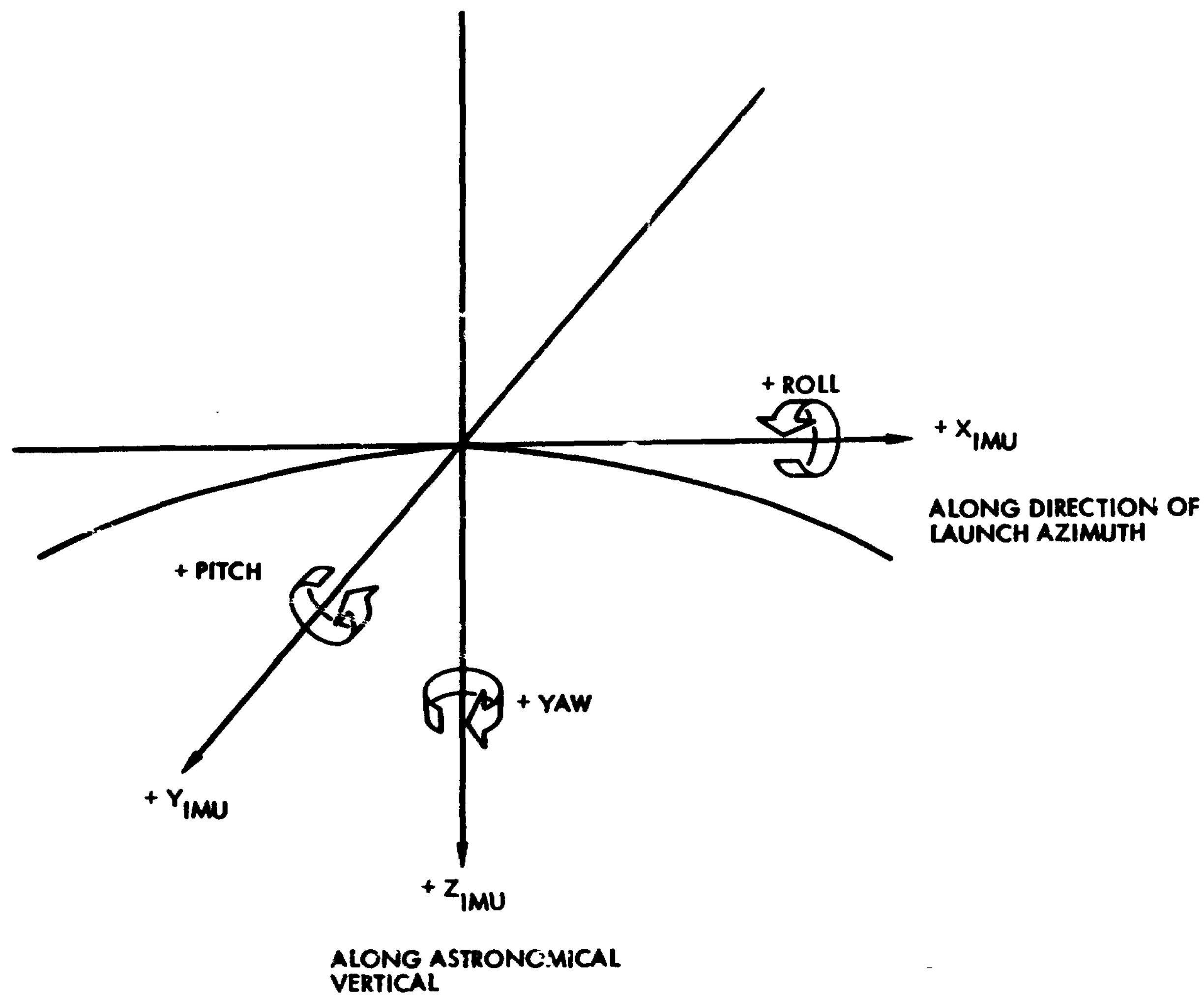

Figure 1.- Spacecraft inertial measurement unit (IMU) reference system.

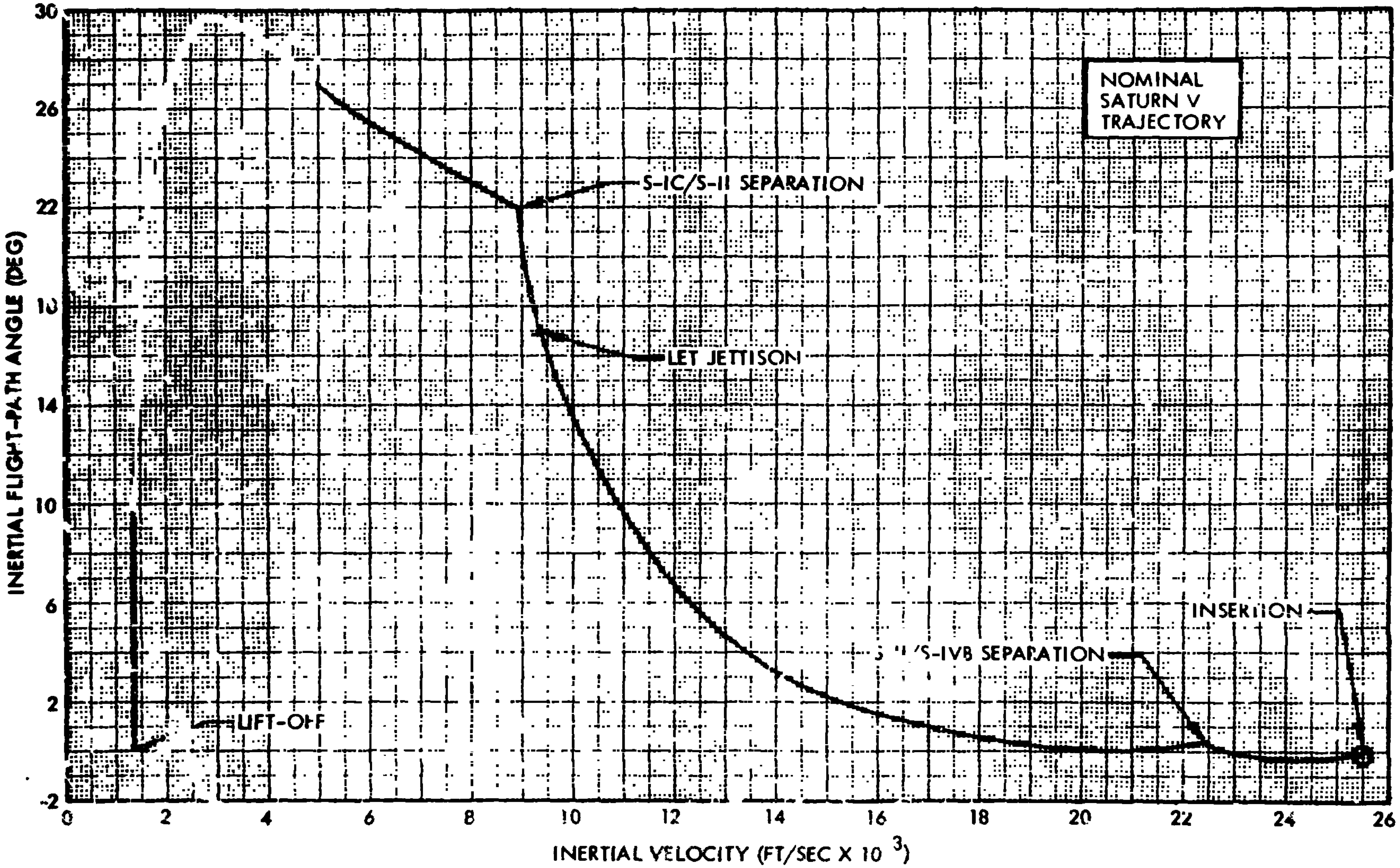

Figure 2.- Nominal launch trajectory for a typical Saturn V mission - inertial flight-path angle versus inertial velocity.

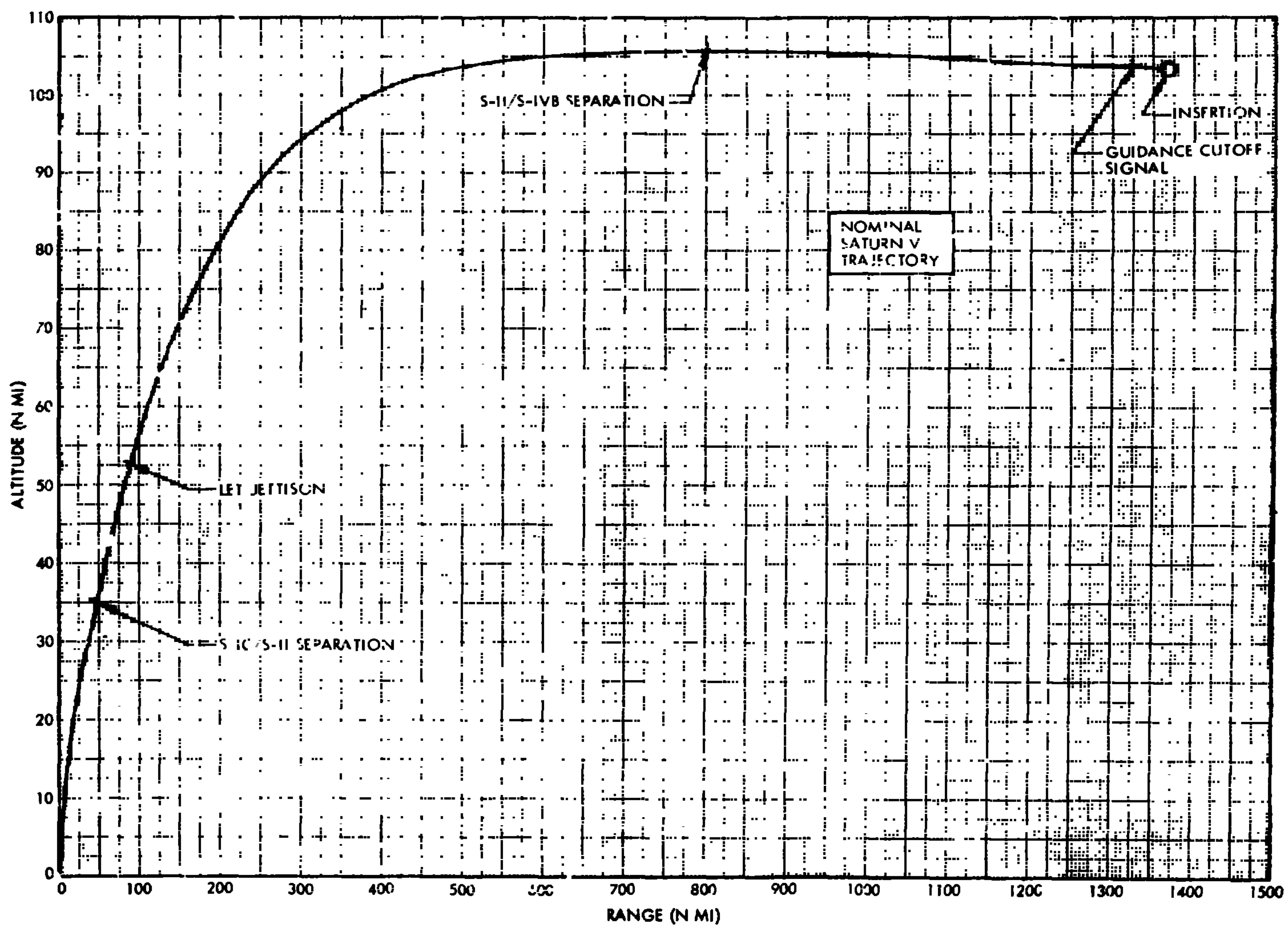

Figure 3.- Nominal launch trajectory for a typical Saturn V mission - altitude versus range.

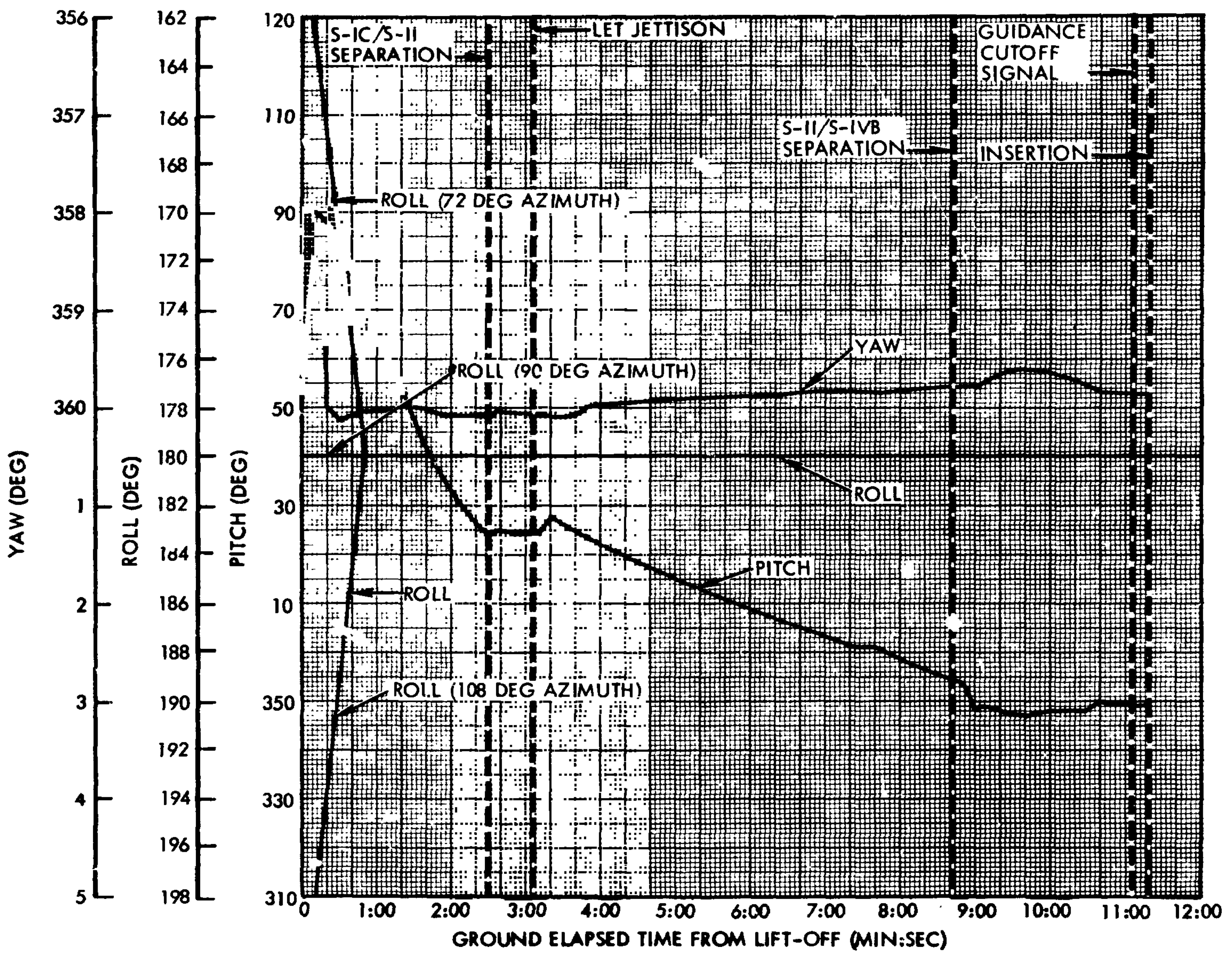

Figure 4.- Nominal spacecraft inertial measurement unit pitch, yaw, and roll platform gimbal angle readouts for a typical Saturn V mission.

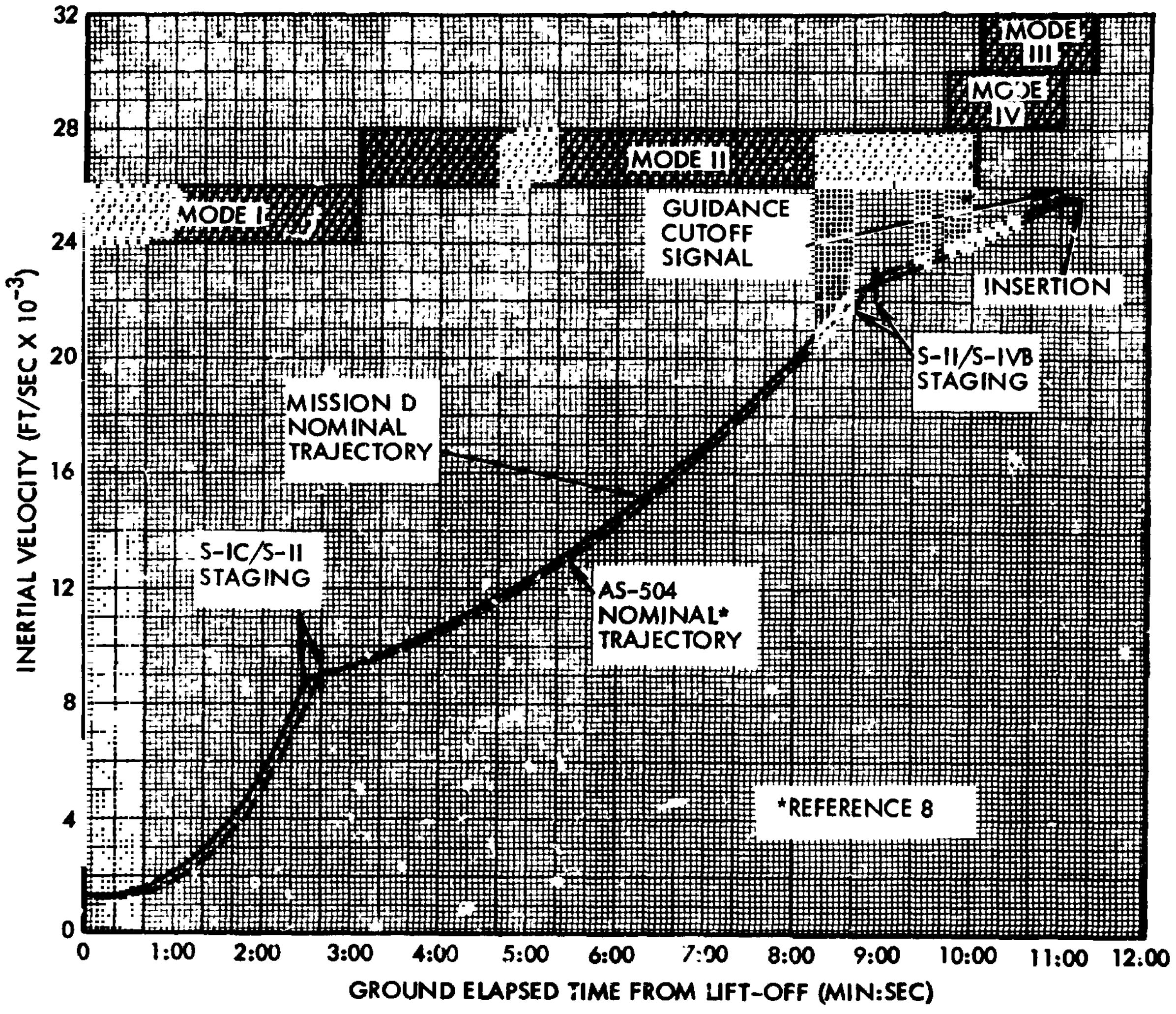

Figure 5.- Inertial velocity and nominal launch abort regions for a typical Saturn V mission.

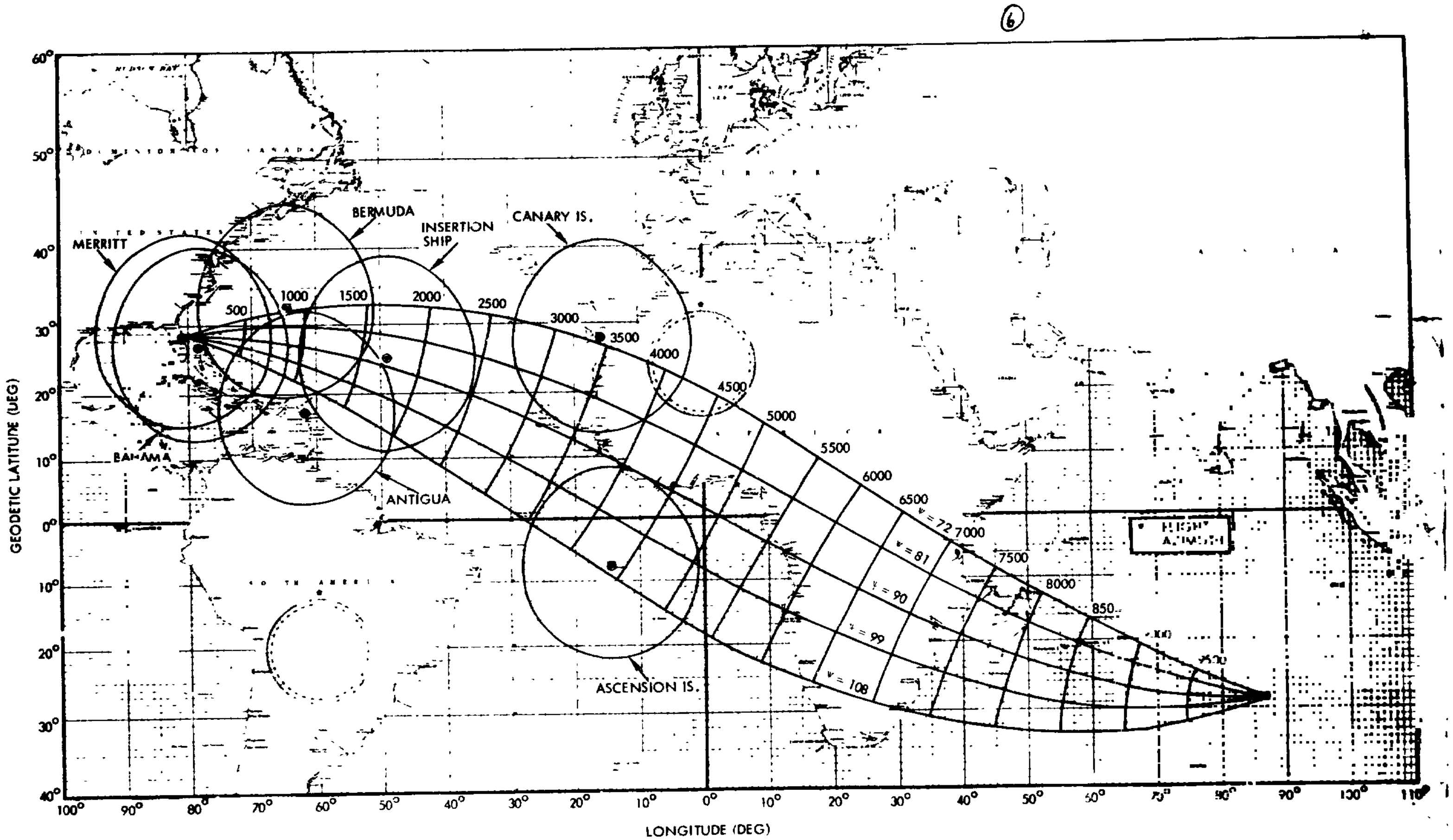

Figure 6. - Constant range lines, ground track traces, and acquisition circles for a typical Saturn V mission.

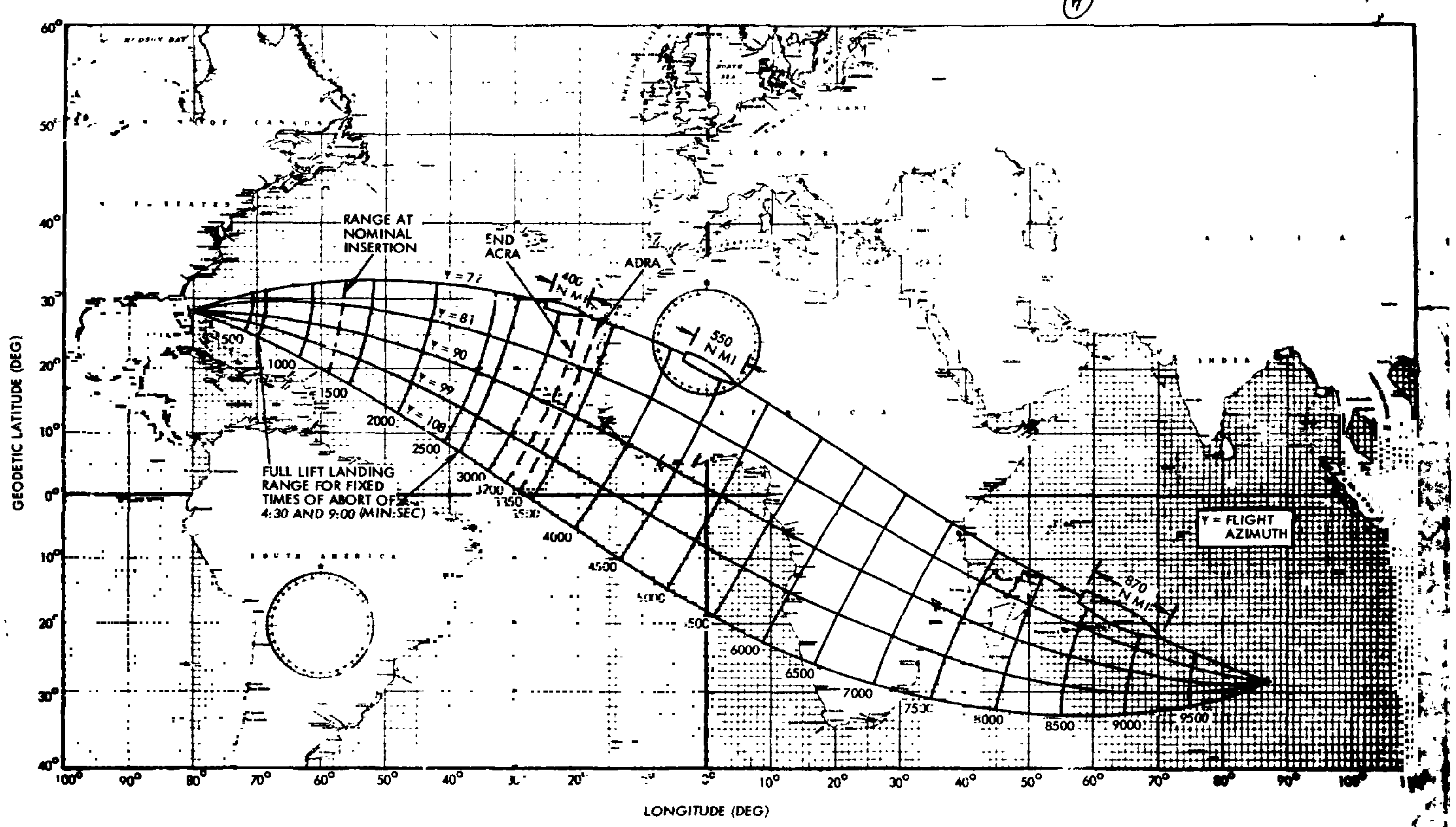

Figure 7. - Constant range lines, ground track traces, and selected landing footprints for a typical Saturn V mission.

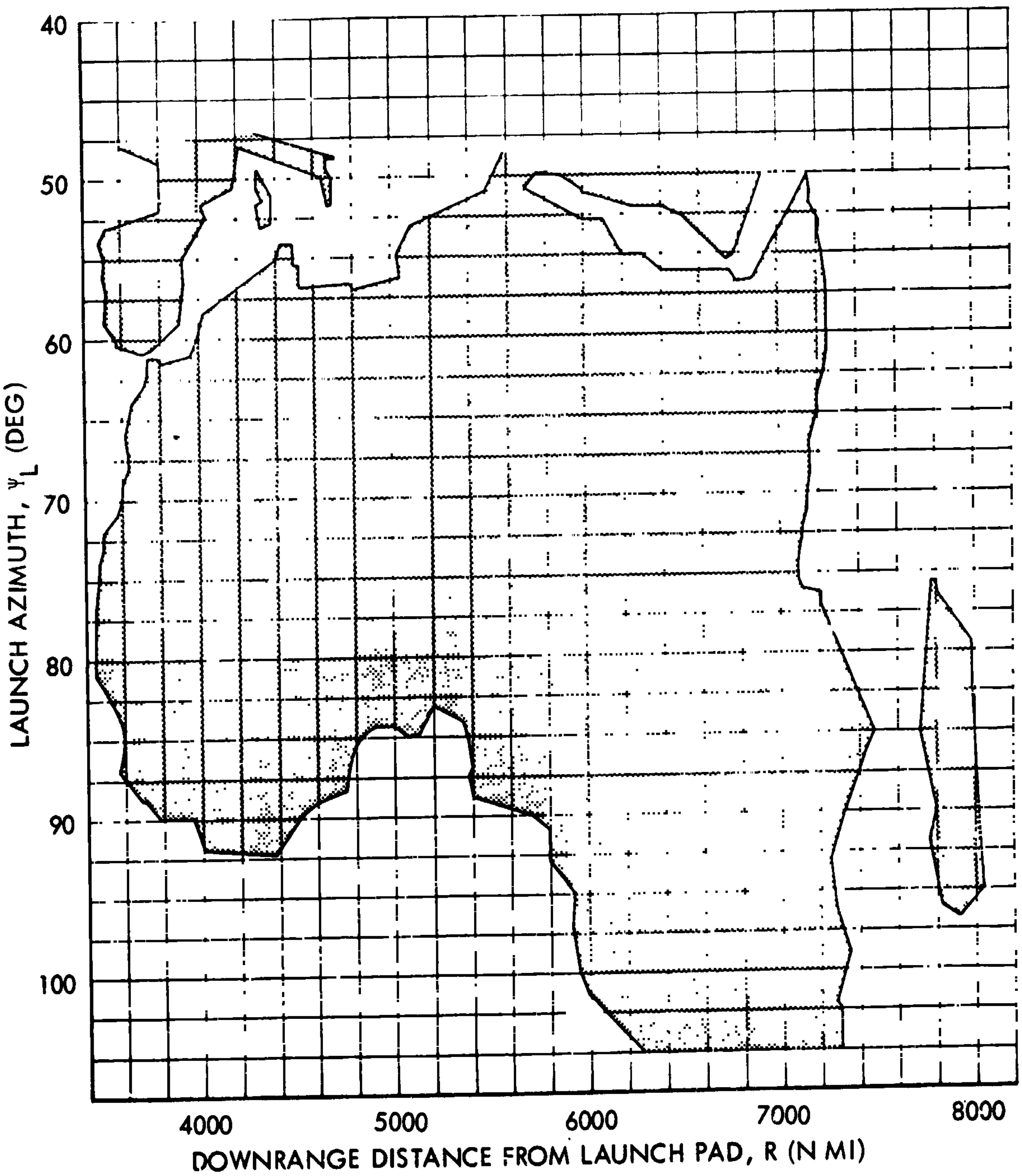

Figure 8.- African land mass for typical Saturn V missions on variable flight azimuths.

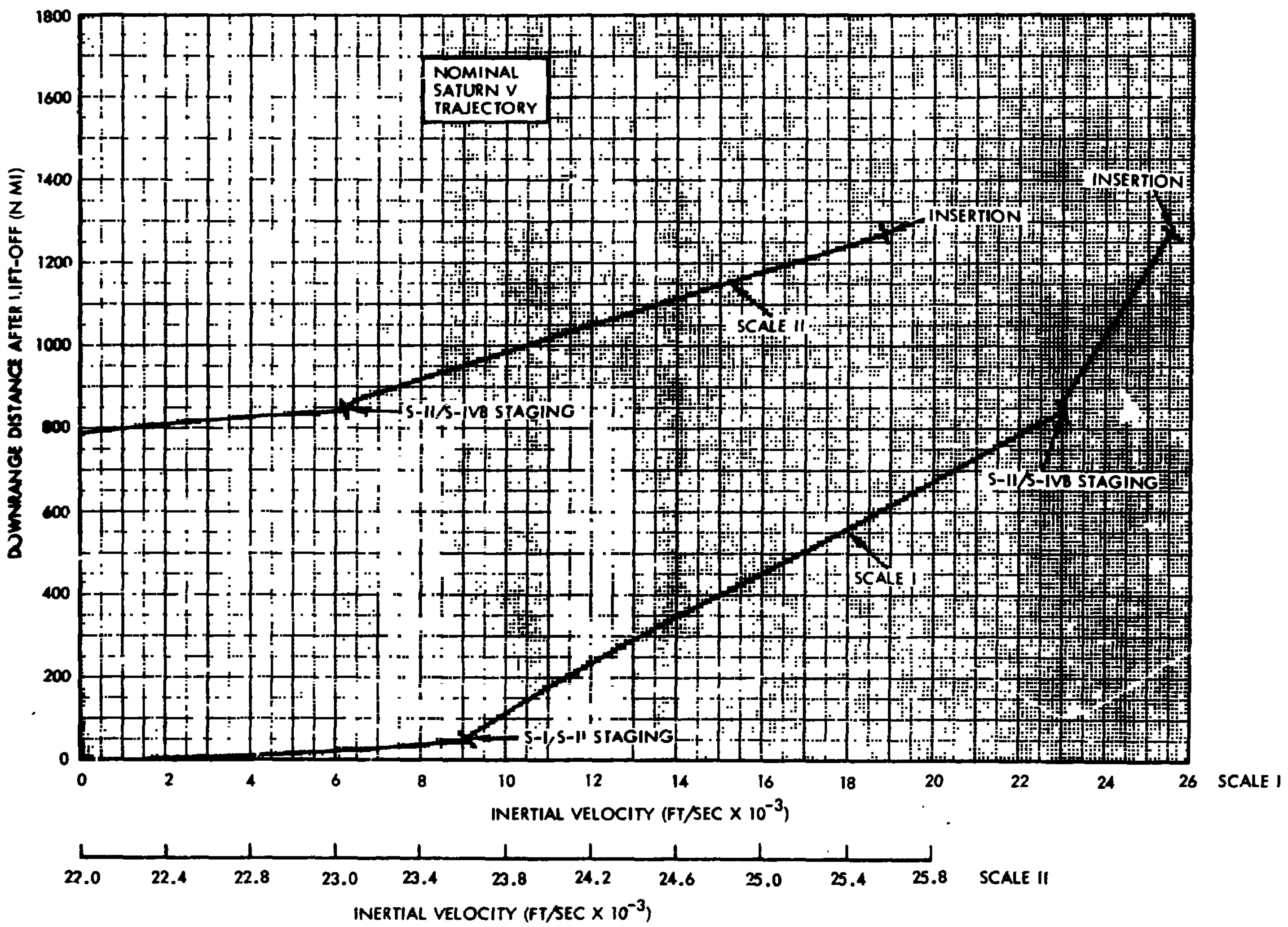

Figure 9.- Down-range distance from lift-off versus inertial velocity for a typical Saturn V mission.

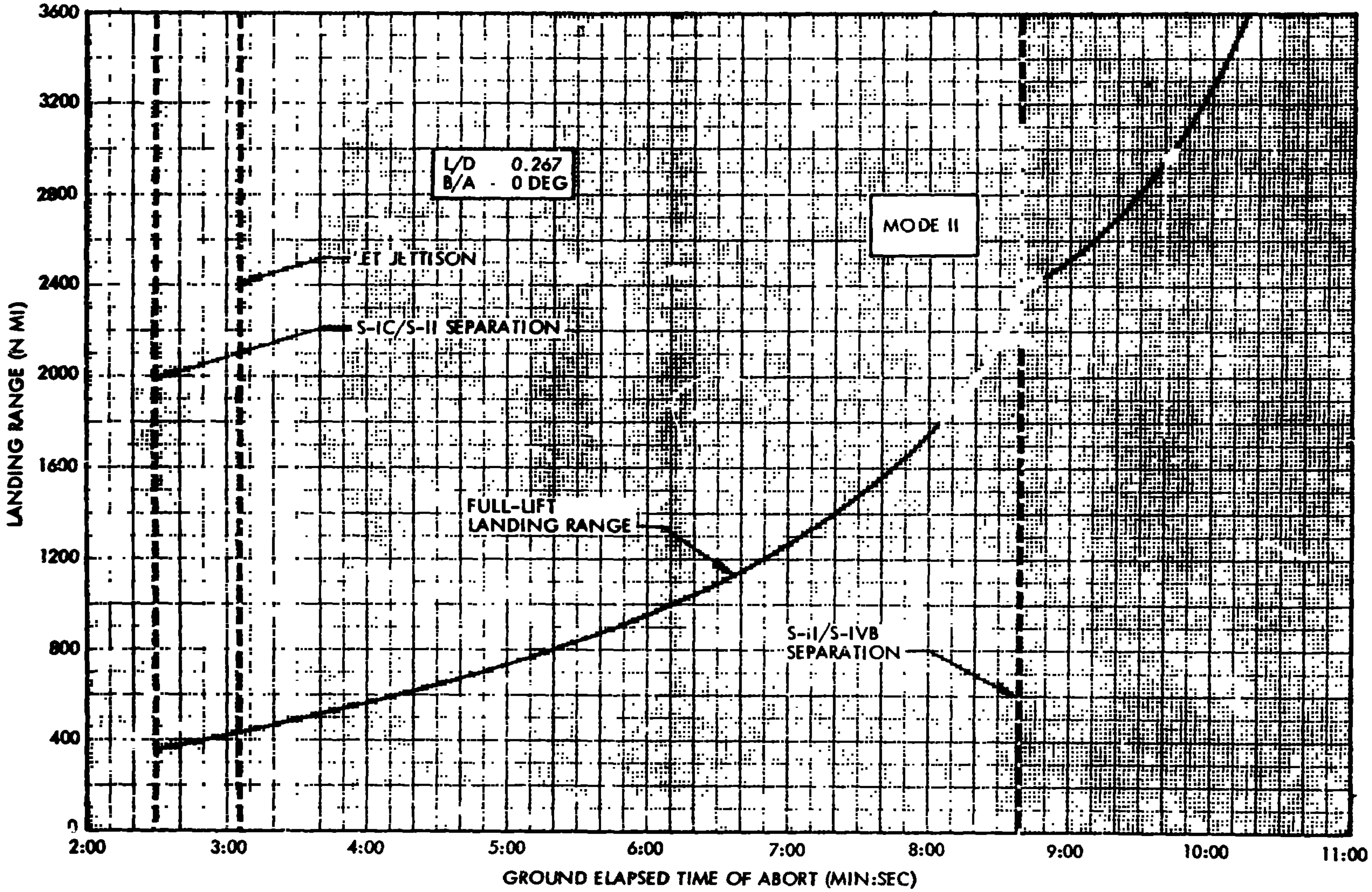

Figure 10.- Full-lift landing range following mode II aborts from the nominal trajectory for a typical Saturn V mission.

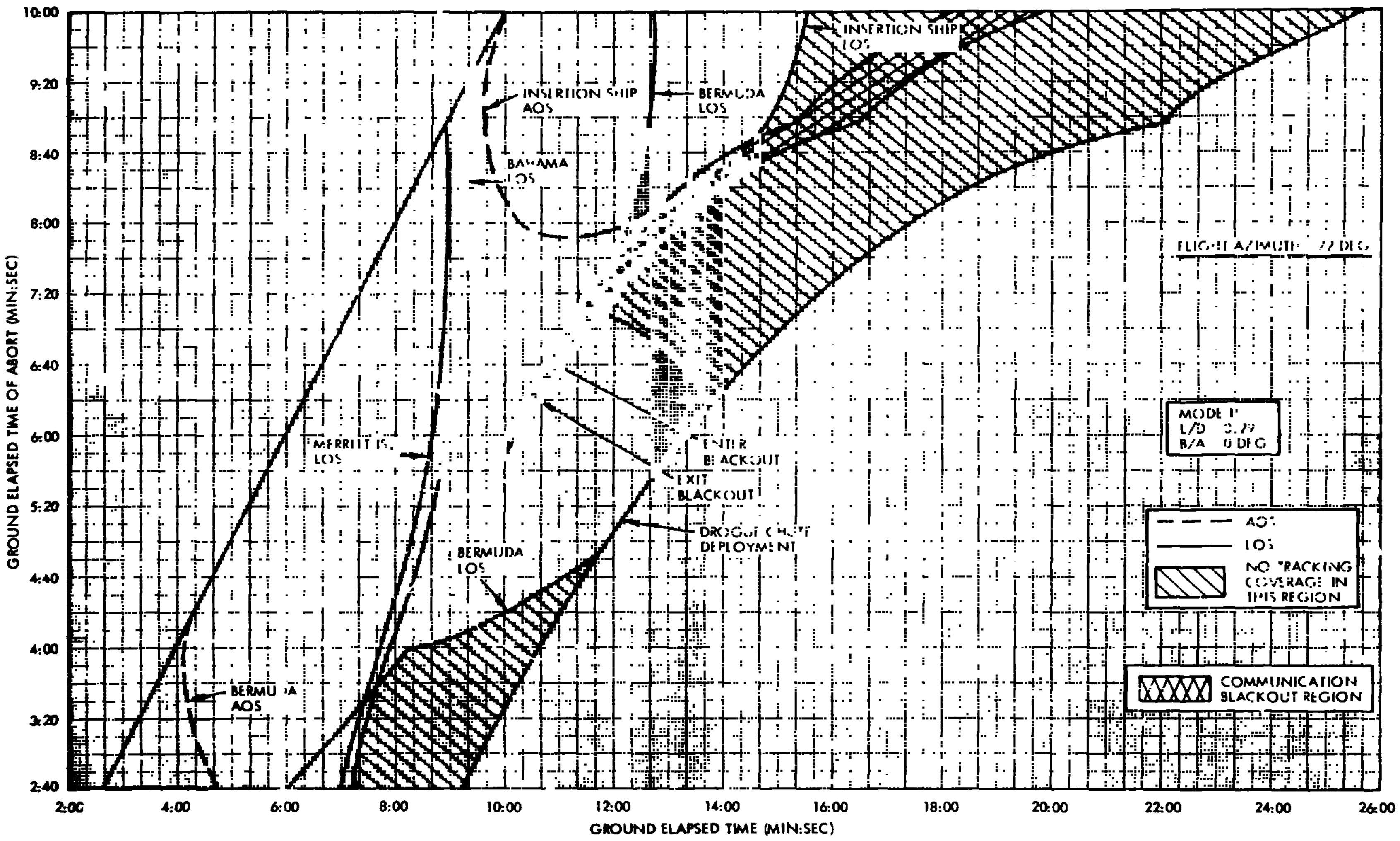

Figure 11.- Tracking coverage during nominal mode II aborts for a typical Saturn V mission - 72-degree flight azimuth.

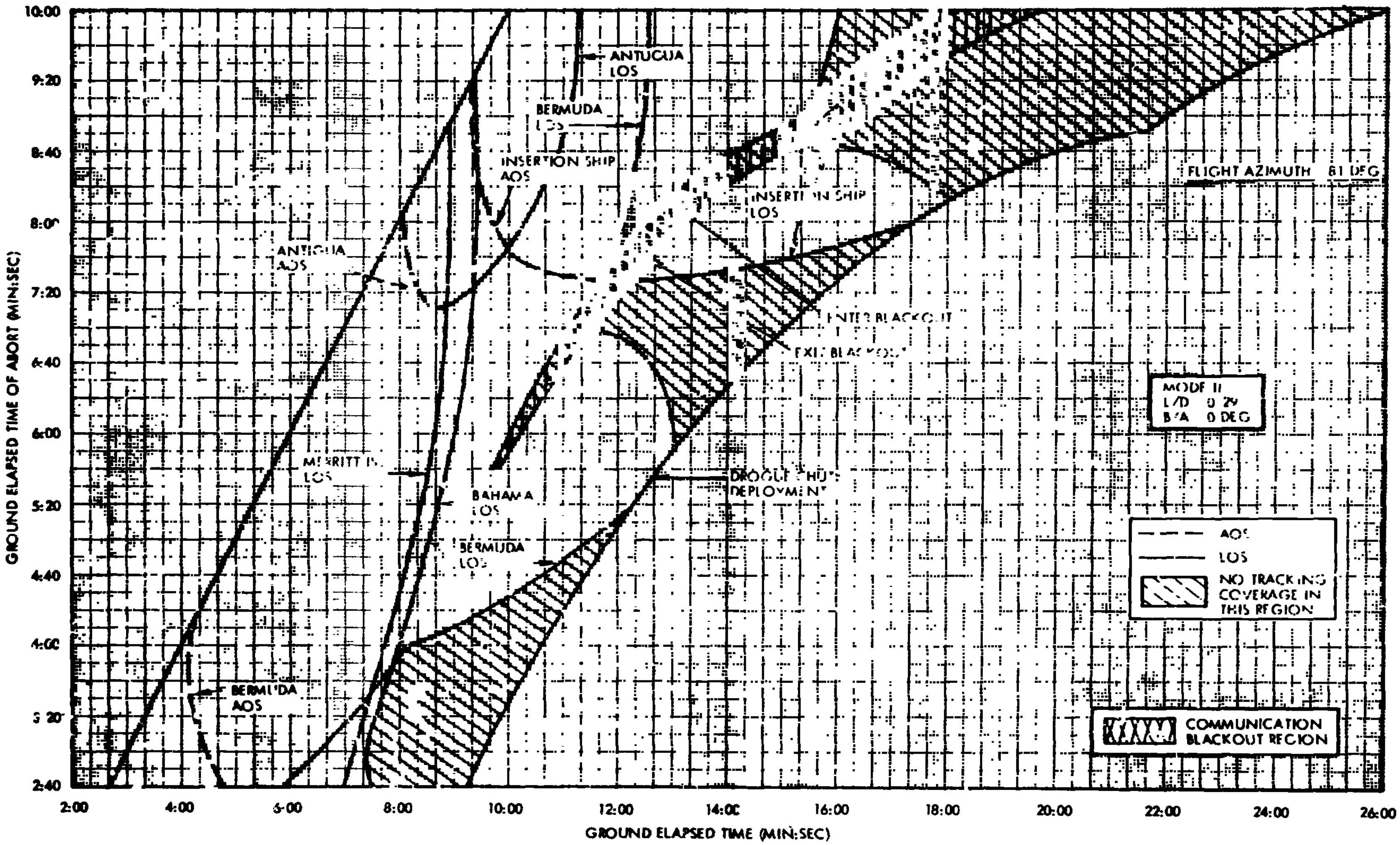

Figure 12.- Tracking coverage during nominal mode II aborts for a typical Saturn V mission - 81-degree flight azimuth.

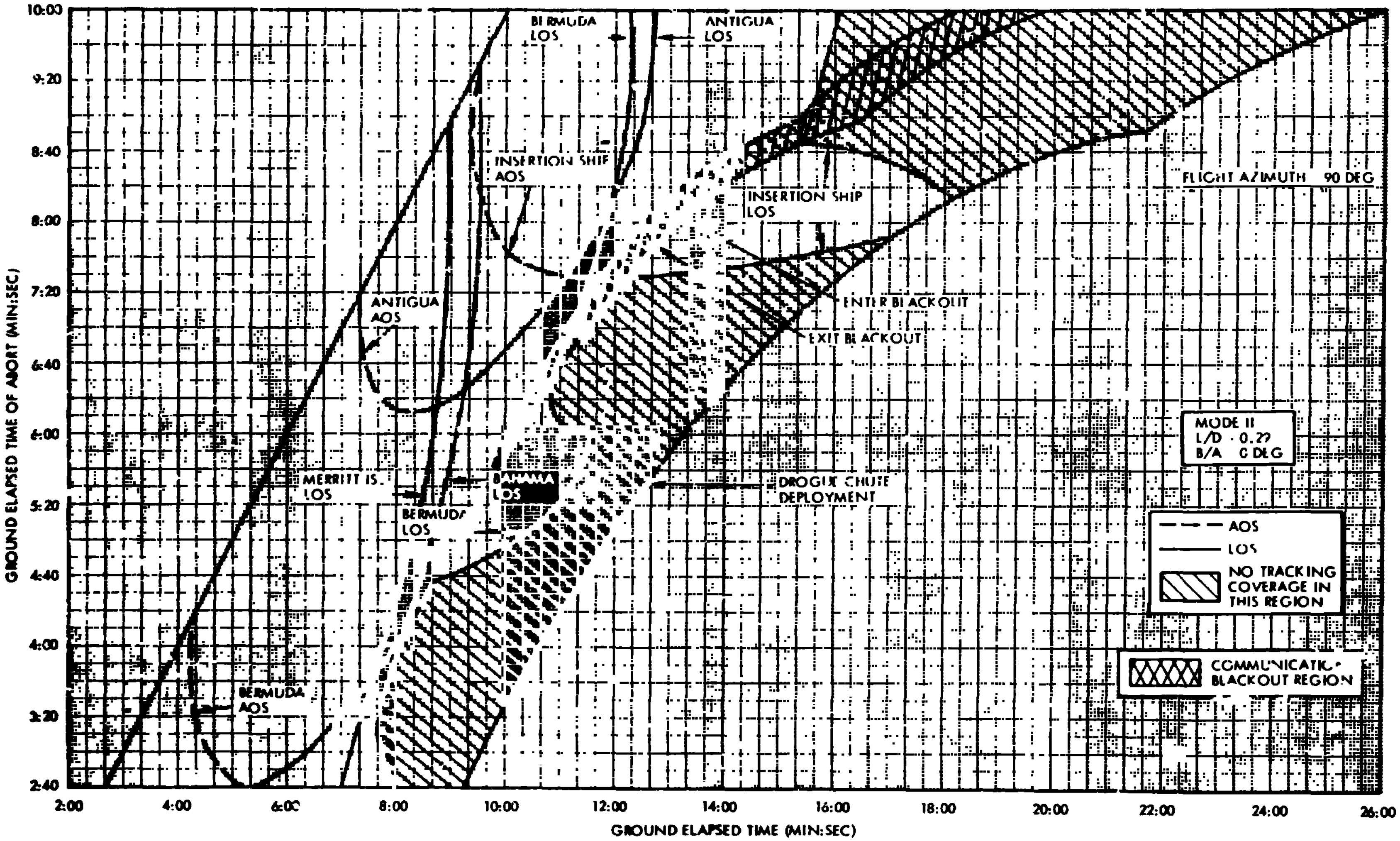

Figure 13.- Tracking coverage during nominal mode II aborts for a typical Saturn V mission - 90-degree flight azimuth.

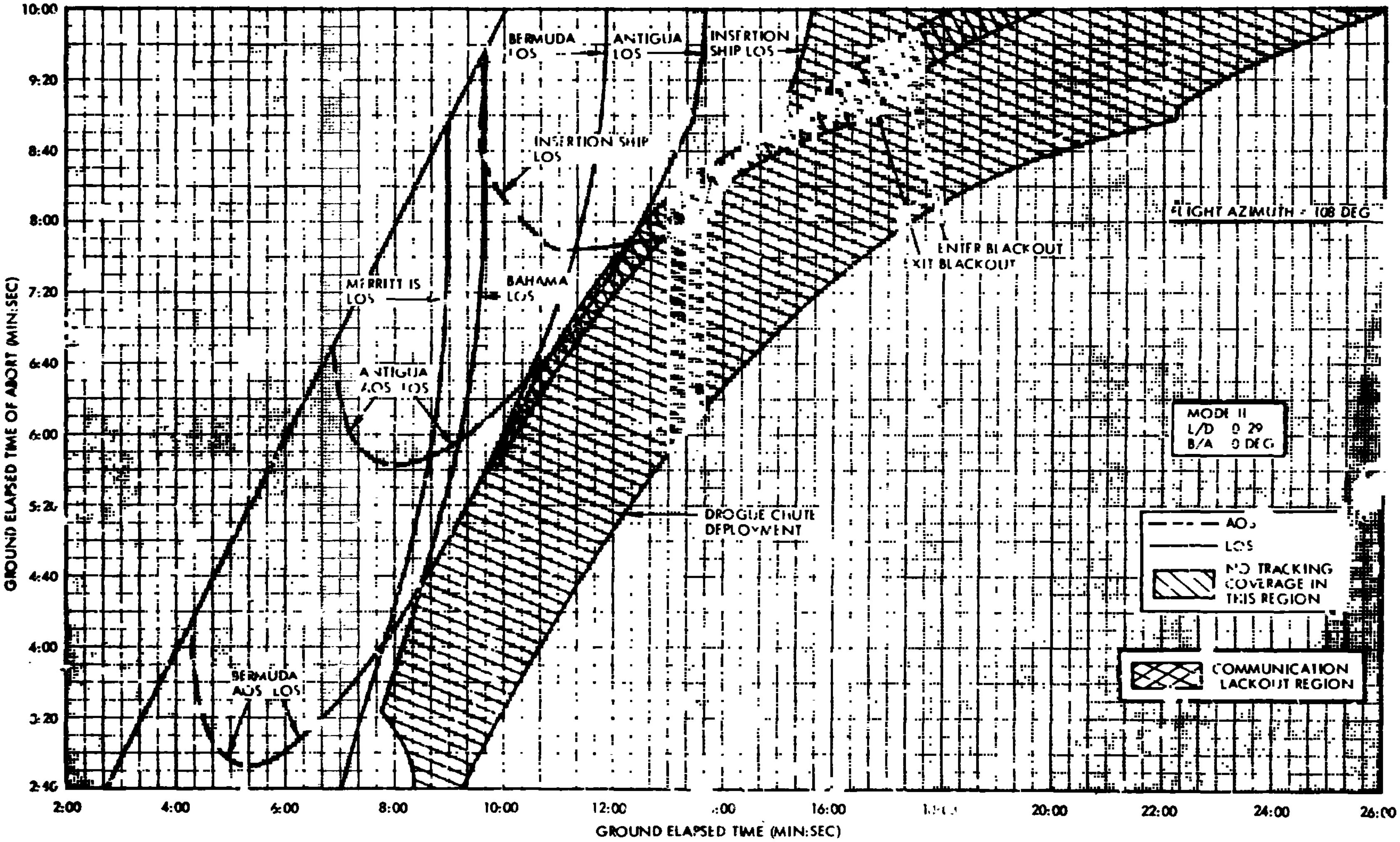

Figure 14.- Tracking coverage during nominal mode II aborts for a typical Saturn V mission - 99-degree flight azimuth.

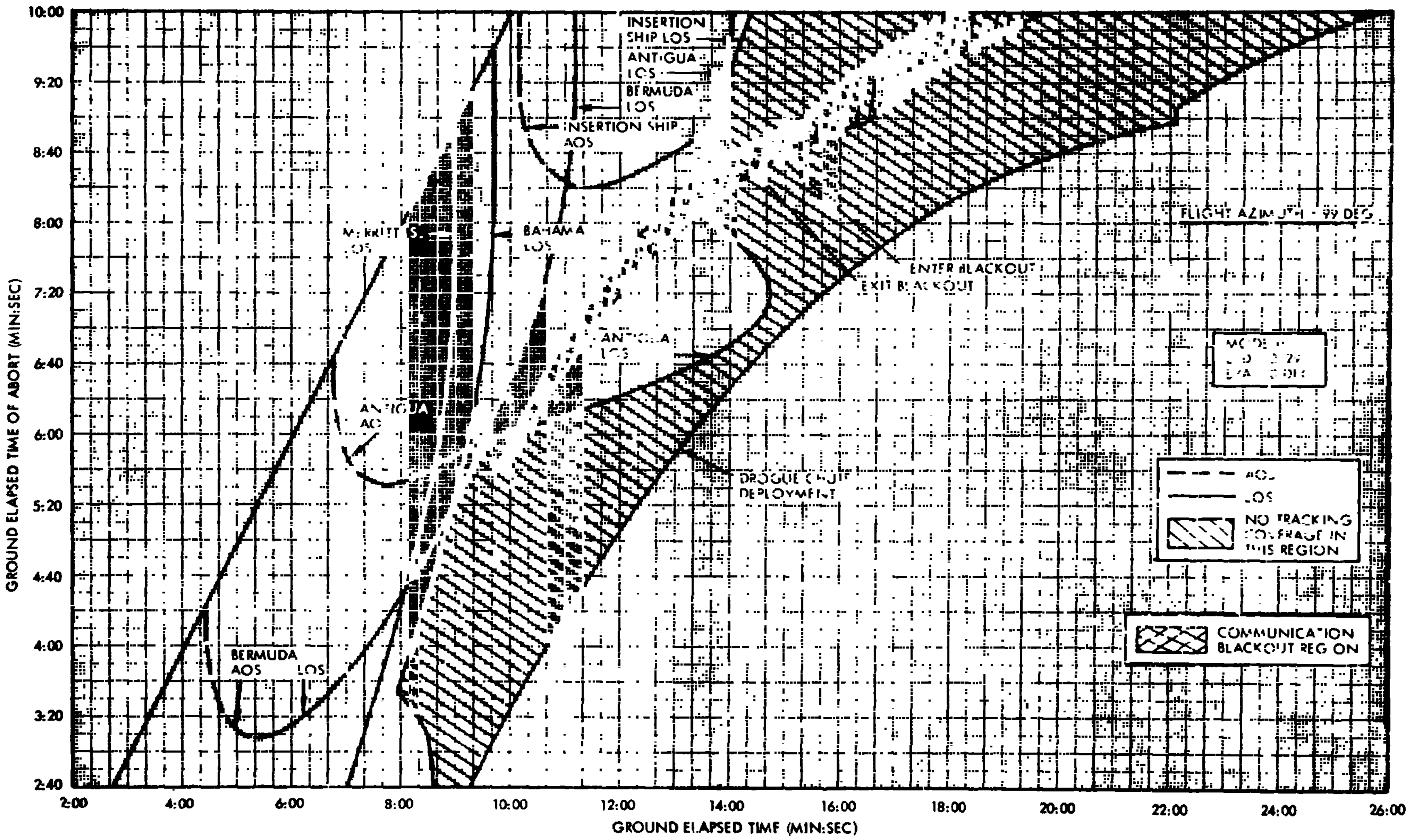

Figure 15.- Tracking coverage during nominal mode II aborts for a typical Saturn V mission - 108-degree flight azimuth.

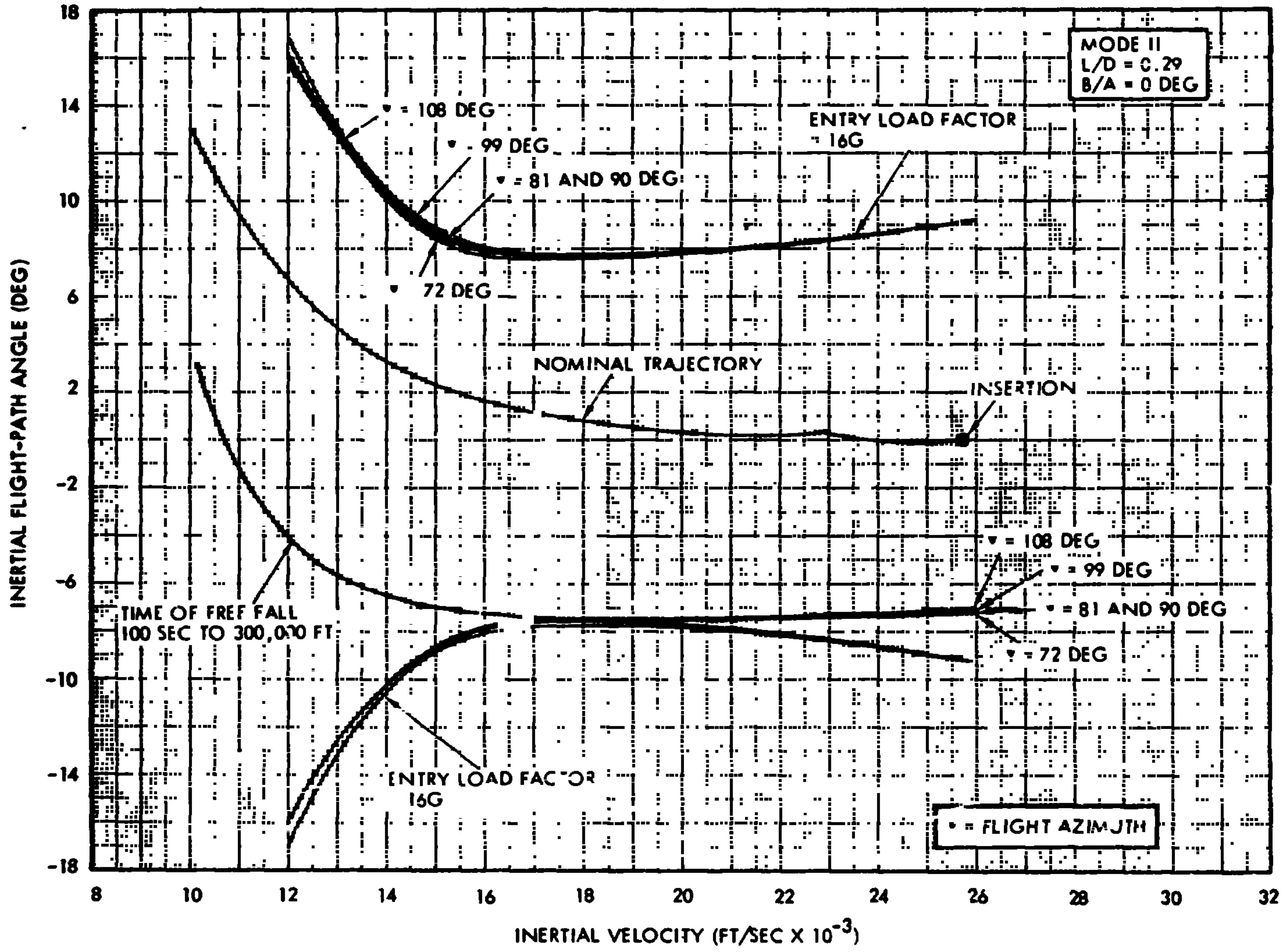

Figure 16.- Variation in the maximum-entry-load-factor and time-of-free-fall limit lines as a function of flight azimuth for a typical Saturn V mission.

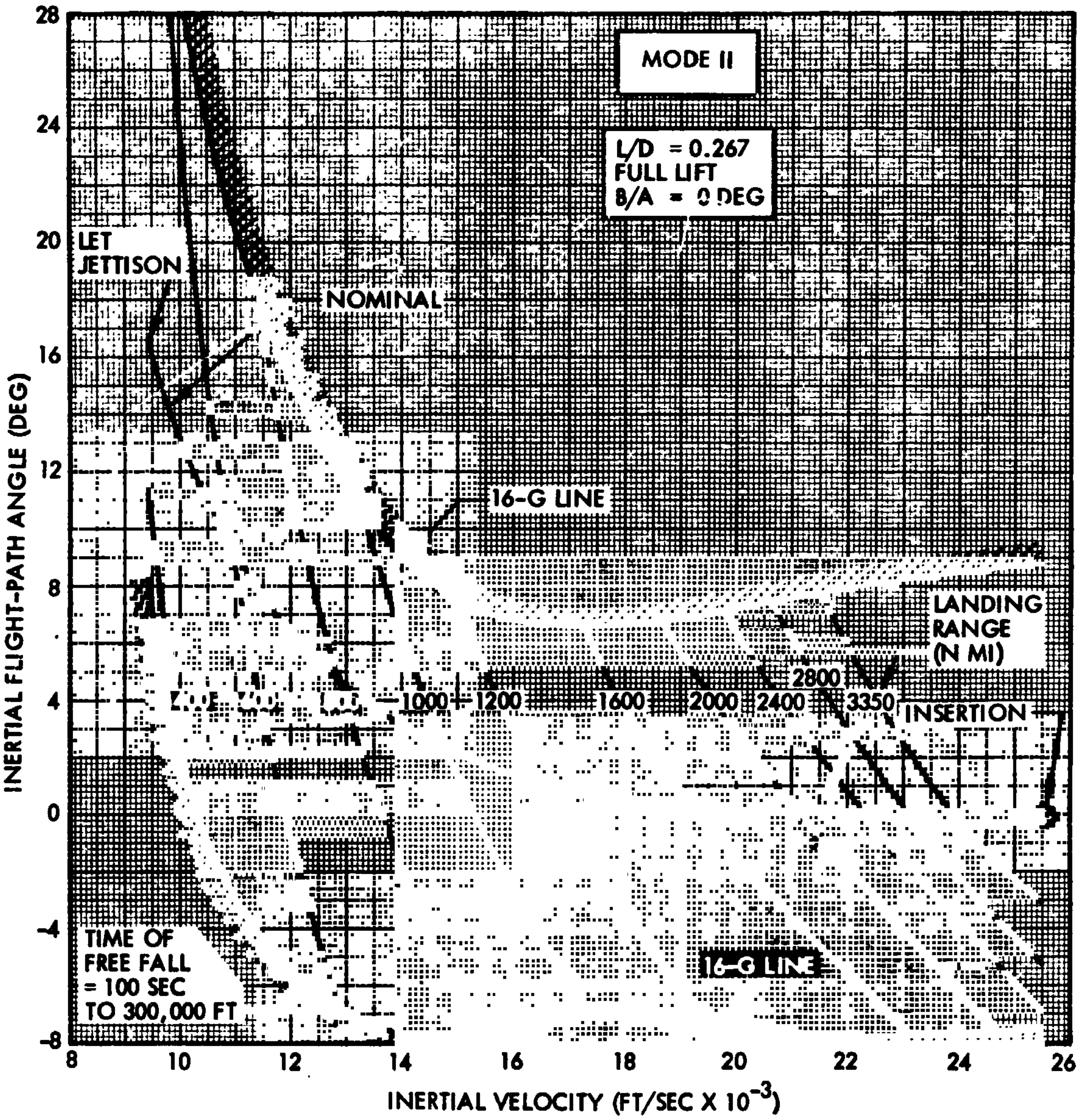

Figure 17.- Variation in full-lift landing range lines for a typical Sat::rn V mission.

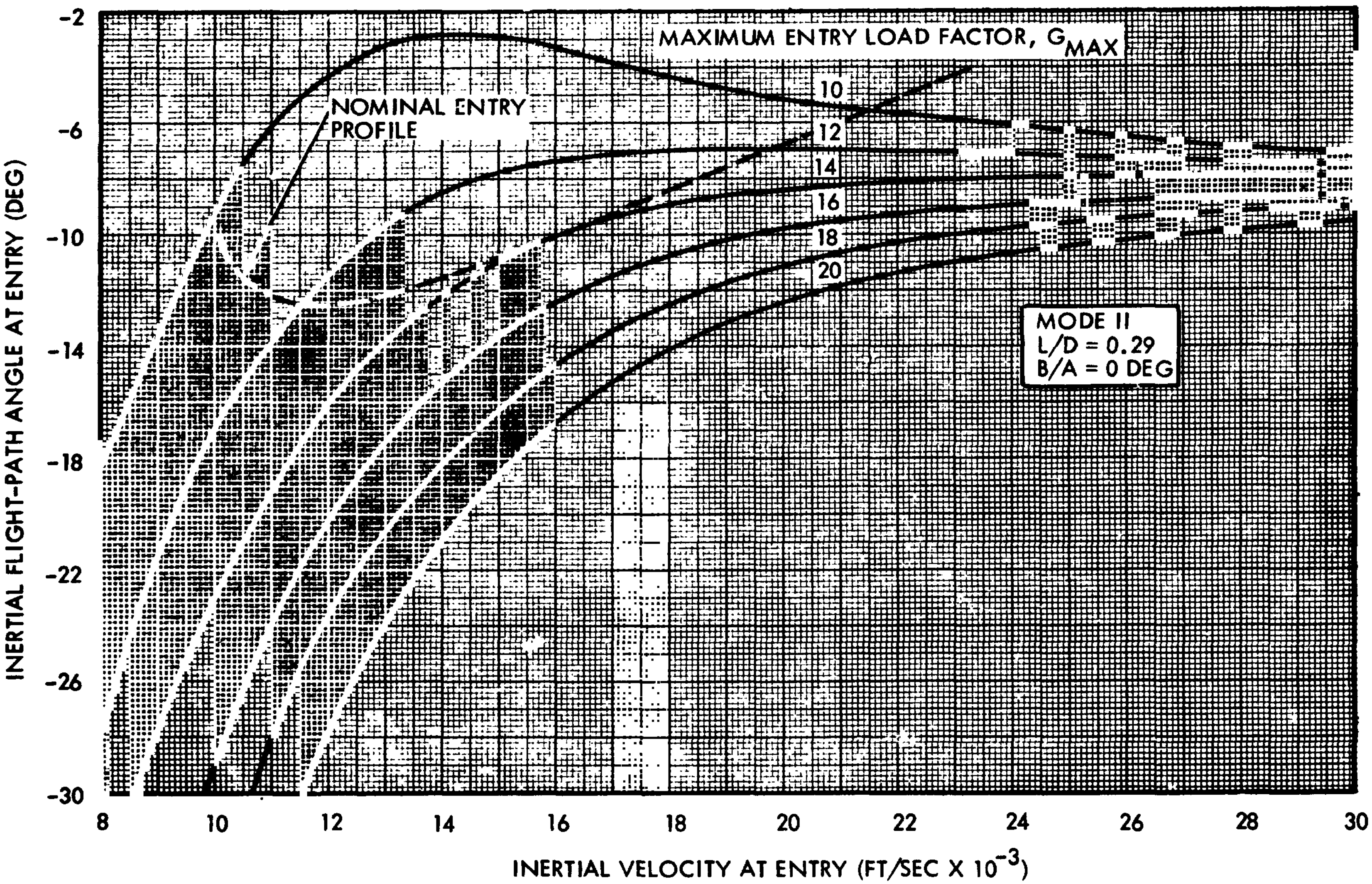

Figure 18.- Maximum-entry-load-factor lines as functions of conditions at entry interface (400 000 ft).

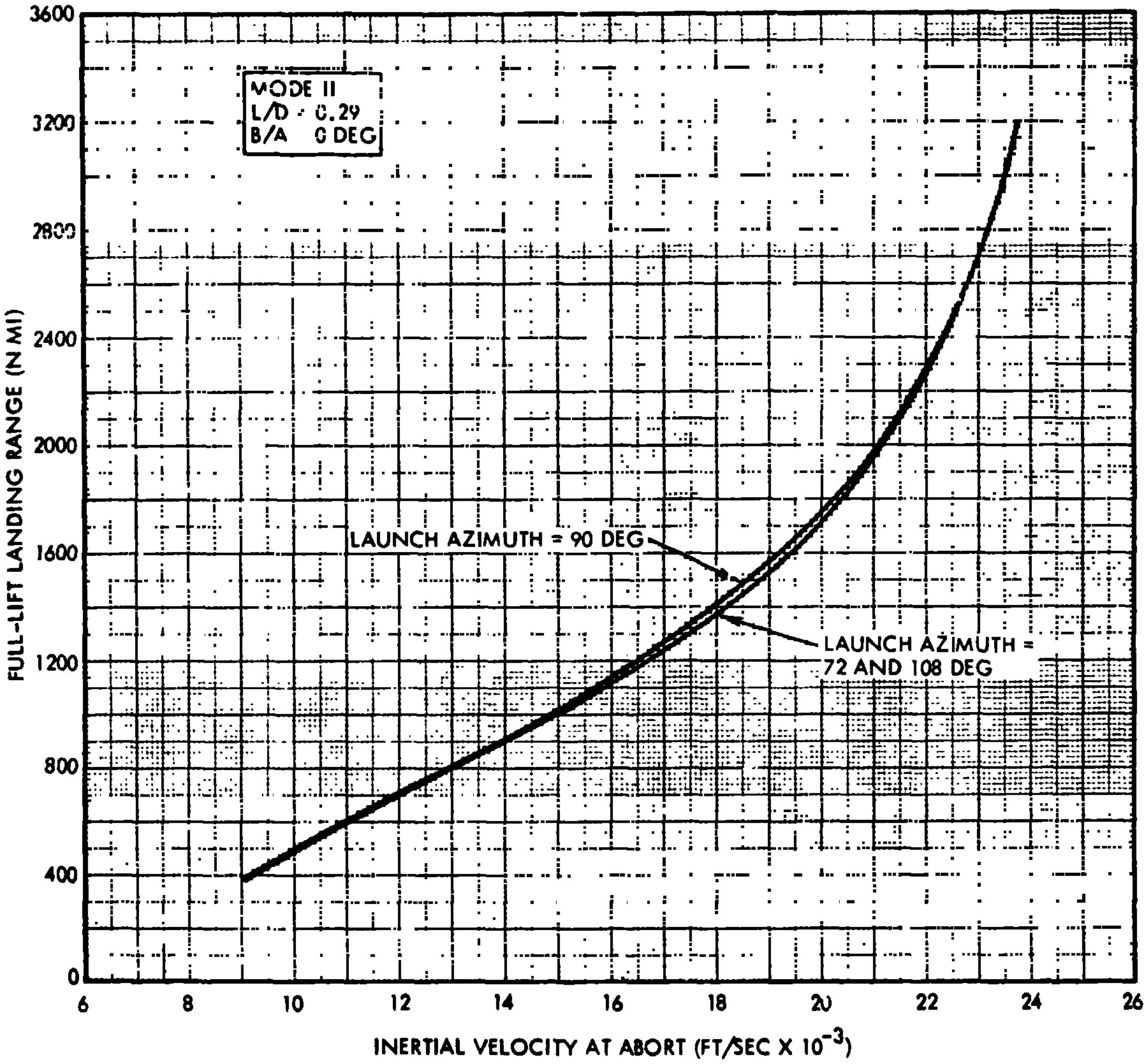

Figure 19.- Maximum variation in the full-lift landing range for a typical Saturn V mission.

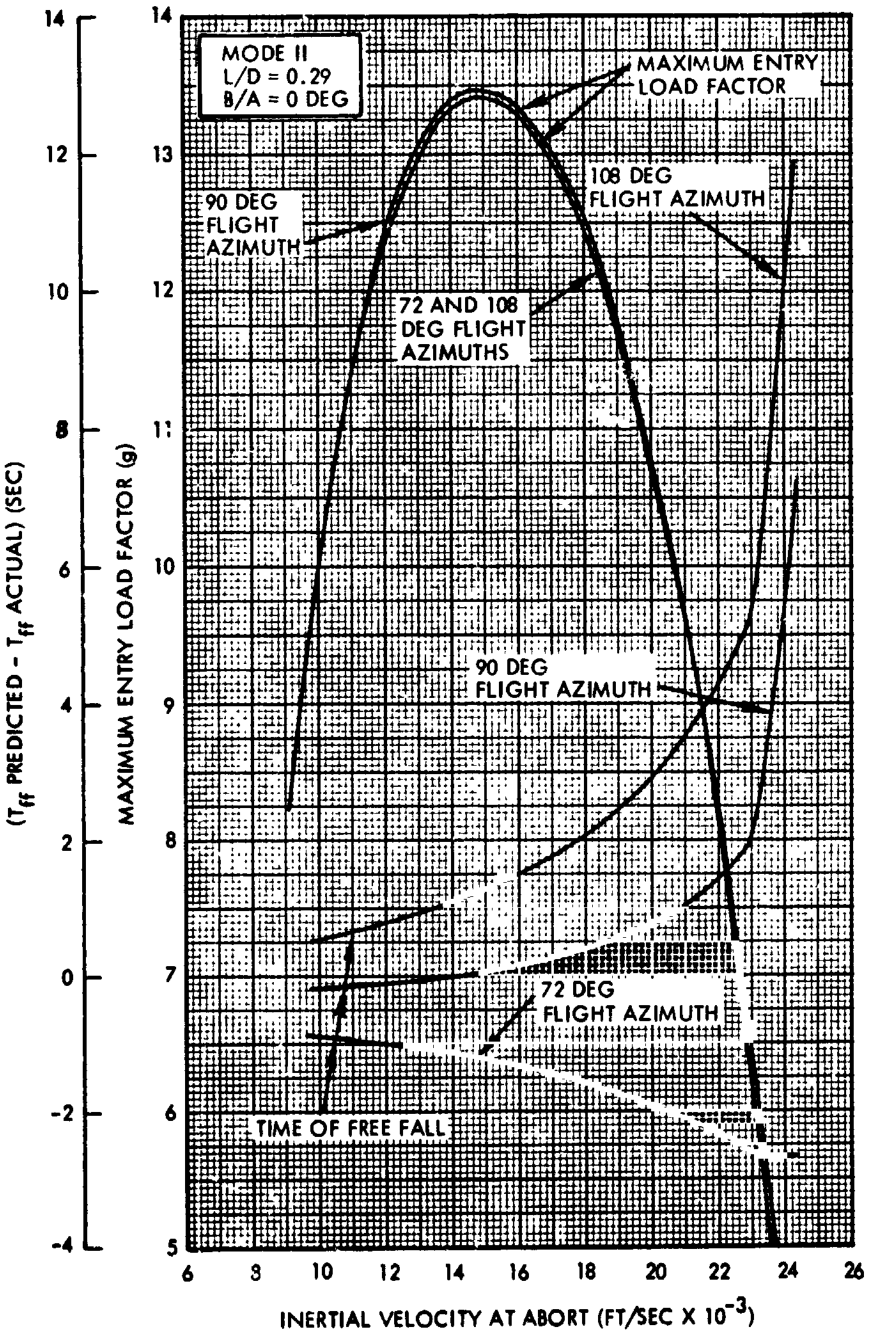

Figure 20.- Variation in maximum entry load factor and time of free fall to 300 000 ft following nominal mode II aborts for a typical Saturn V mission.

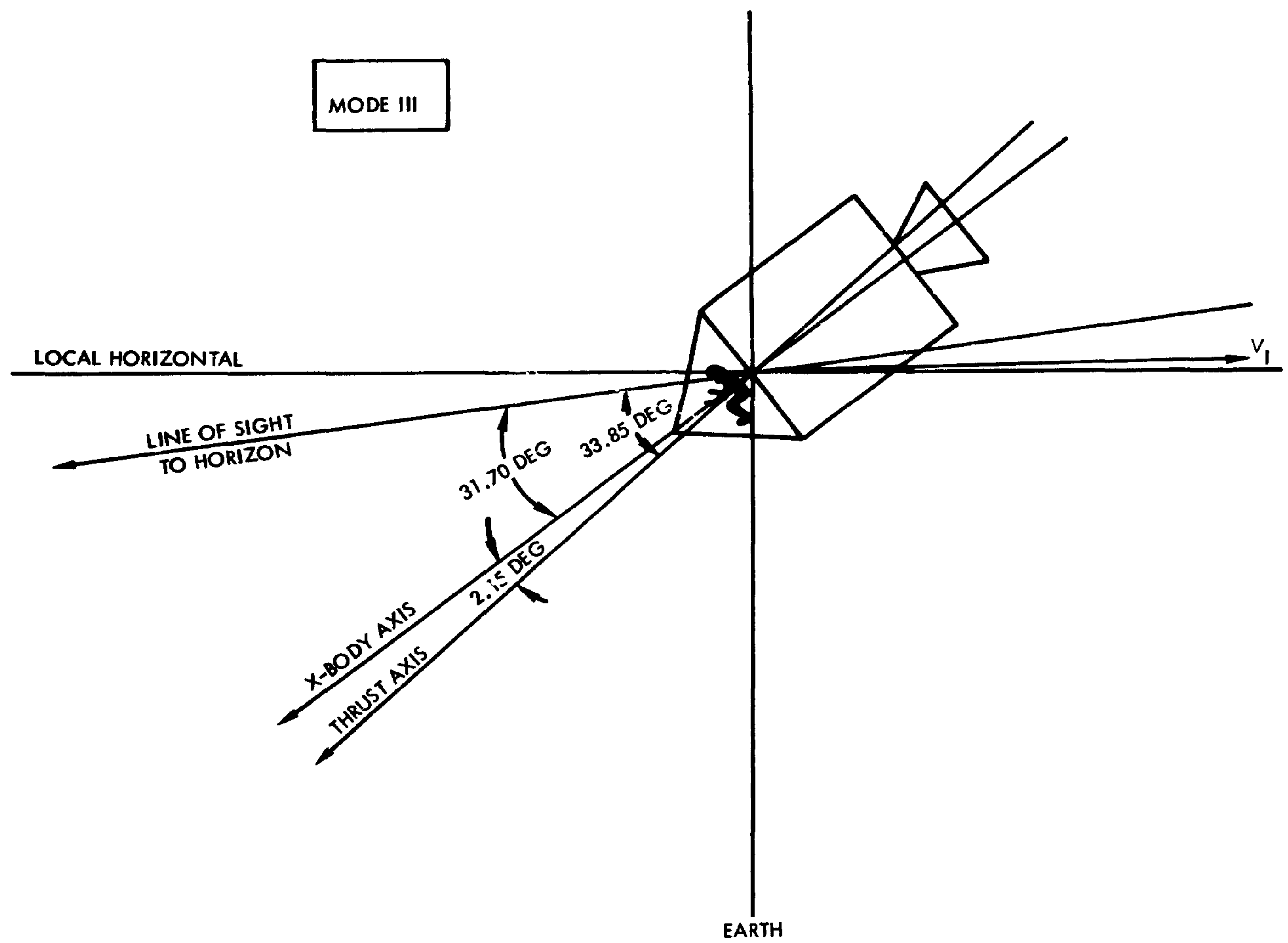

Figure 21.- Command service module orientation at SPS ignition for mode III launch aborts.

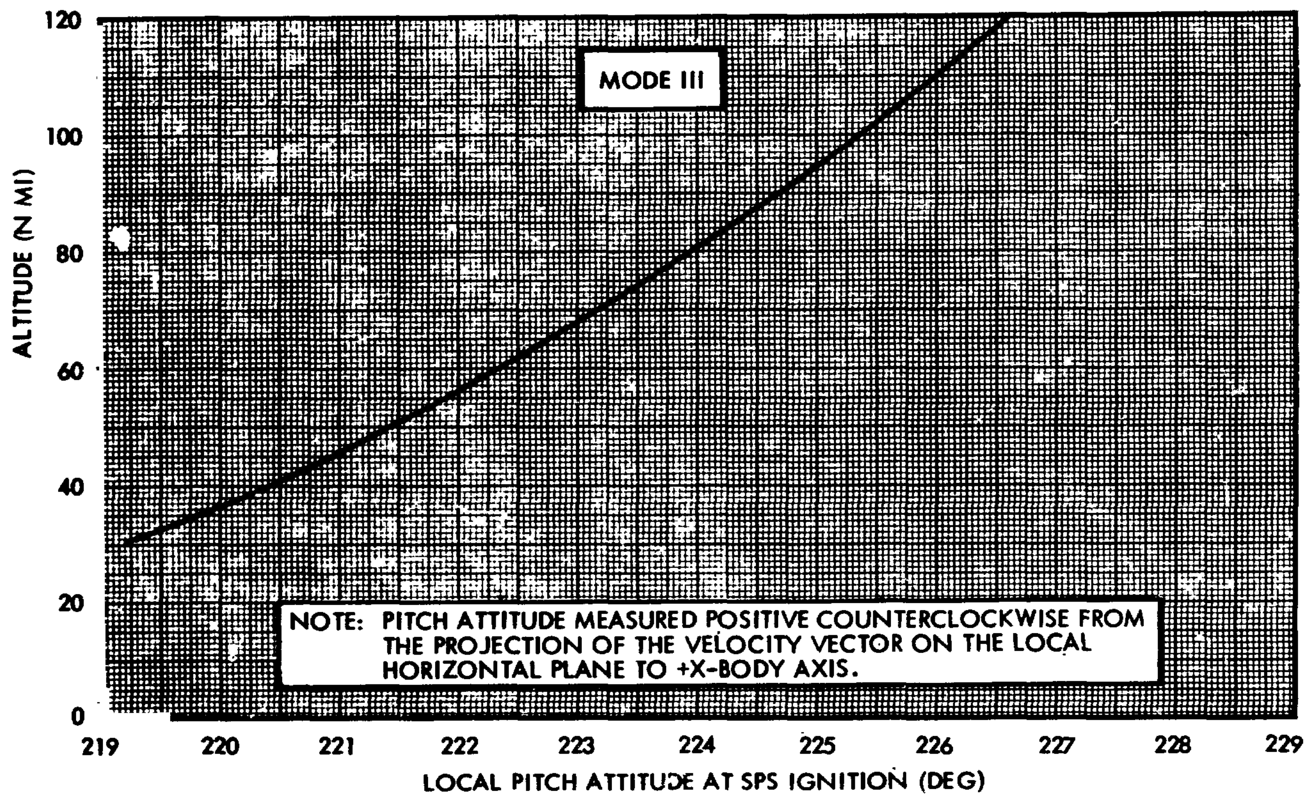

Figure 22.- Command service module local pitch attitude at SPS ignition for mode III aborts.

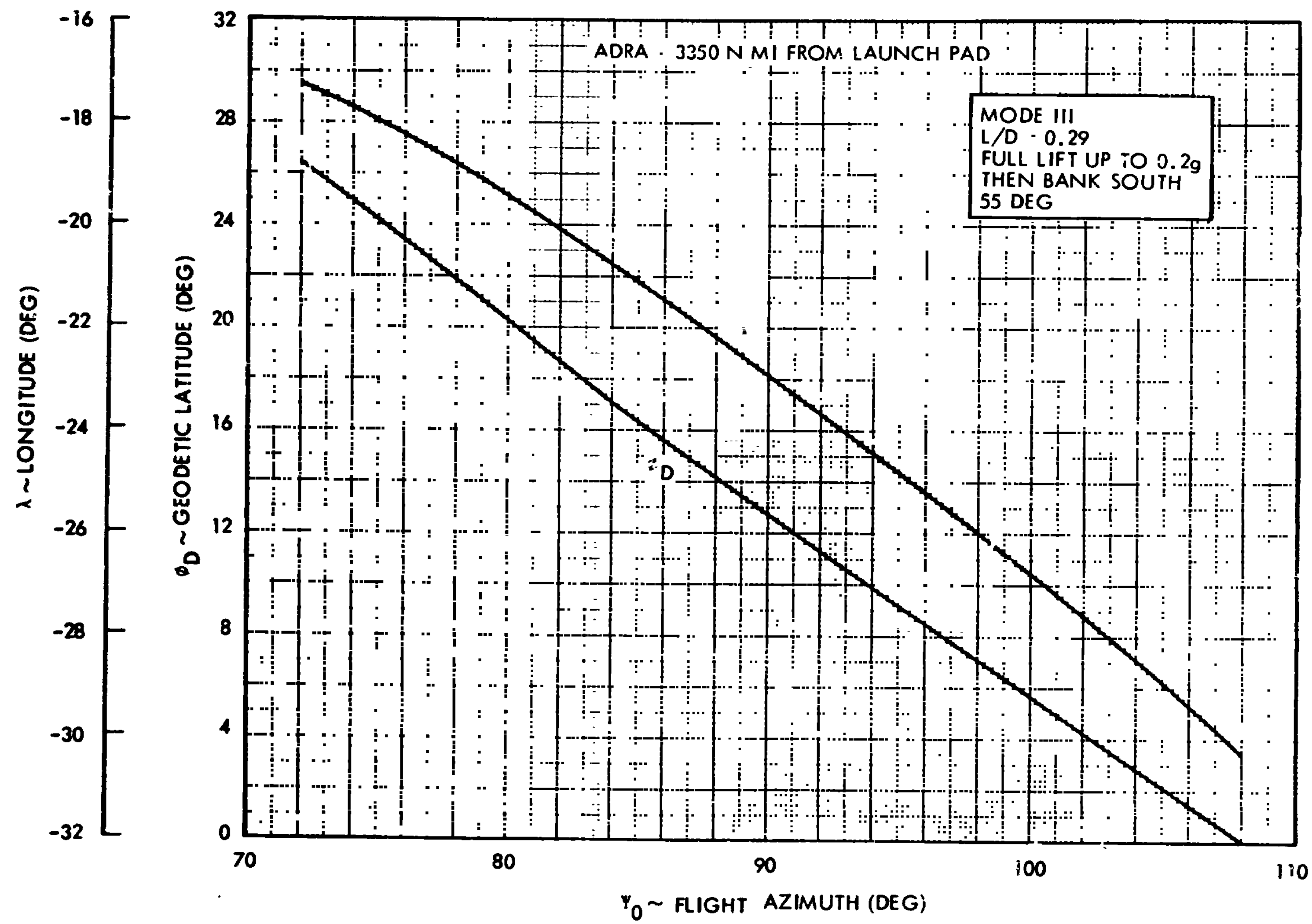

Figure 23.- Movement of ADRA target as a function of flight azimuth for a typical Saturn V mission.

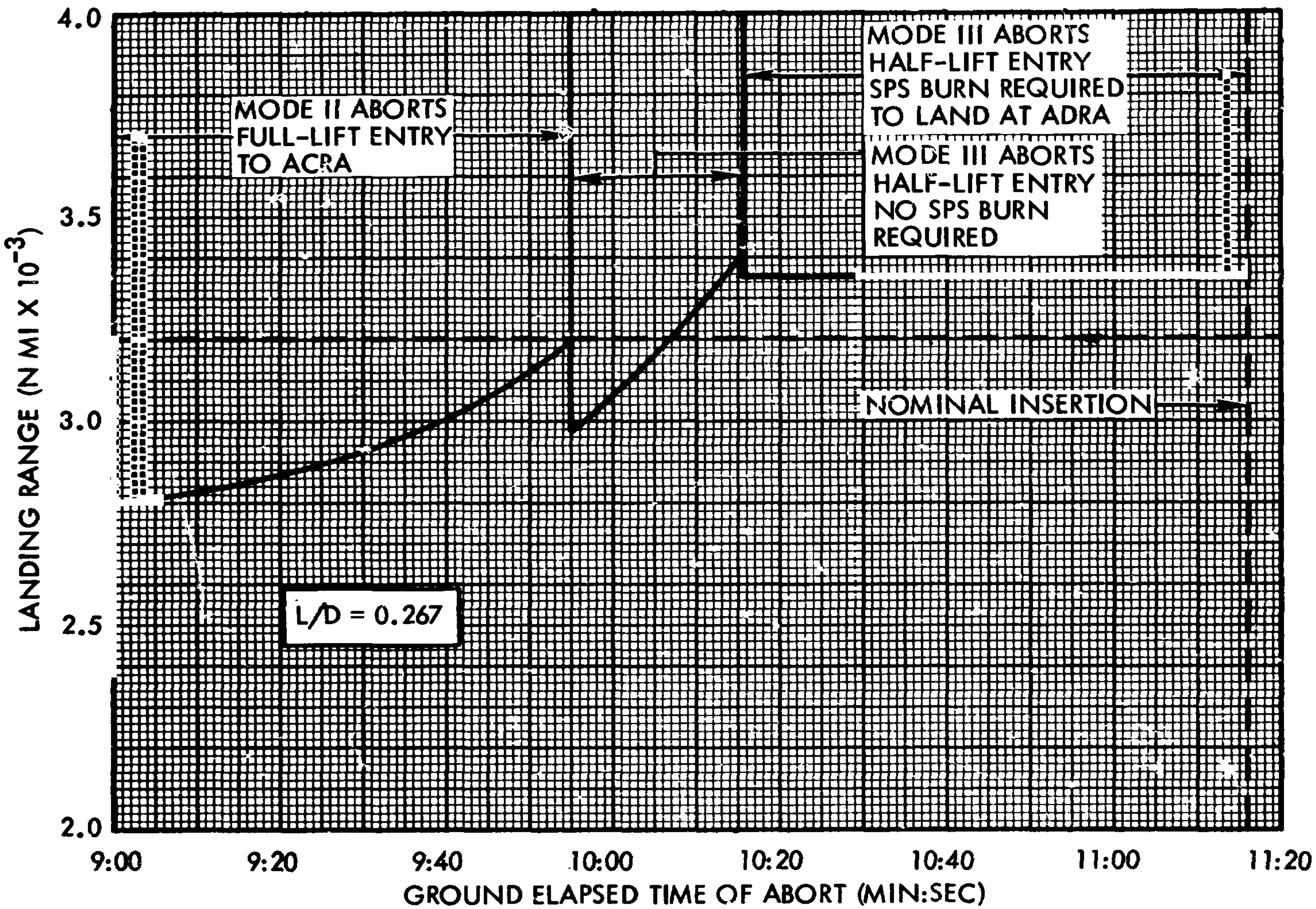

Figure 24.- Landing range summary following nominal mode II and mode III aborts for a typical Saturn V mission.

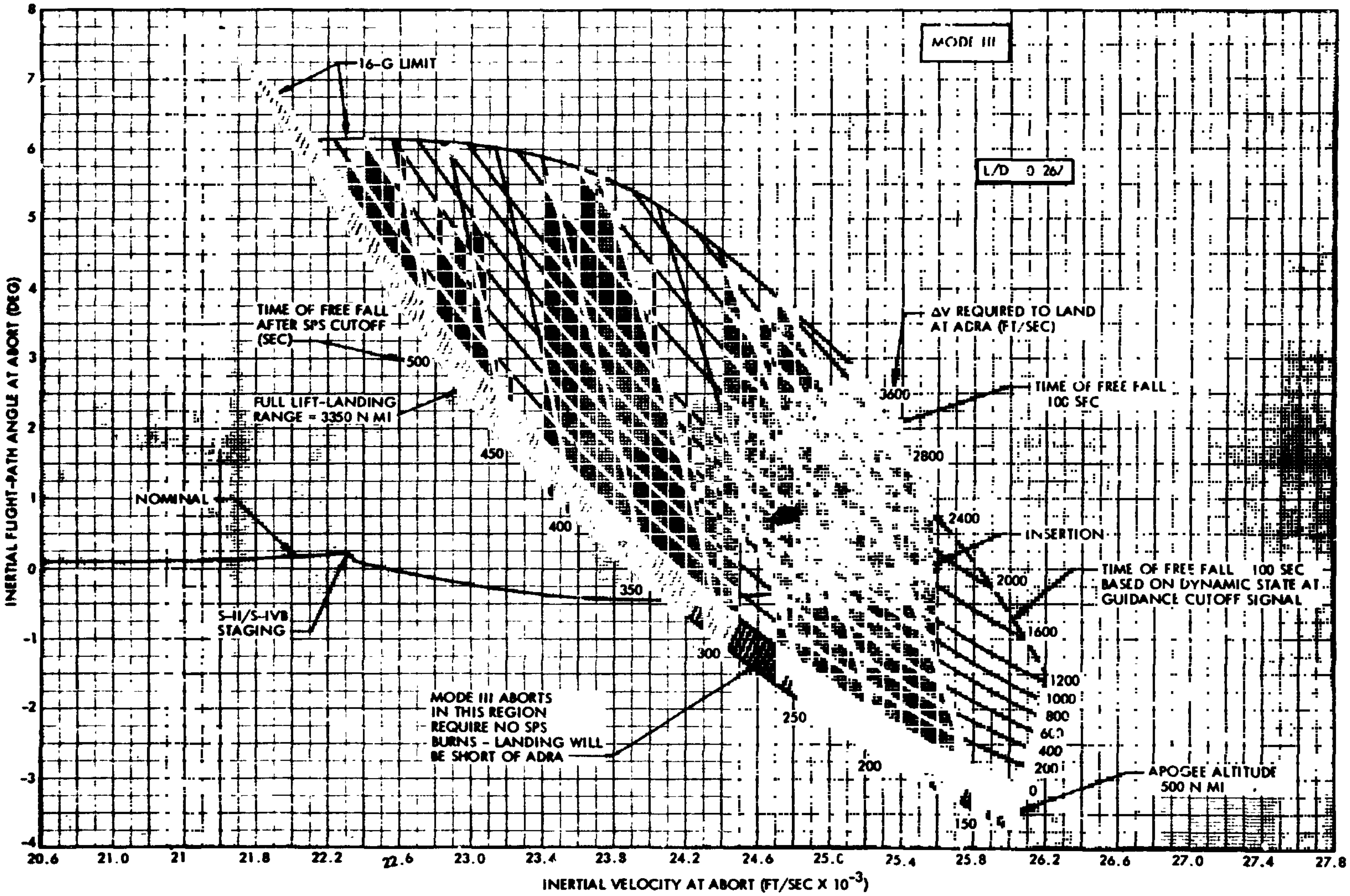

Figure 25.- mode III abort region for a typical Saturn V mission - nominal attitude at abort.

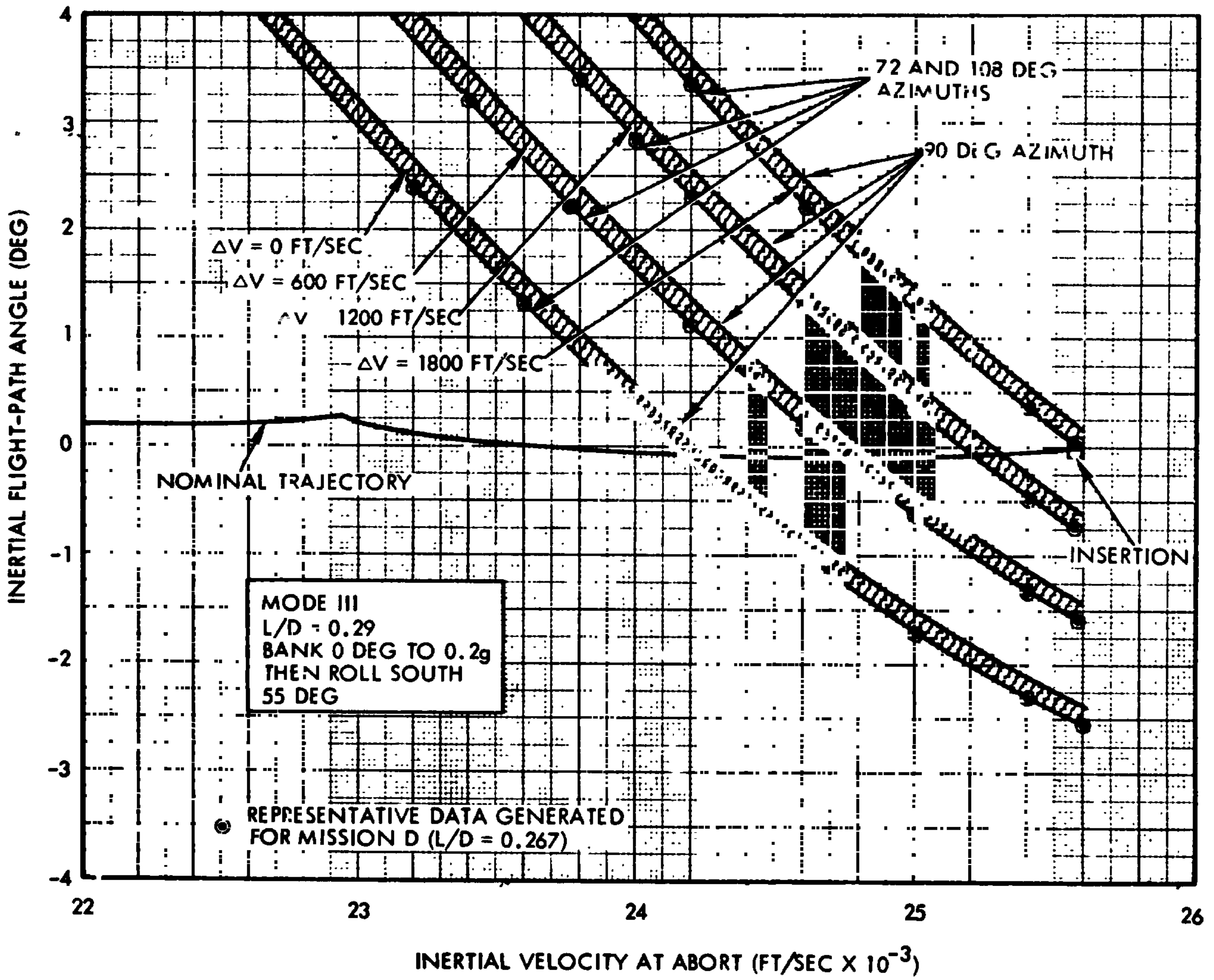

Figure 26.- Maximum variation of selected constant ΔV lines for mode III aborts on flight azimuths between 72 and 108 degrees.

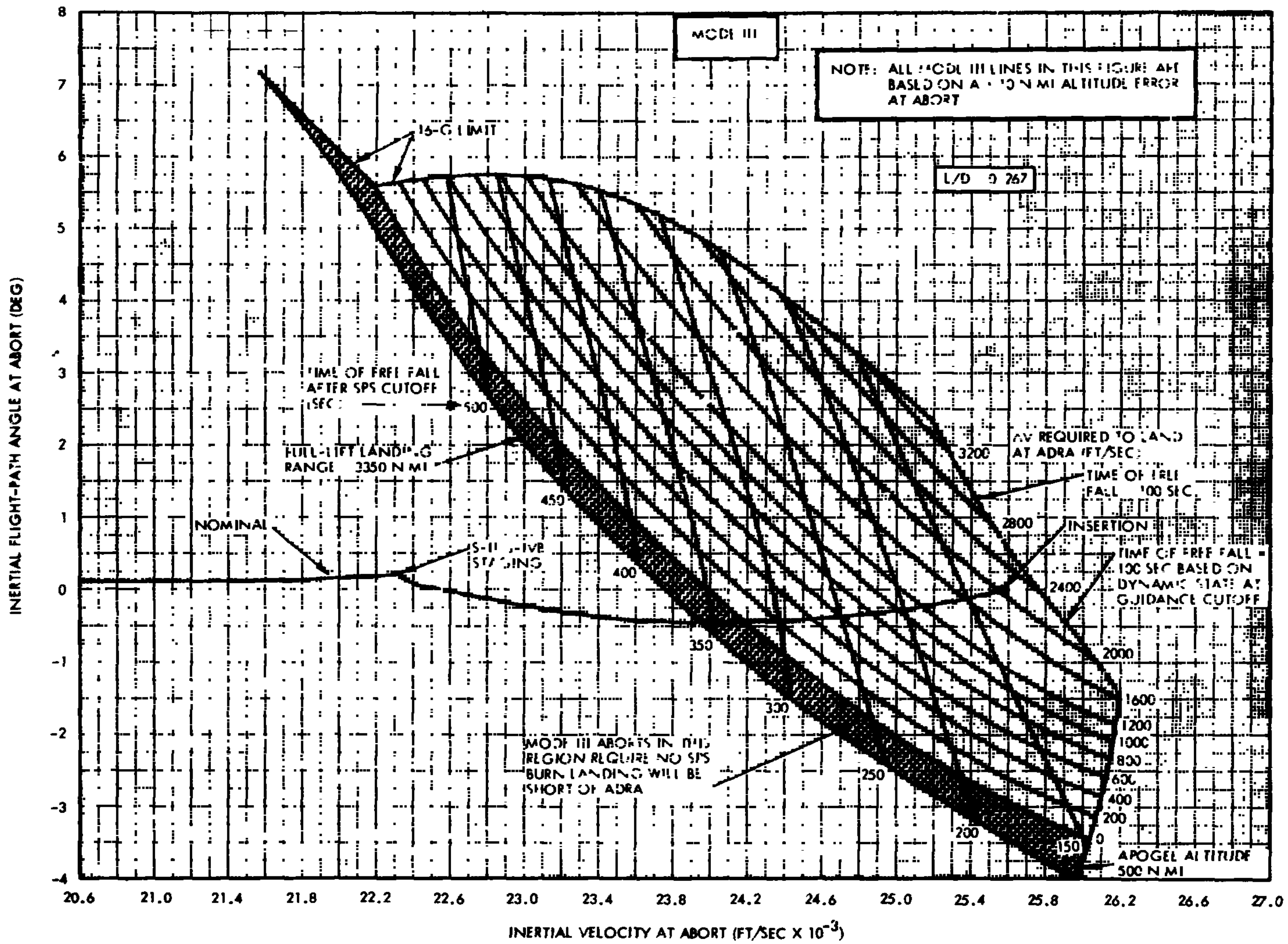

Figure 27.- mode III abort region for a typical Saturn V mission - plus-10-nautical-mile altitude deviation at abort.

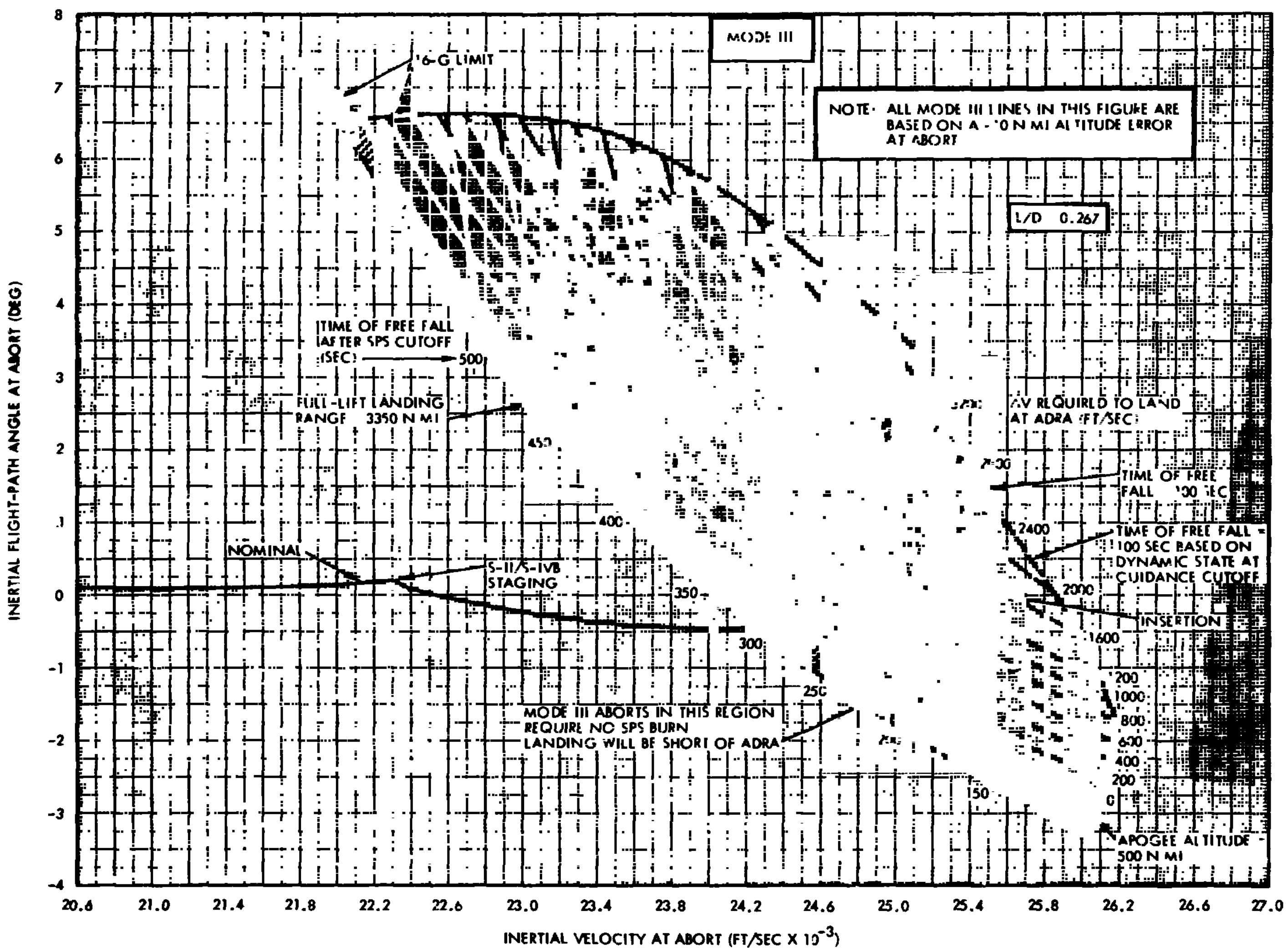

Figure 28.- mode III abort region for a typical Saturn V mission - minus-10-nautical-mile altitude deviation at abort.

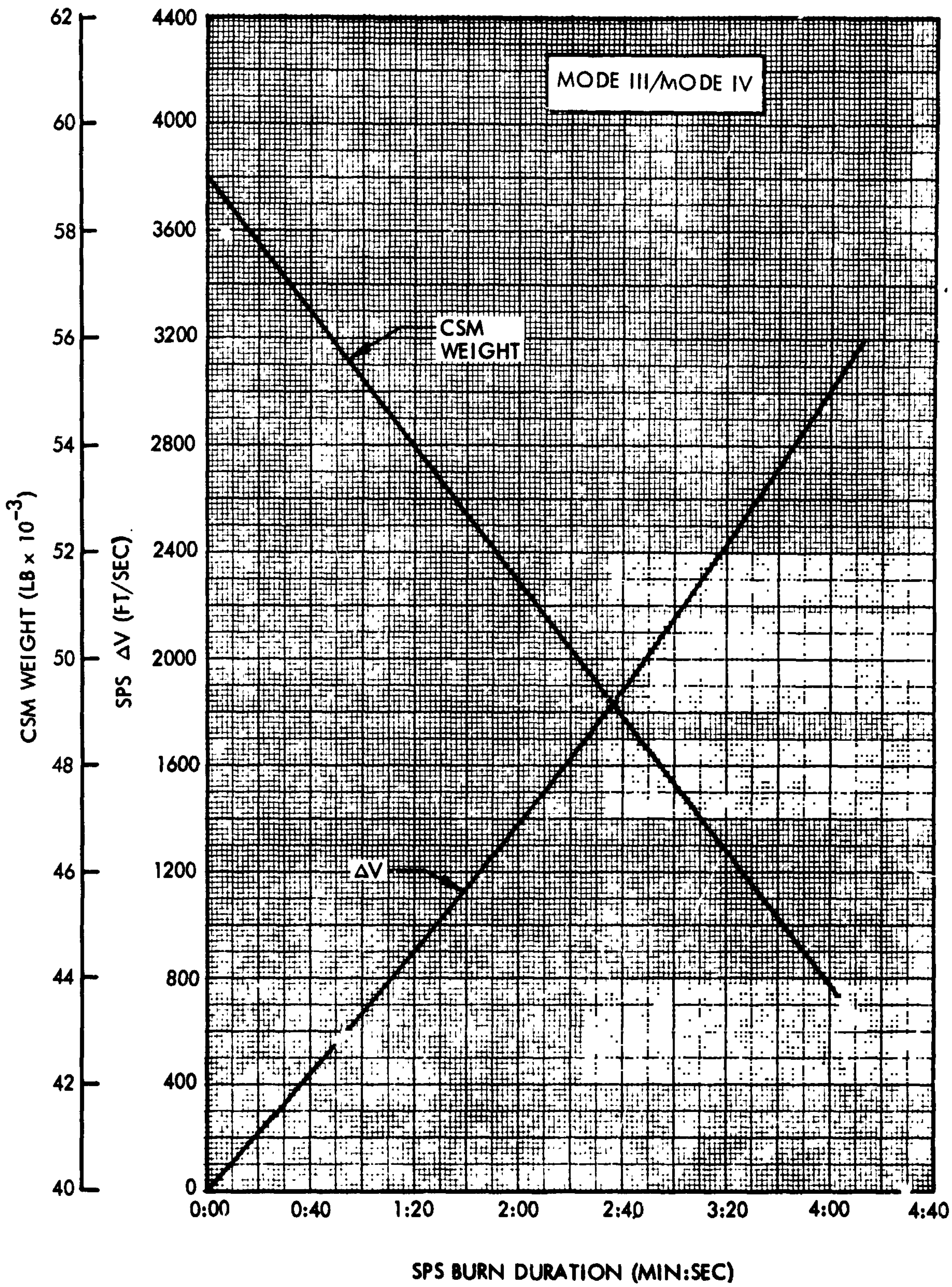

Figure 29.- Typical CSM weight and SPS ΔV changes during mode III and mode IV aborts for a typical Saturn V mission.

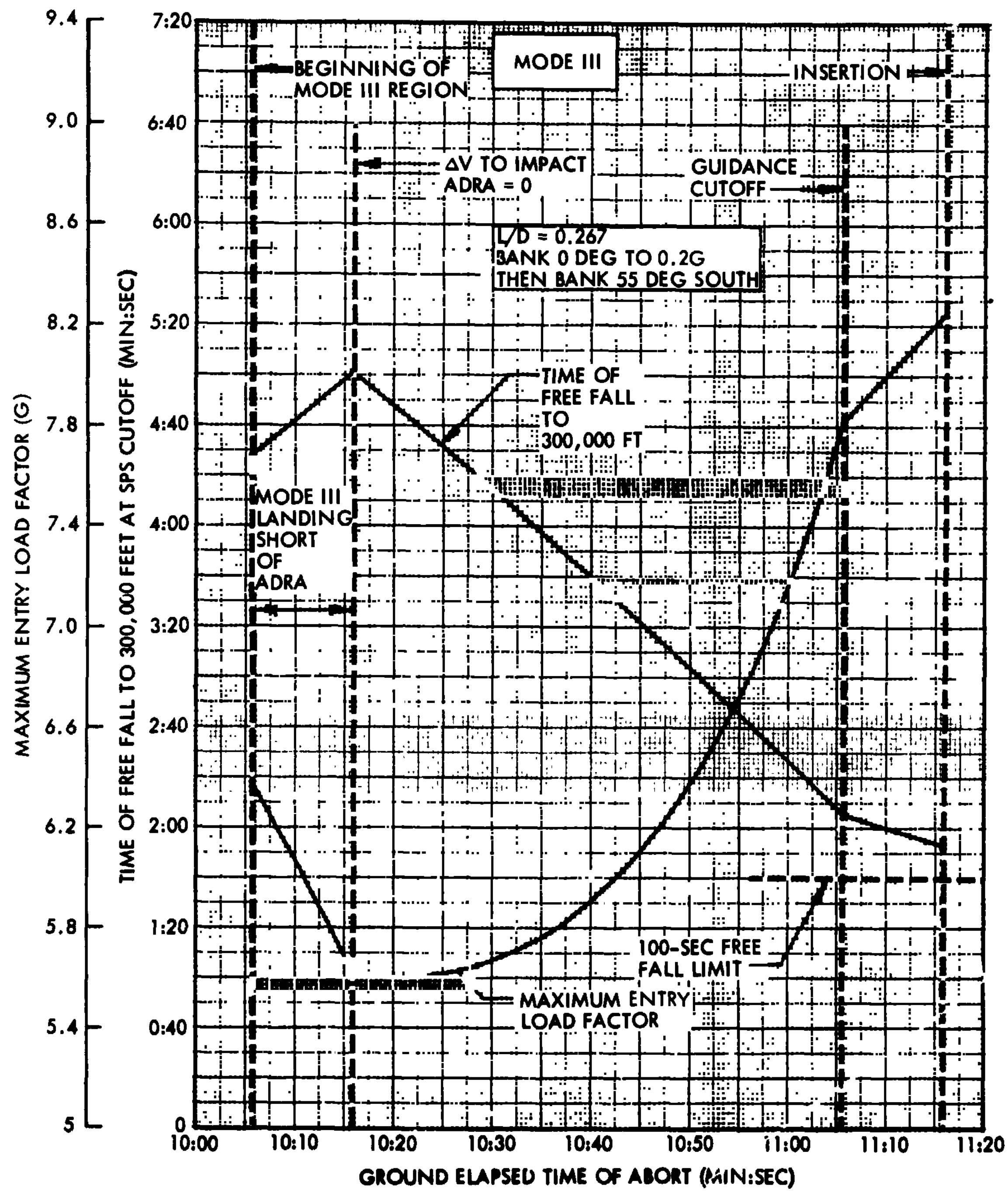

Figure 30.- Time of free fall to 300 000 ft and maximum entry load factor following nominal mode III aborts for a typical Saturn V mission.

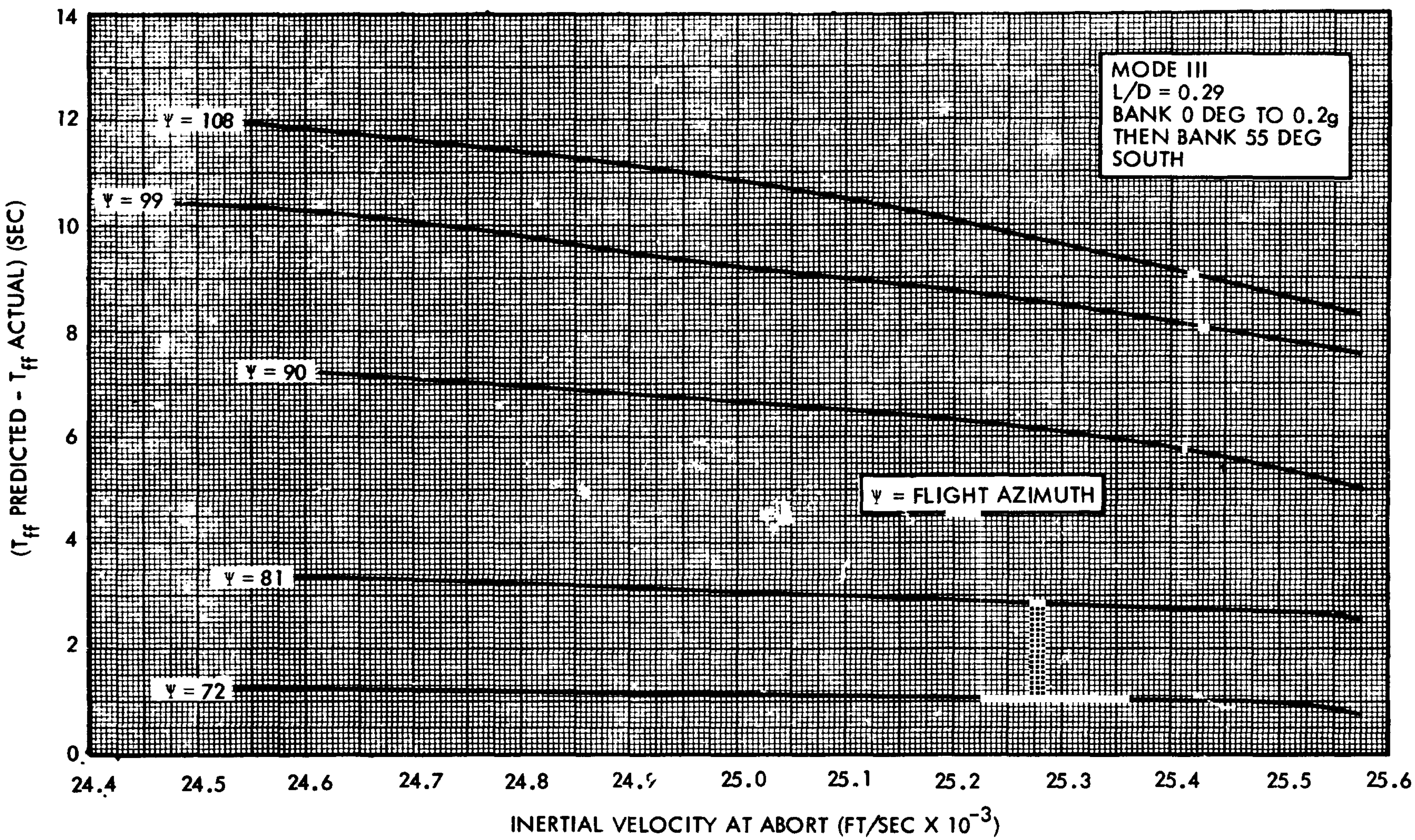

Figure 31.- Differences between predicted and actual free fall time to 300 000 ft following nominal mode III aborts for a typical Saturn V mission.

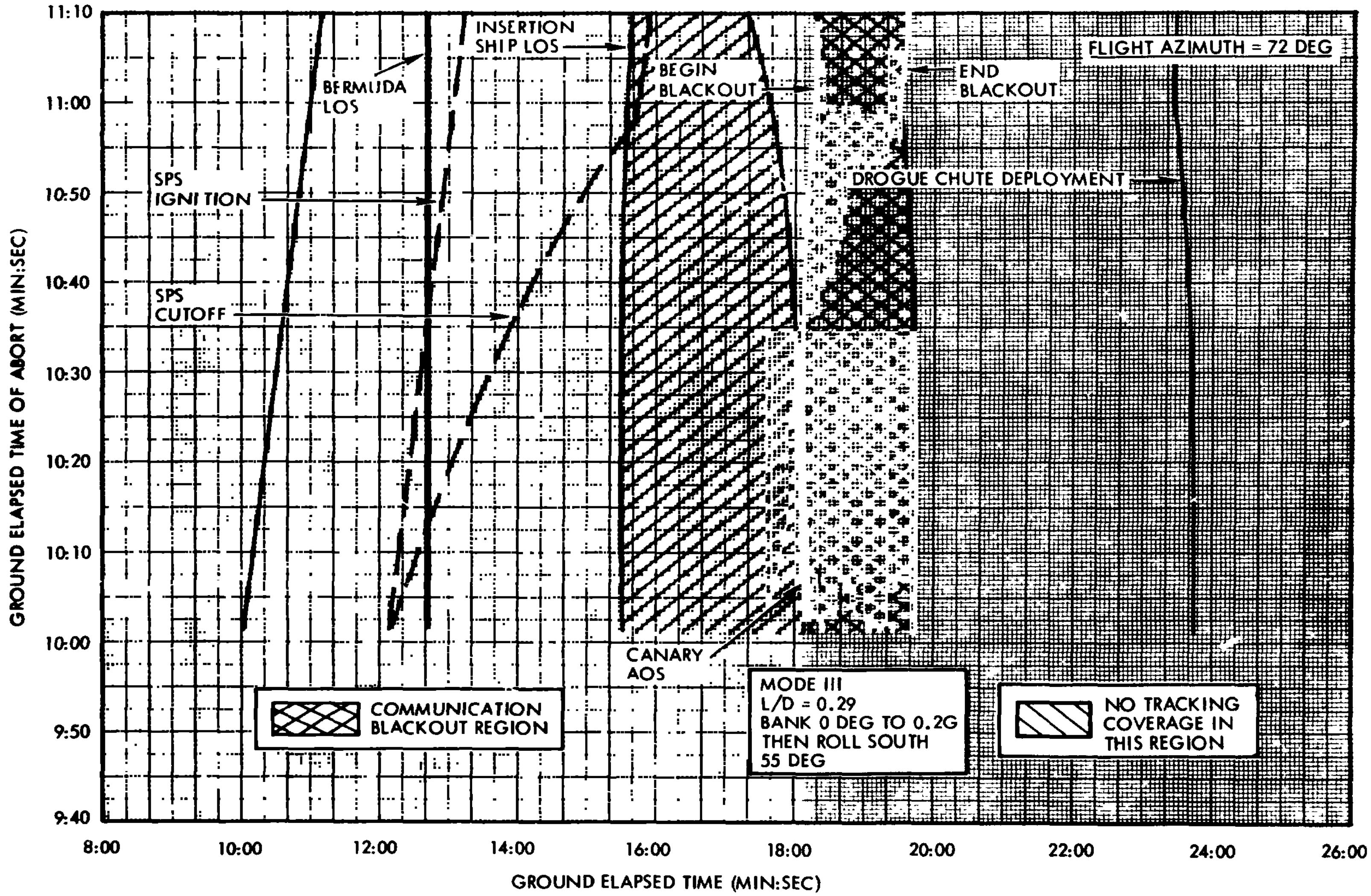

Figure 32.- Tracking coverage during nominal mode III aborts for a typical Saturn V mission - 72-degree flight azimuth.

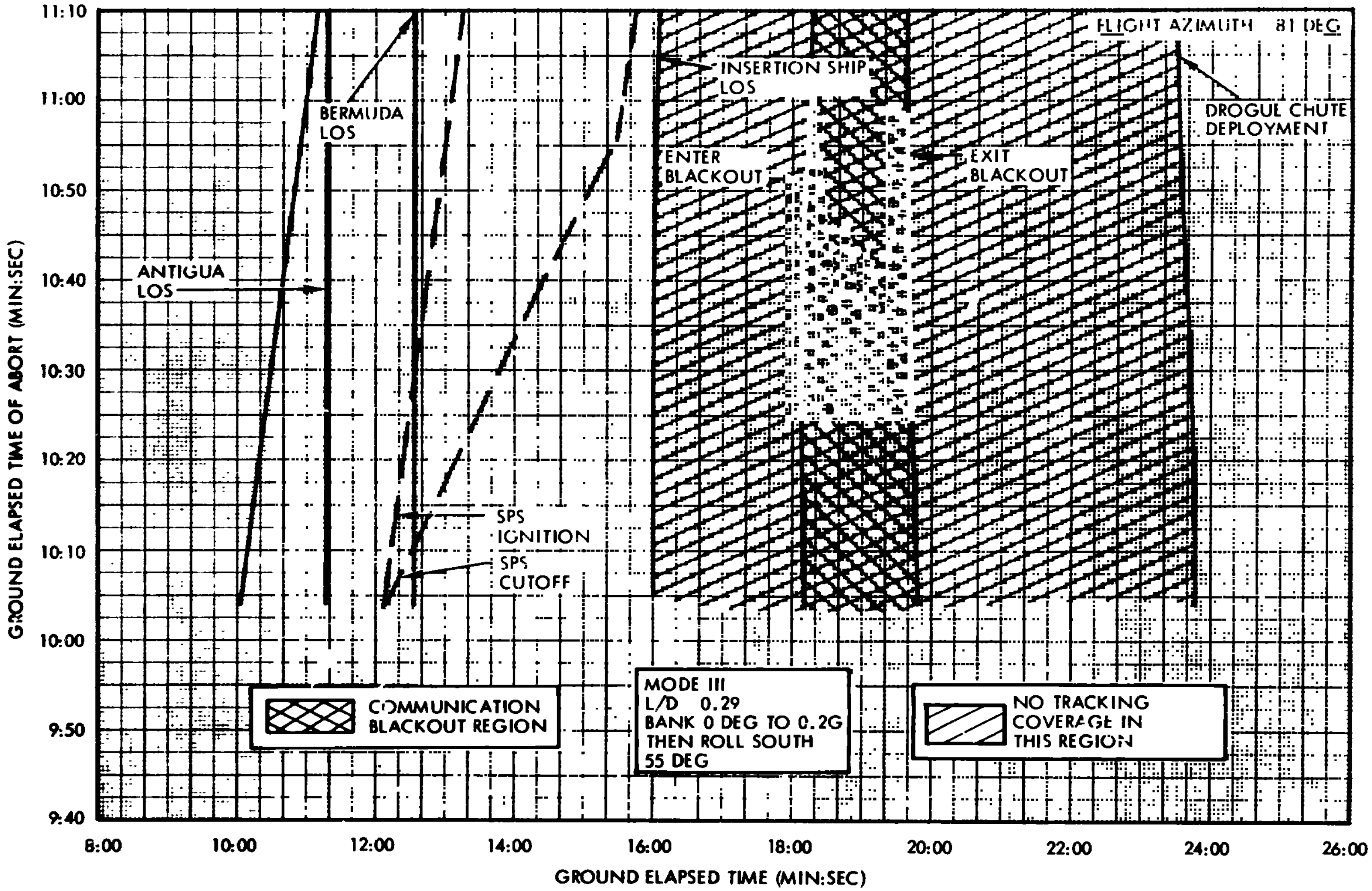

Figure 33.- Tracking coverage during nominal mode III aborts for a typical Saturn V mission - 81-degree flight azimuth.

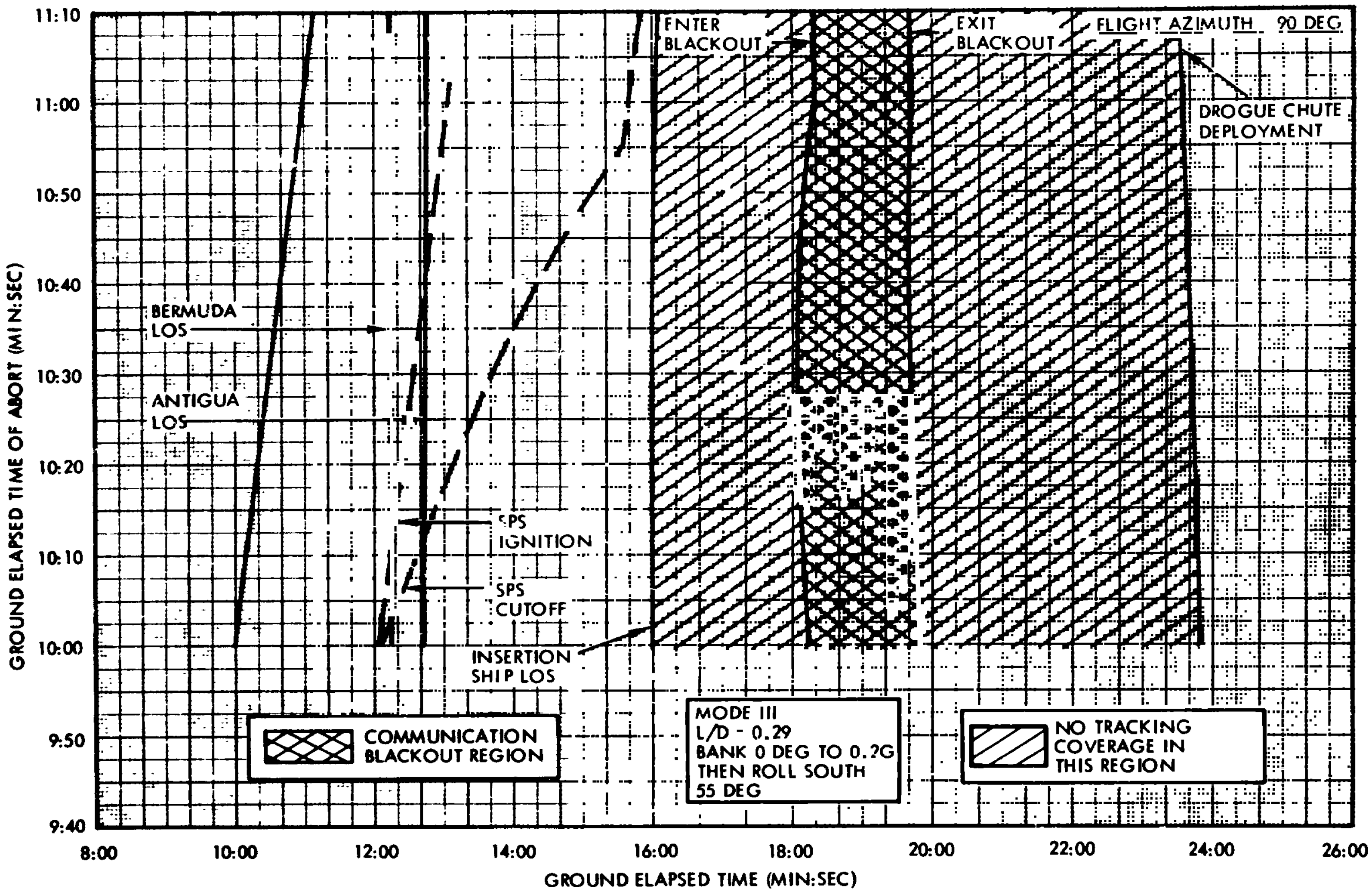

Figure 34.- Tracking coverage during nominal mode III aborts for a typical Saturn V mission - 90-degree flight azimuth.

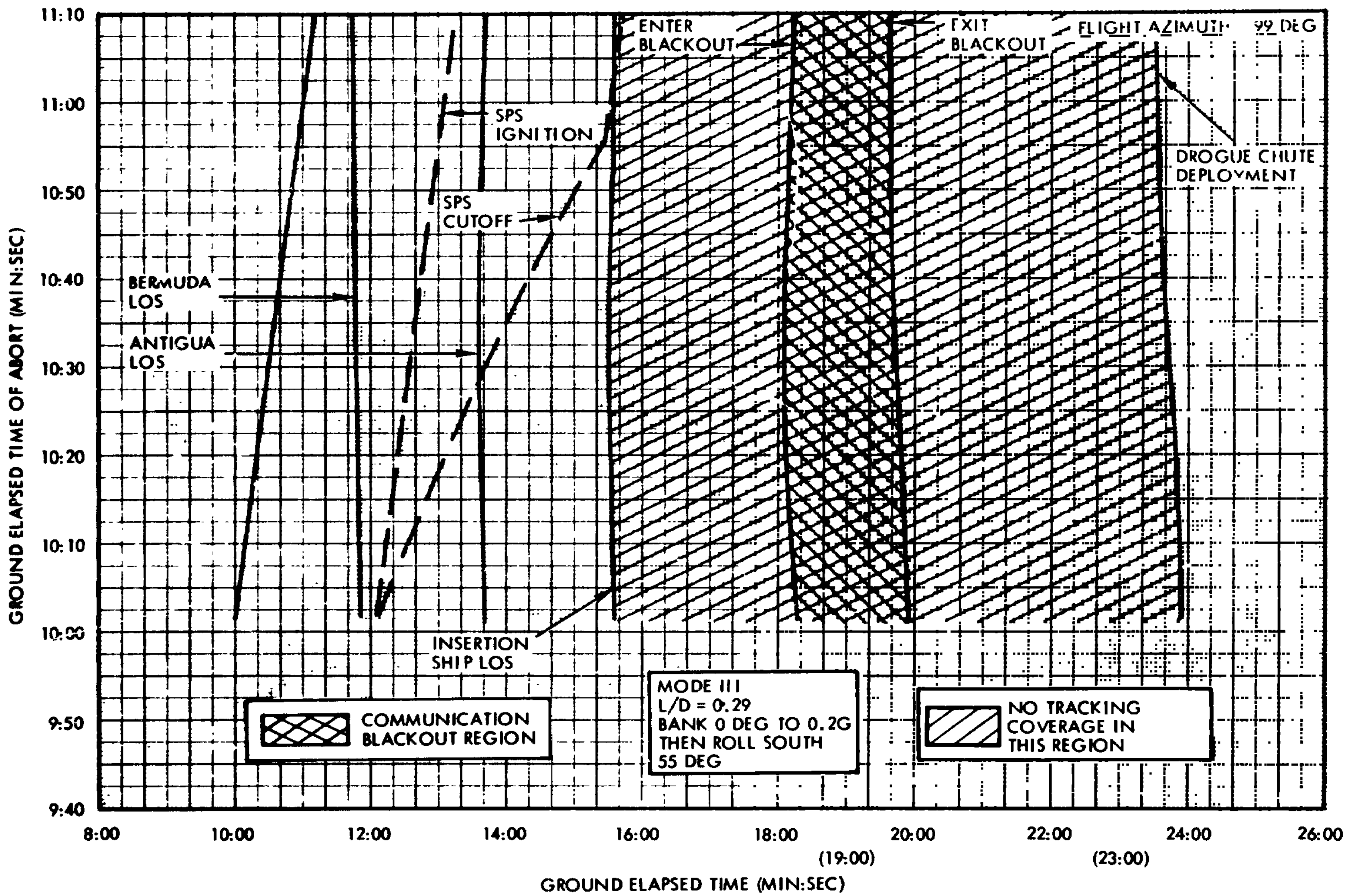

Figure 35.- Tracking coverage during nominal mode III aborts for a typical Saturn V mission - 99-degree flight azimuth.

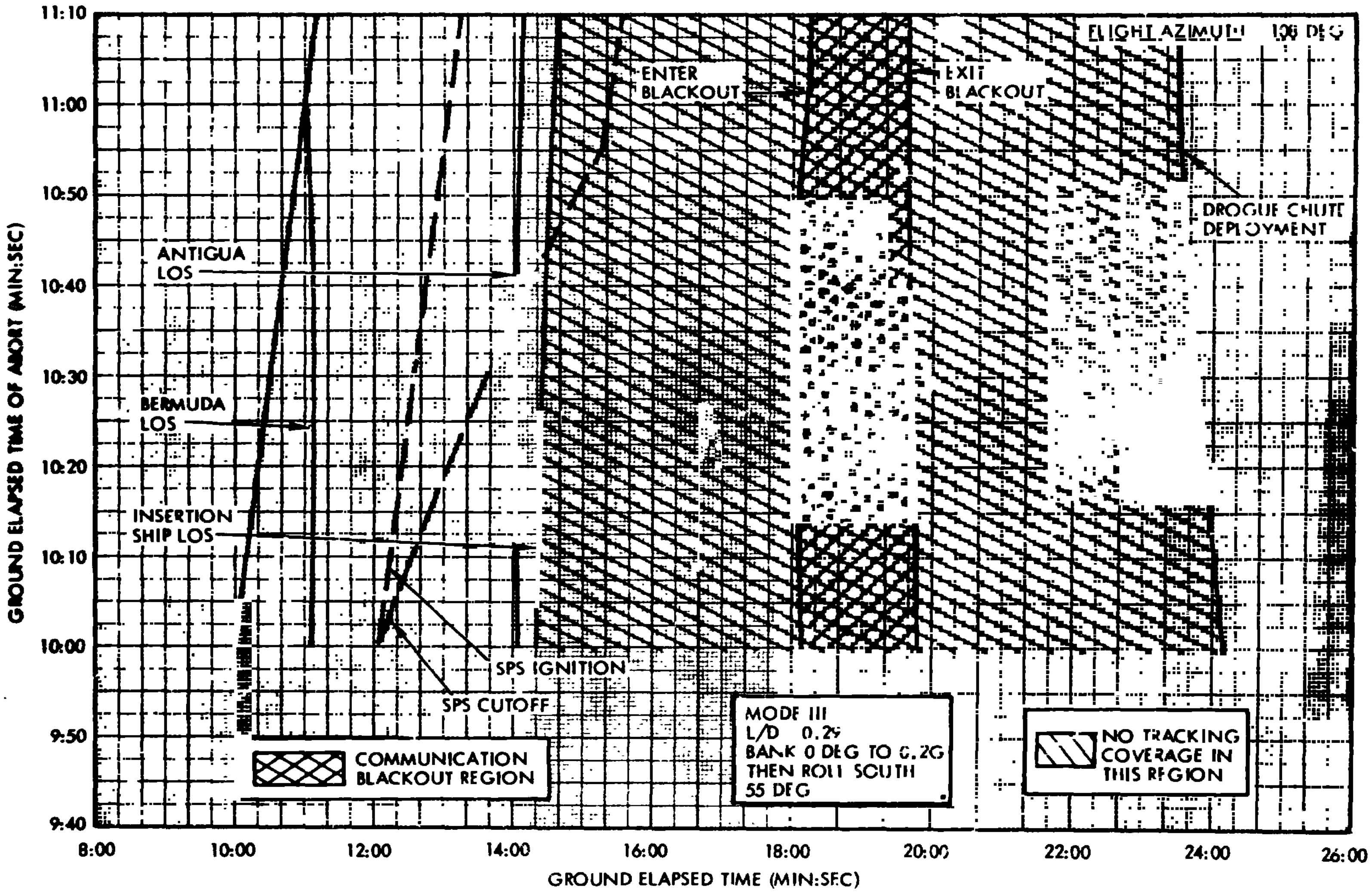

Figure 36.- Tracking coverage during nominal mode III aborts for a typical Saturn V mission - 108-degree flight azimuth.

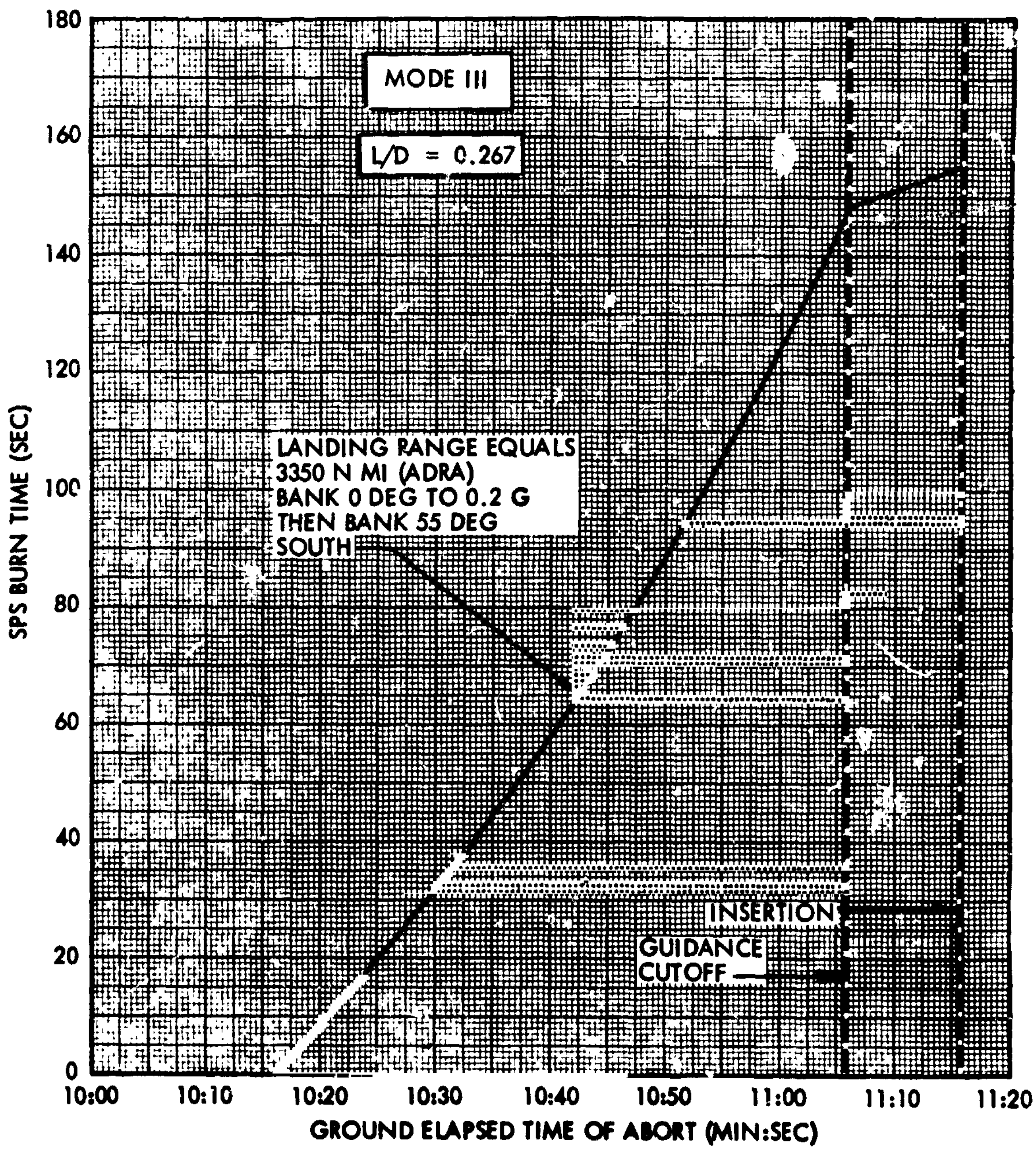

Figure 37.- SPS burn time required to land at the ADRA during nominal mode III aborts for a typical Saturn V mission.

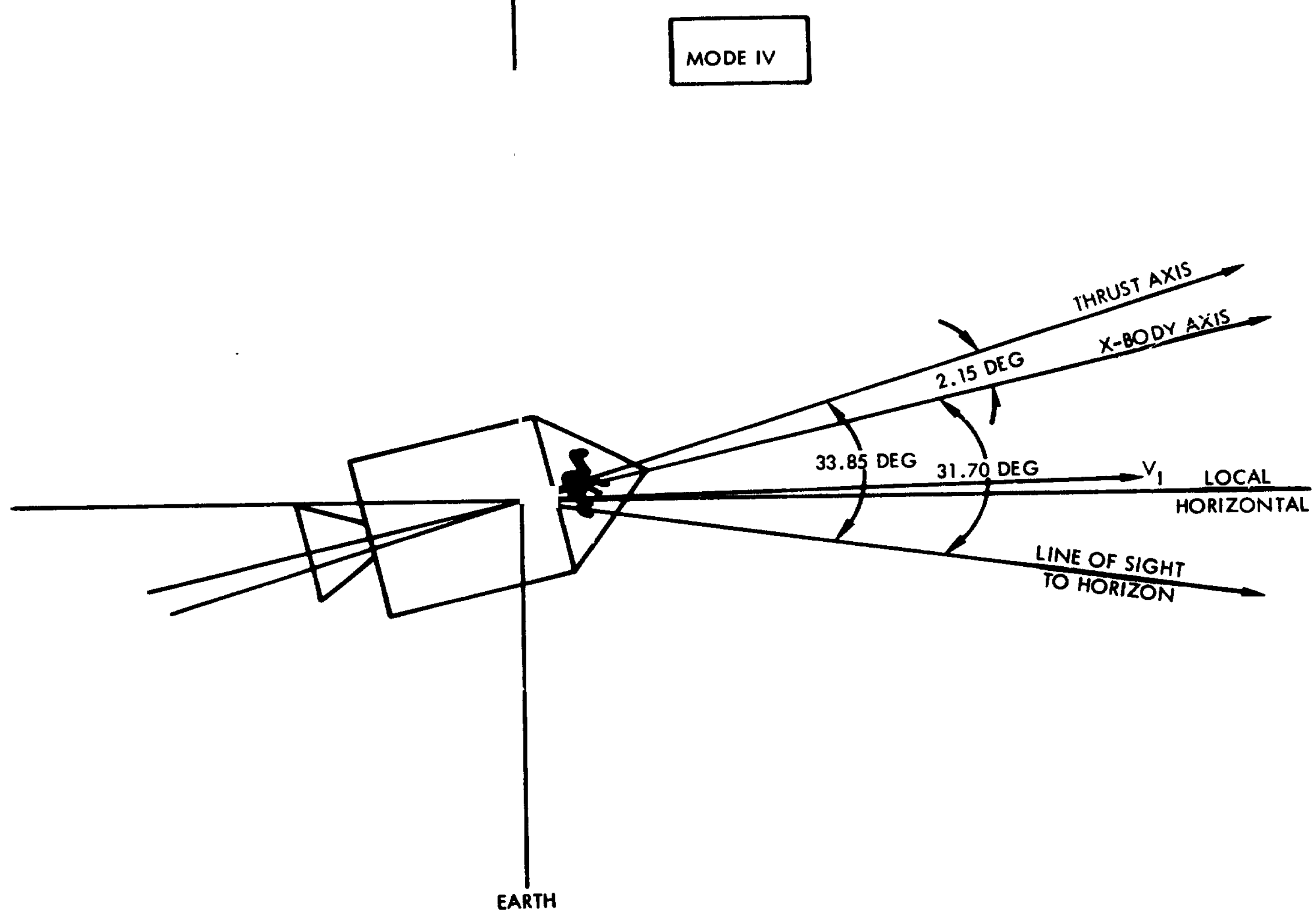

Figure 38.- Command service module orientation at SPS ignition for mode IV launch aborts.

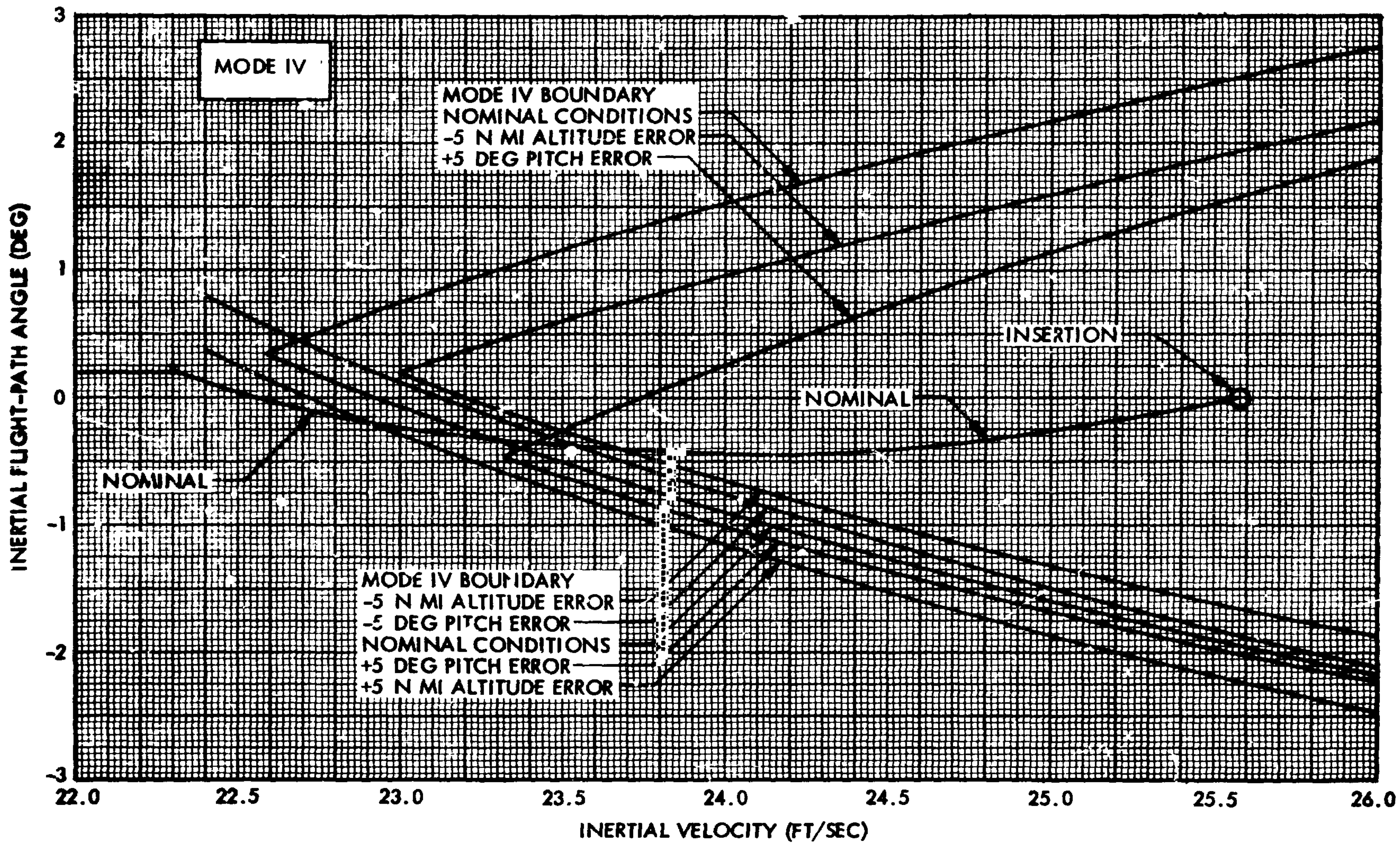

Figure 39.- mode IV boundaries for nominal and off-nominal conditions - Saturn V missions.

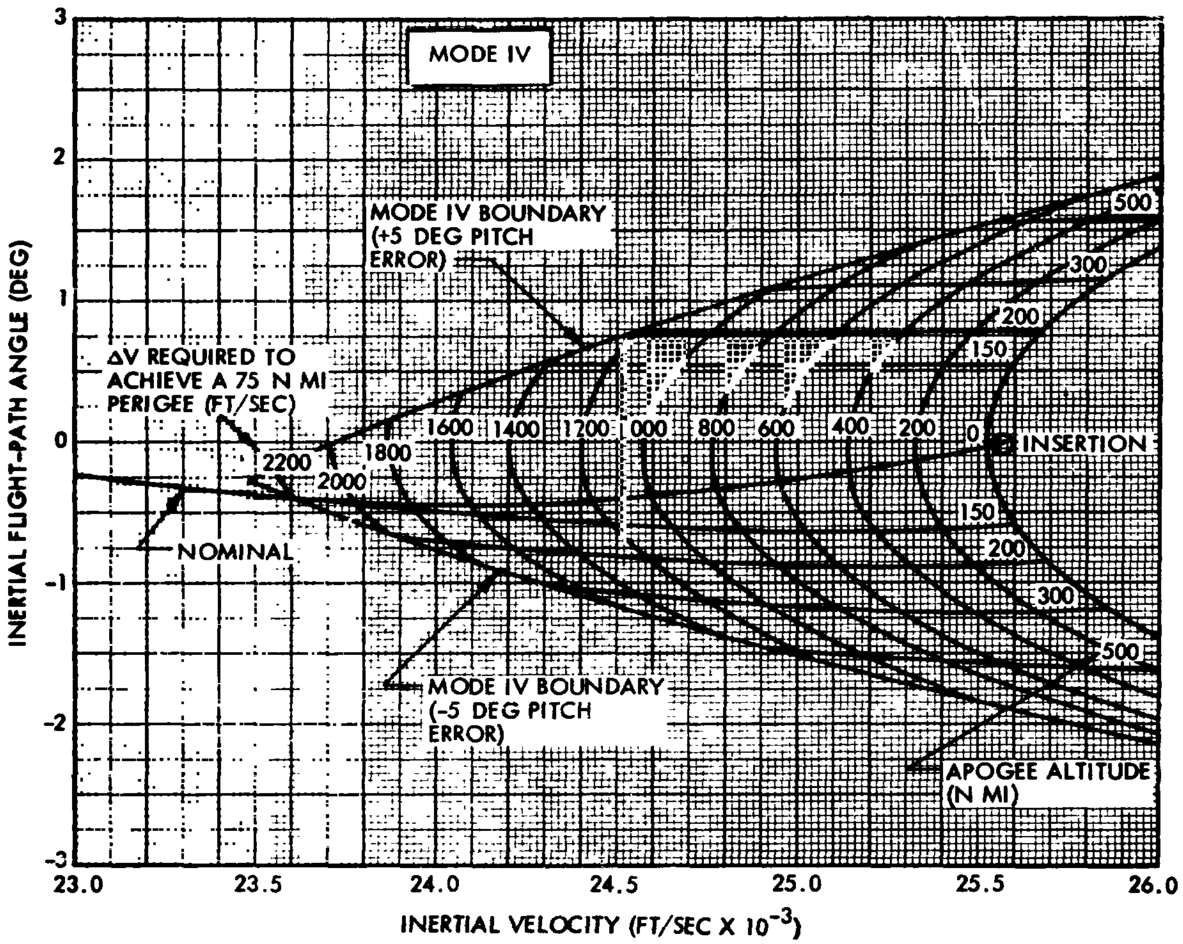

Figure 40.- mode IV abort region with nominal altitude at abort for a typical Saturn V mission.

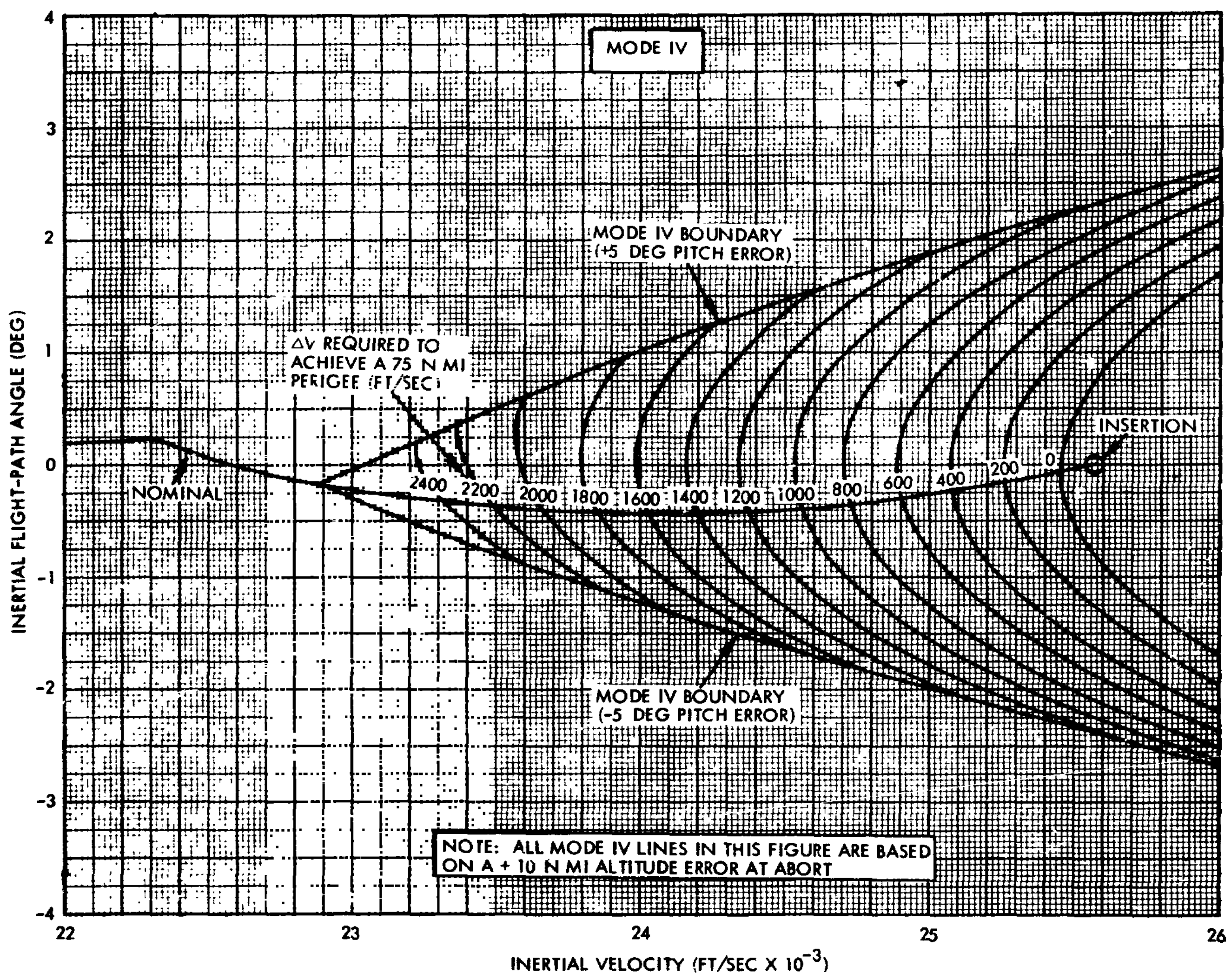

Figure 41.- mode IV abort region with a plus-10-nautical-mile altitude deviation at abort for a typical Saturn V mission.

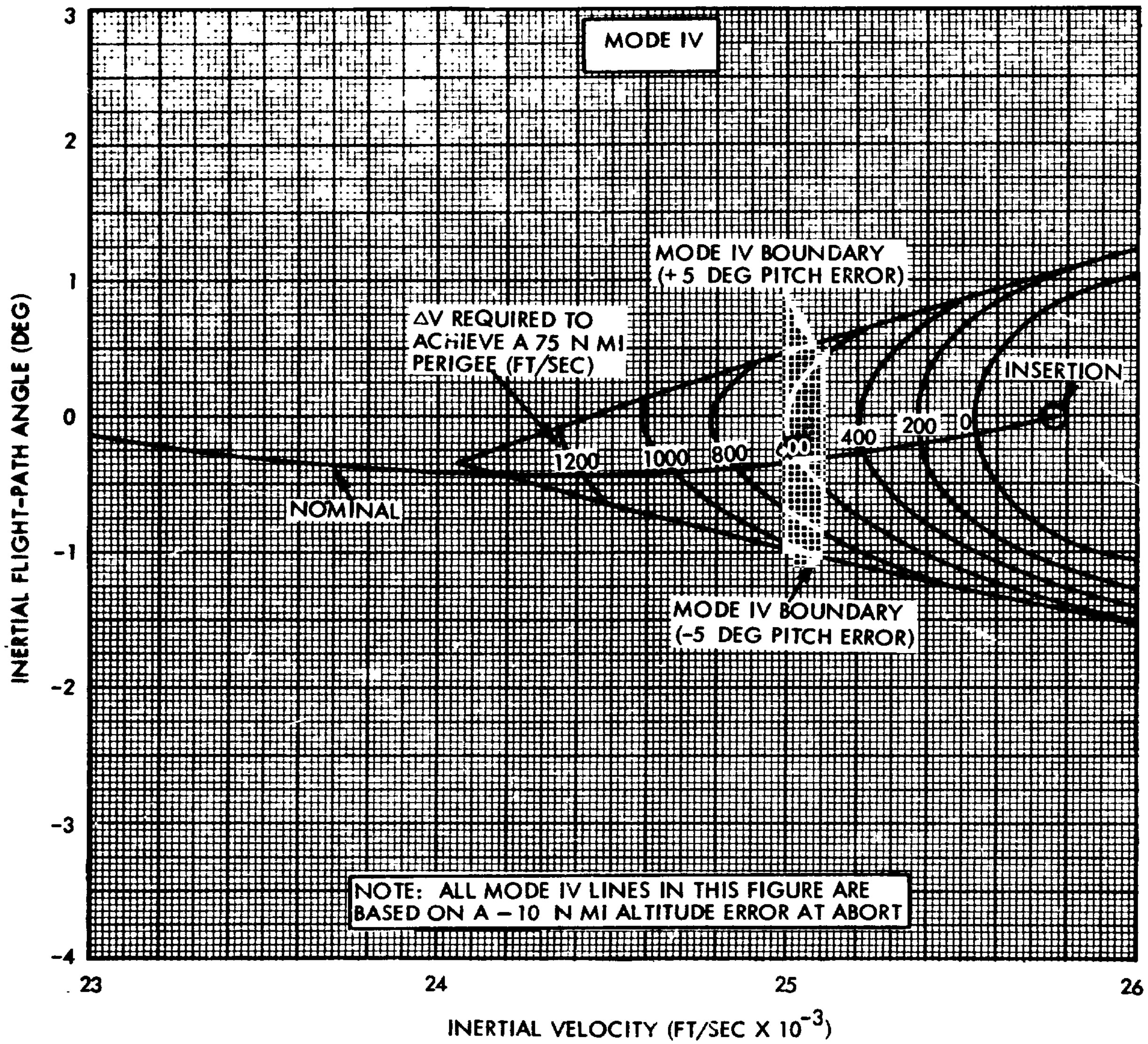

Figure 42.- mode IV abort region with a minus-10-nautical-mile altitude deviation at abort for a typical Saturn V mission.

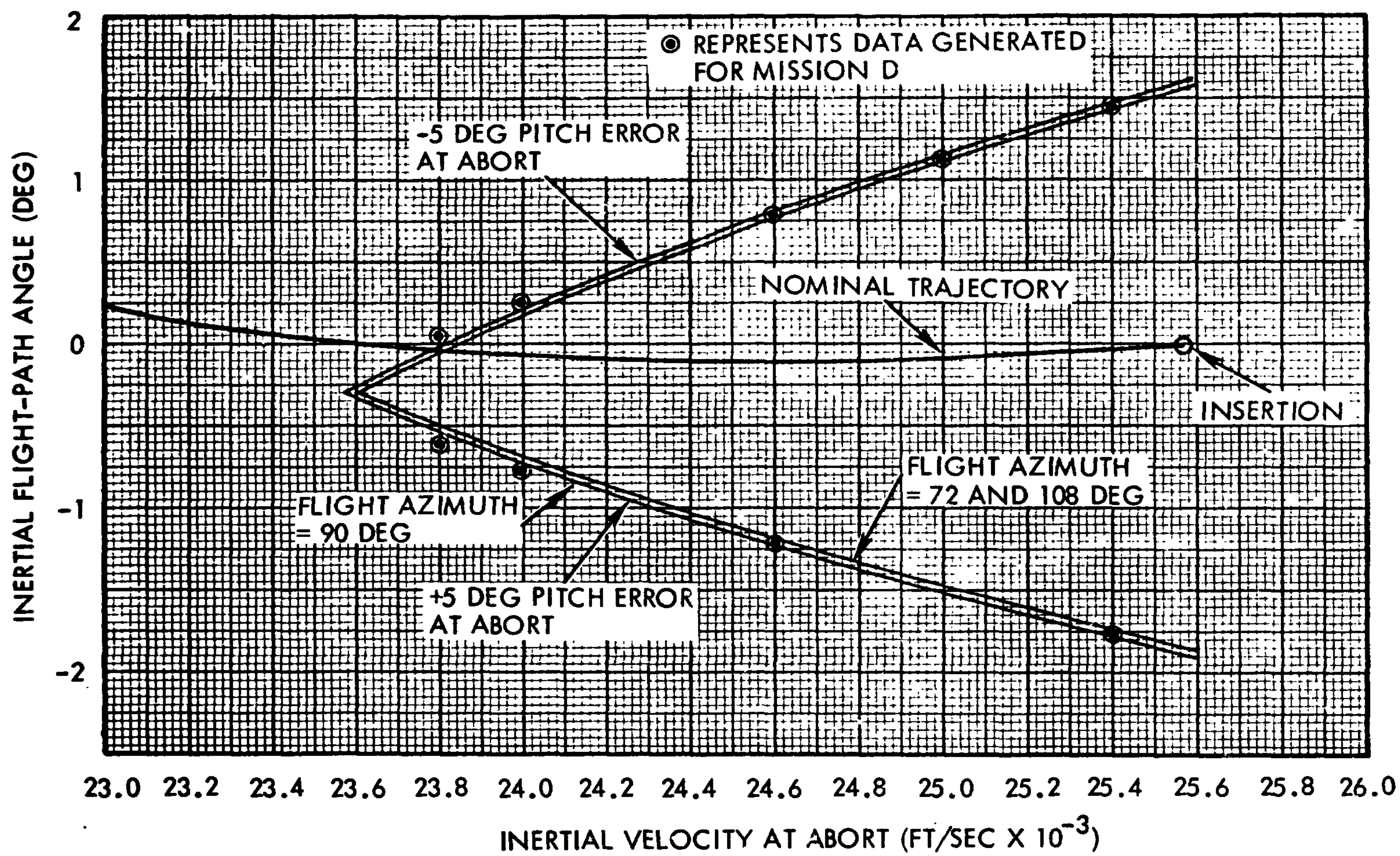

Figure 43.- Movement of the COI region for a typical Saturn V mission on flight azimuths between 72 and 108 degrees.

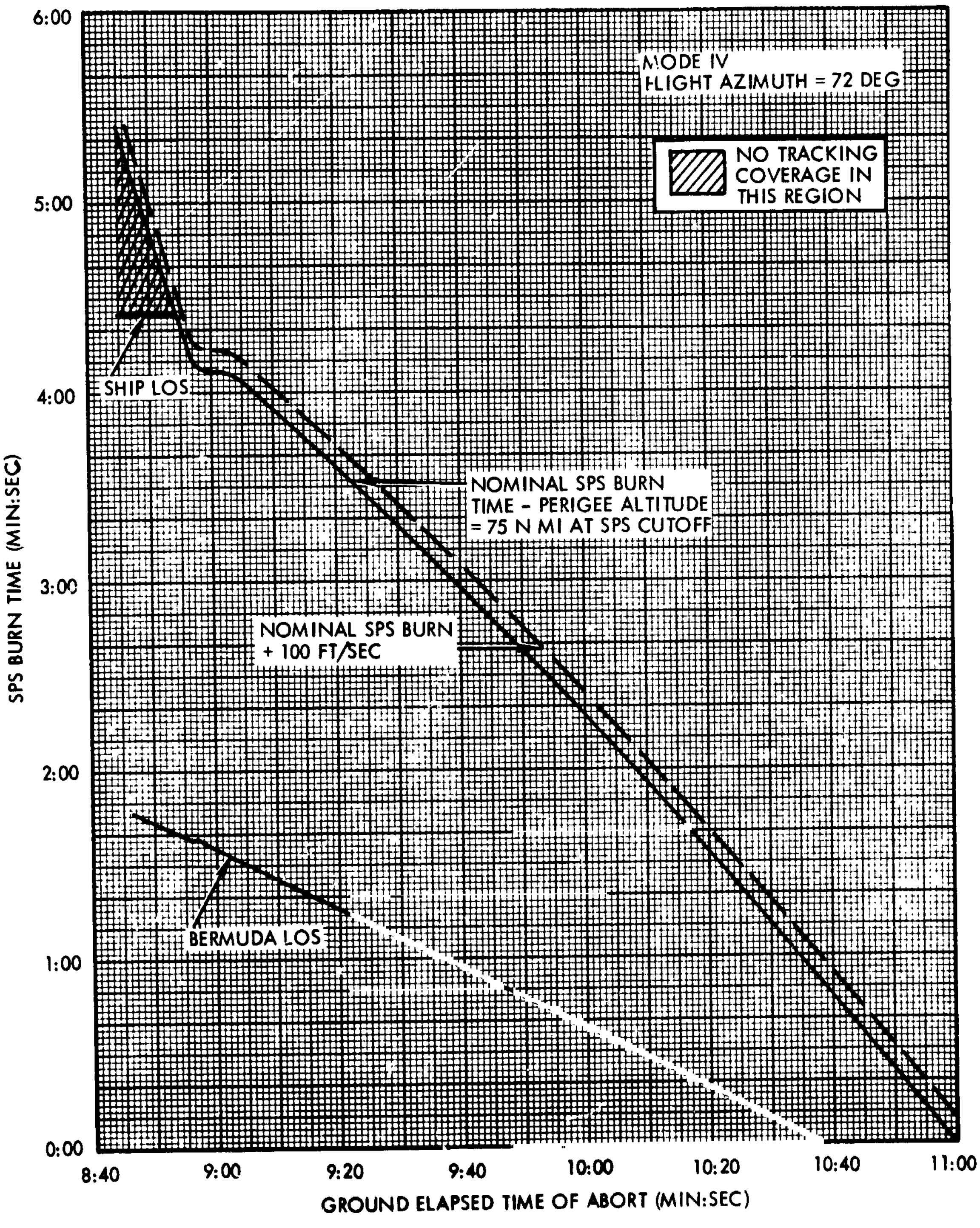

Figure 44.- Tracking coverage during nominal mode IV aborts for a typical Saturn V mission - 72 degree flight azimuth.

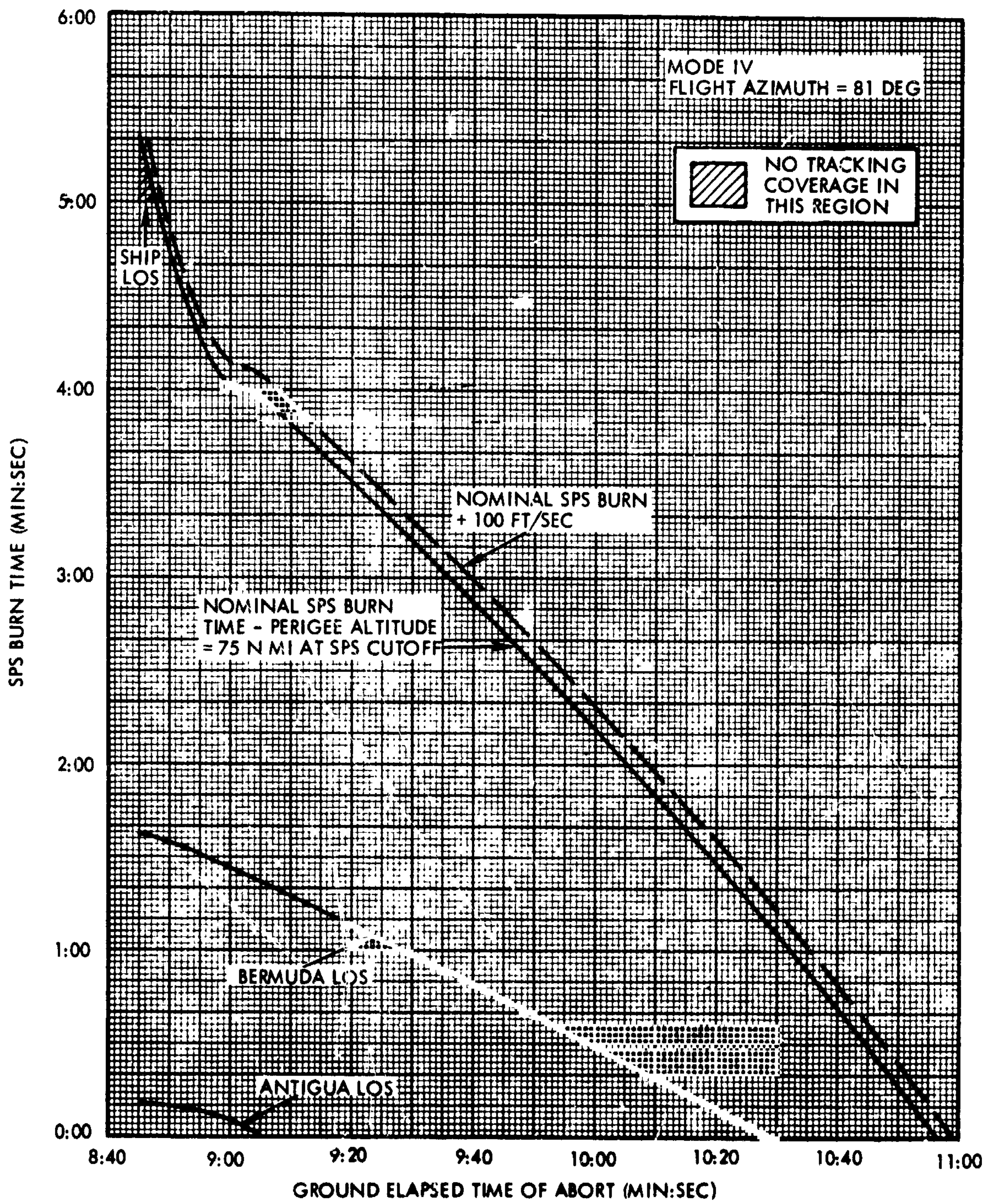

Figure 45.- Tracking coverage during nominal mode IV aborts for a typical Saturn V mission - 81-degree flight azimuth.

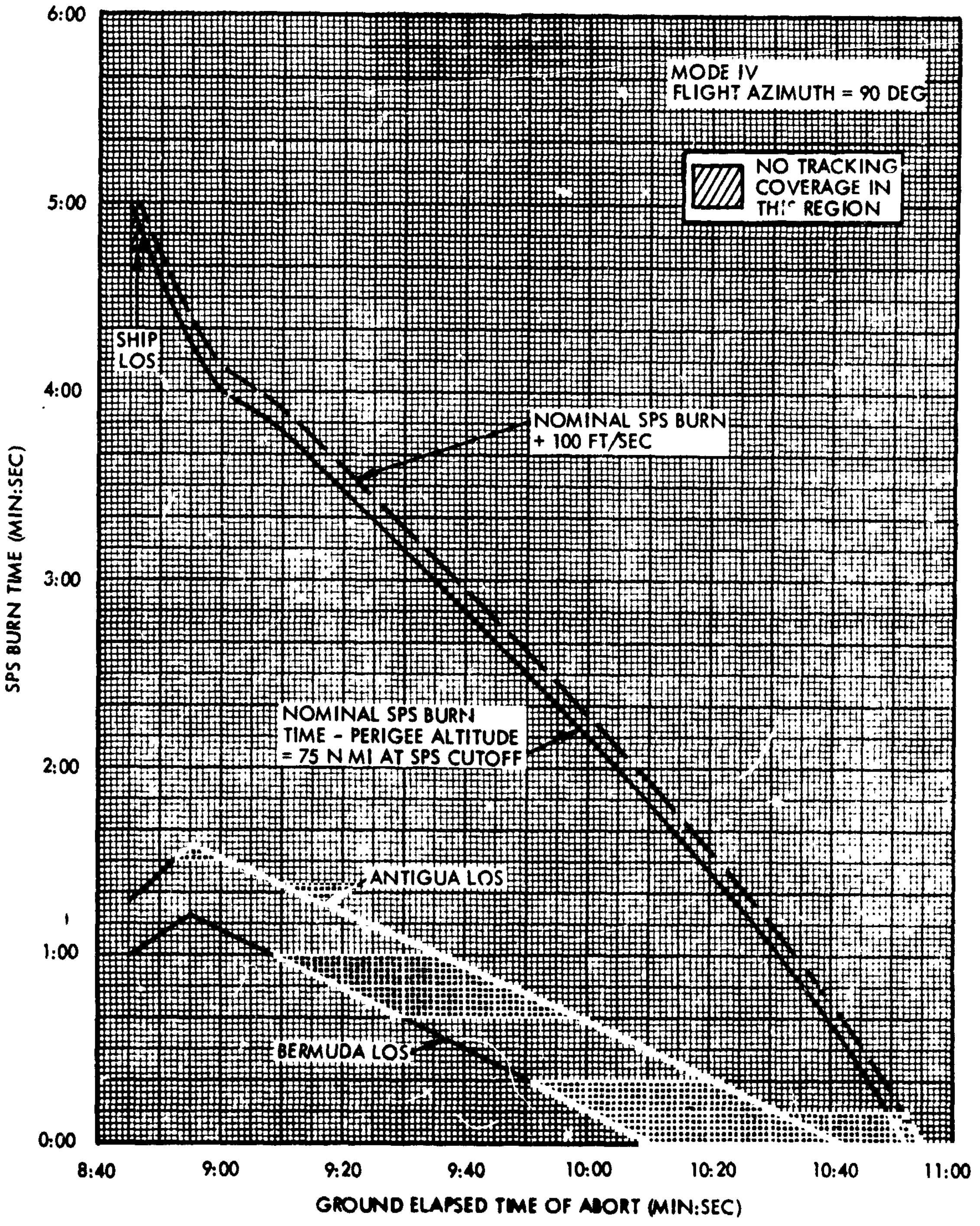

Figure 46.- Tracking coverage during nominal mode IV aborts for a typical Saturn V mission - 90-degree flight azimuth.

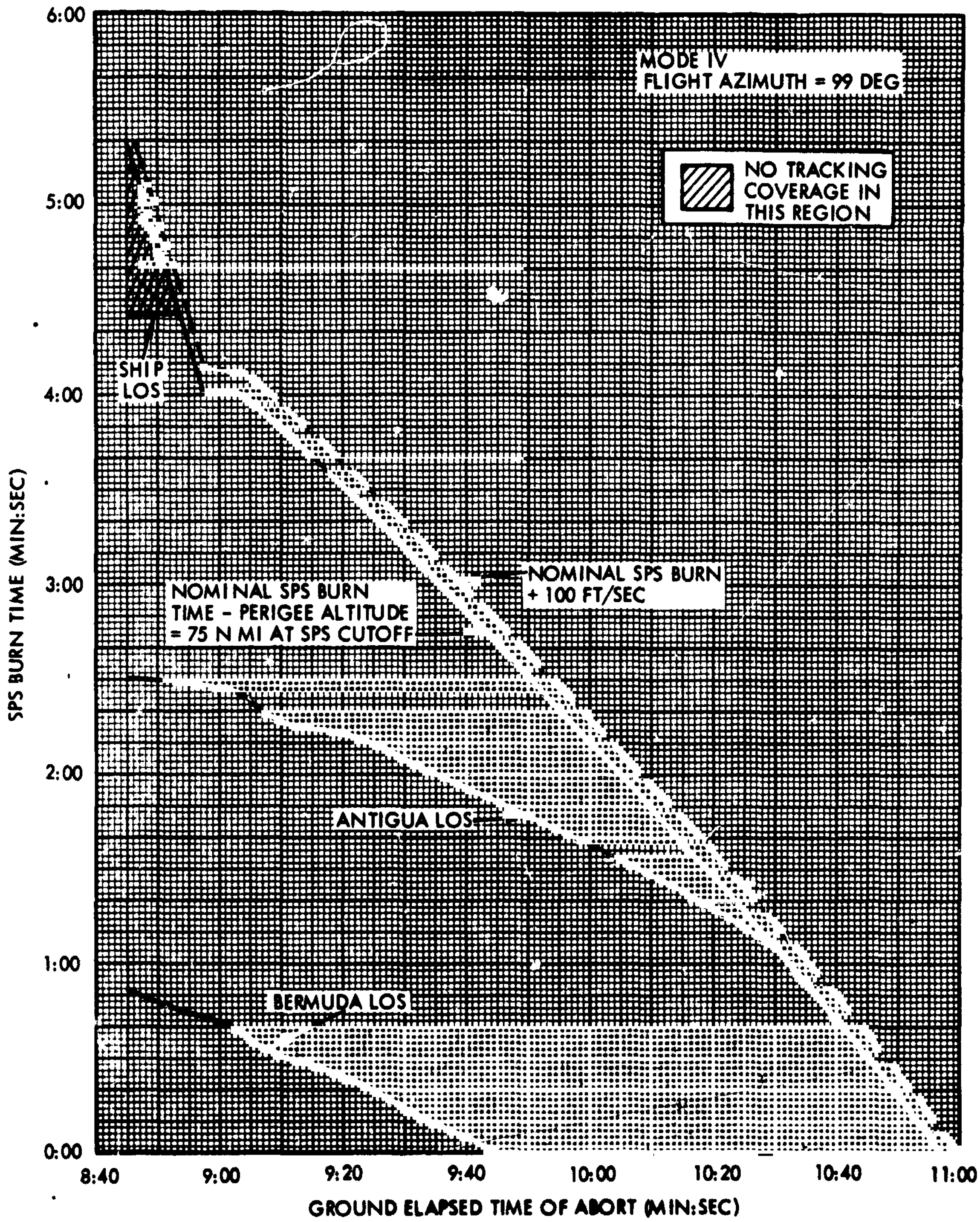

Figure 47.- Tracking coverage during nominal mode IV aborts for a typical Saturn V mission - 99-degree flight azimuth.

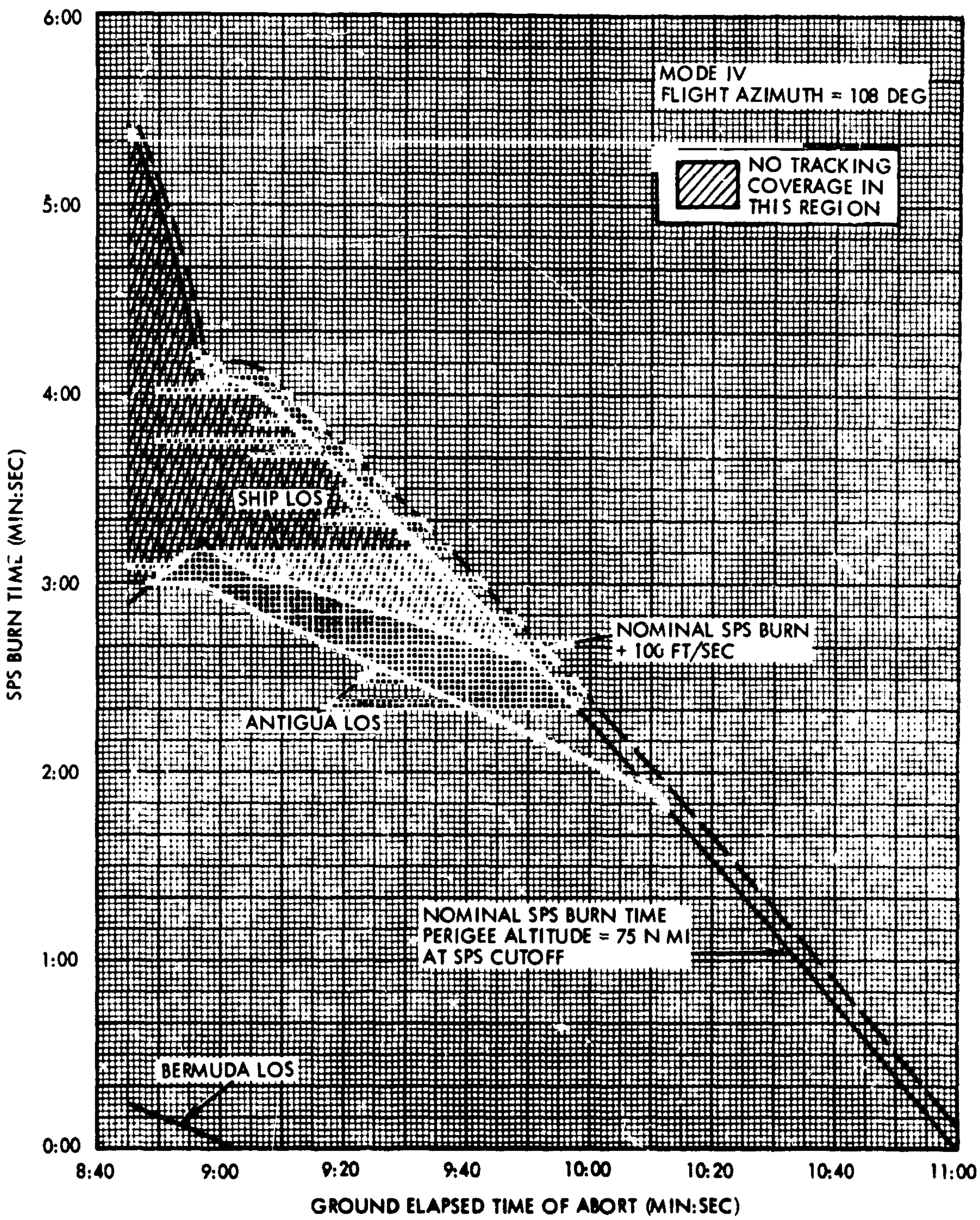

Figure 48.- Tracking coverage during nominal mode IV aborts for a typical Saturn V mission - 108-degree flight azimuth.

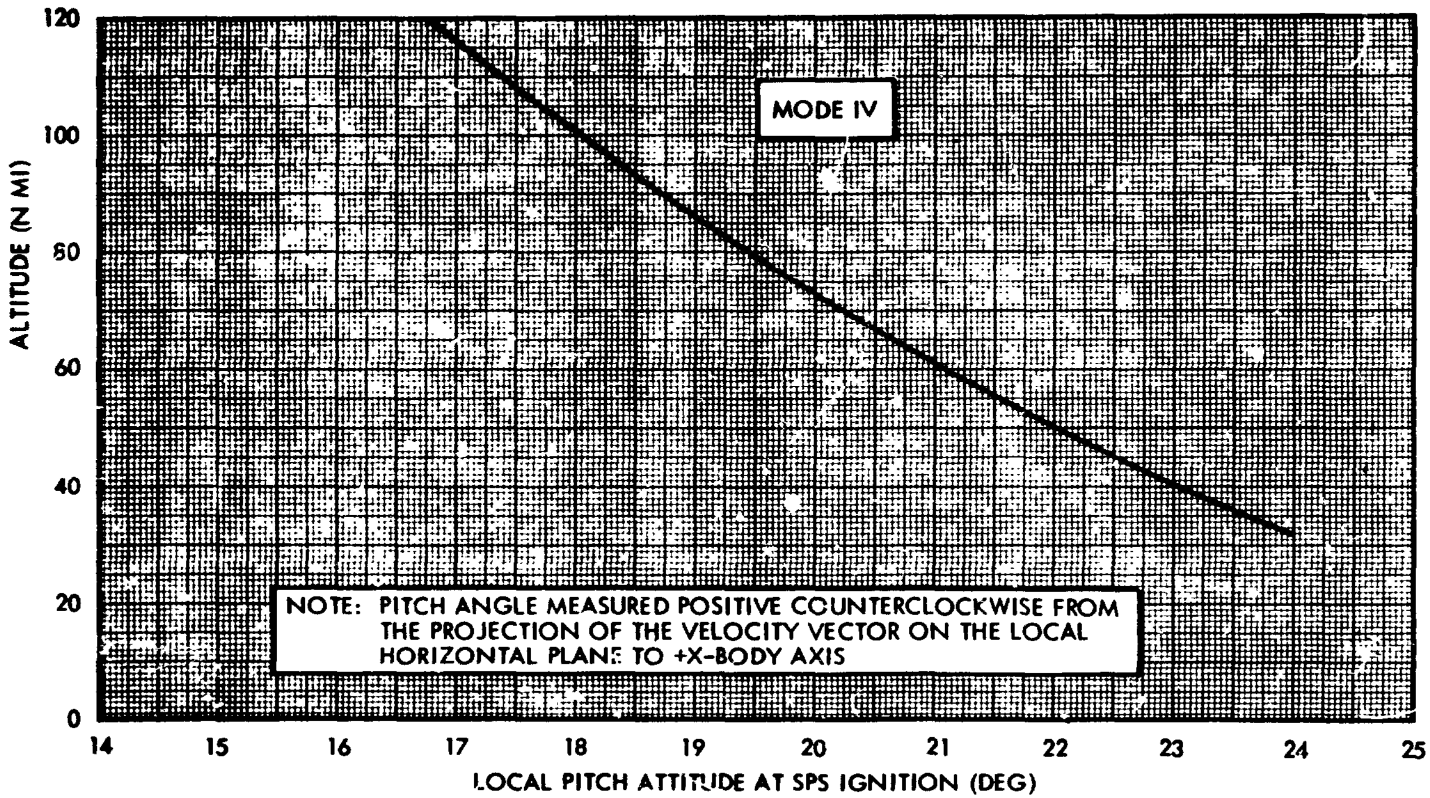

Figure 49.- Command service module local pitch attitude at SPS ignition for typical Saturn V mode IV aborts.

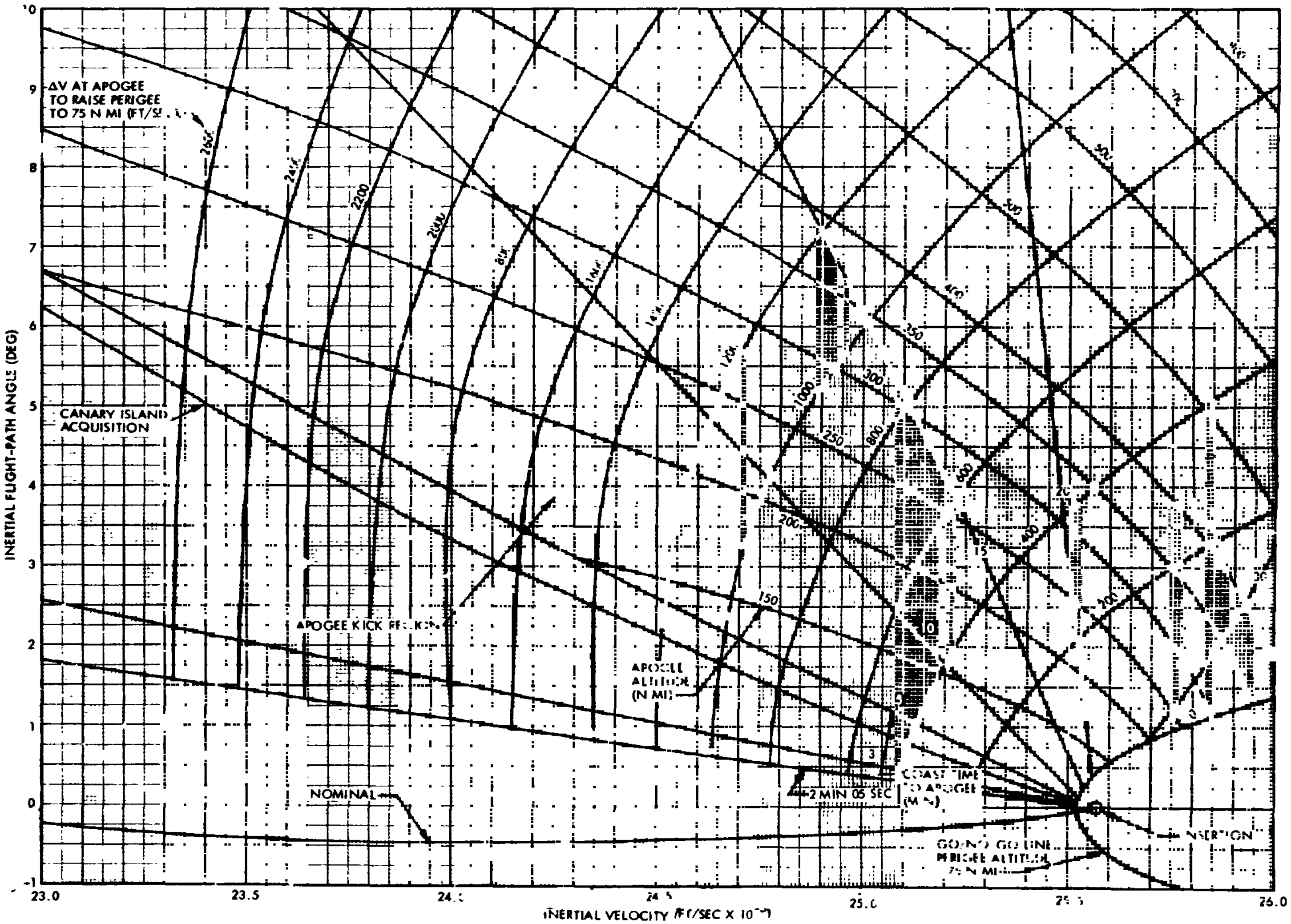

Figure 50.- Apogee kick region for a typical Saturn V mission.

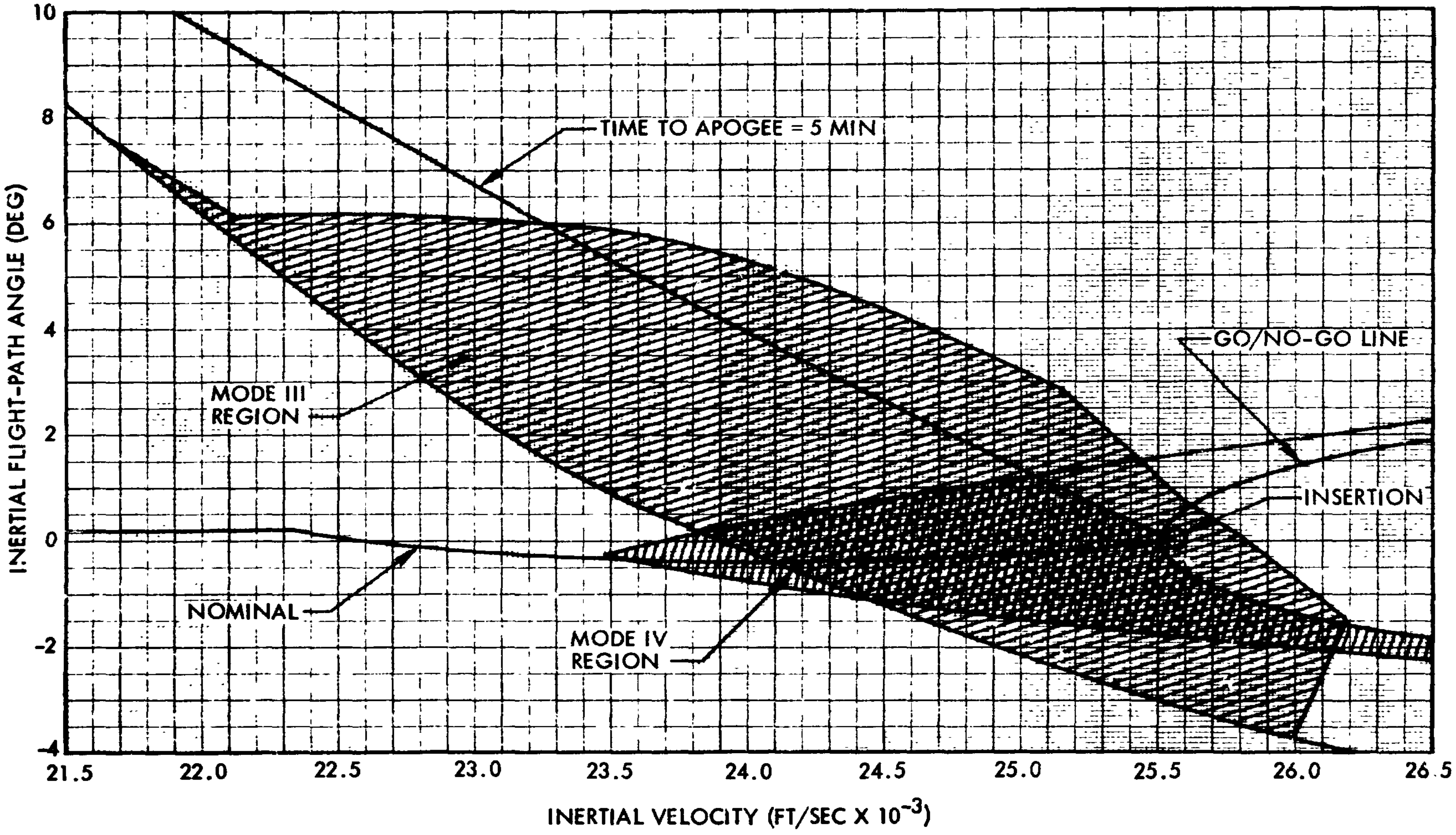

Figure 51.- Near-insertion abort mode overlap for a typical Saturn V mission.

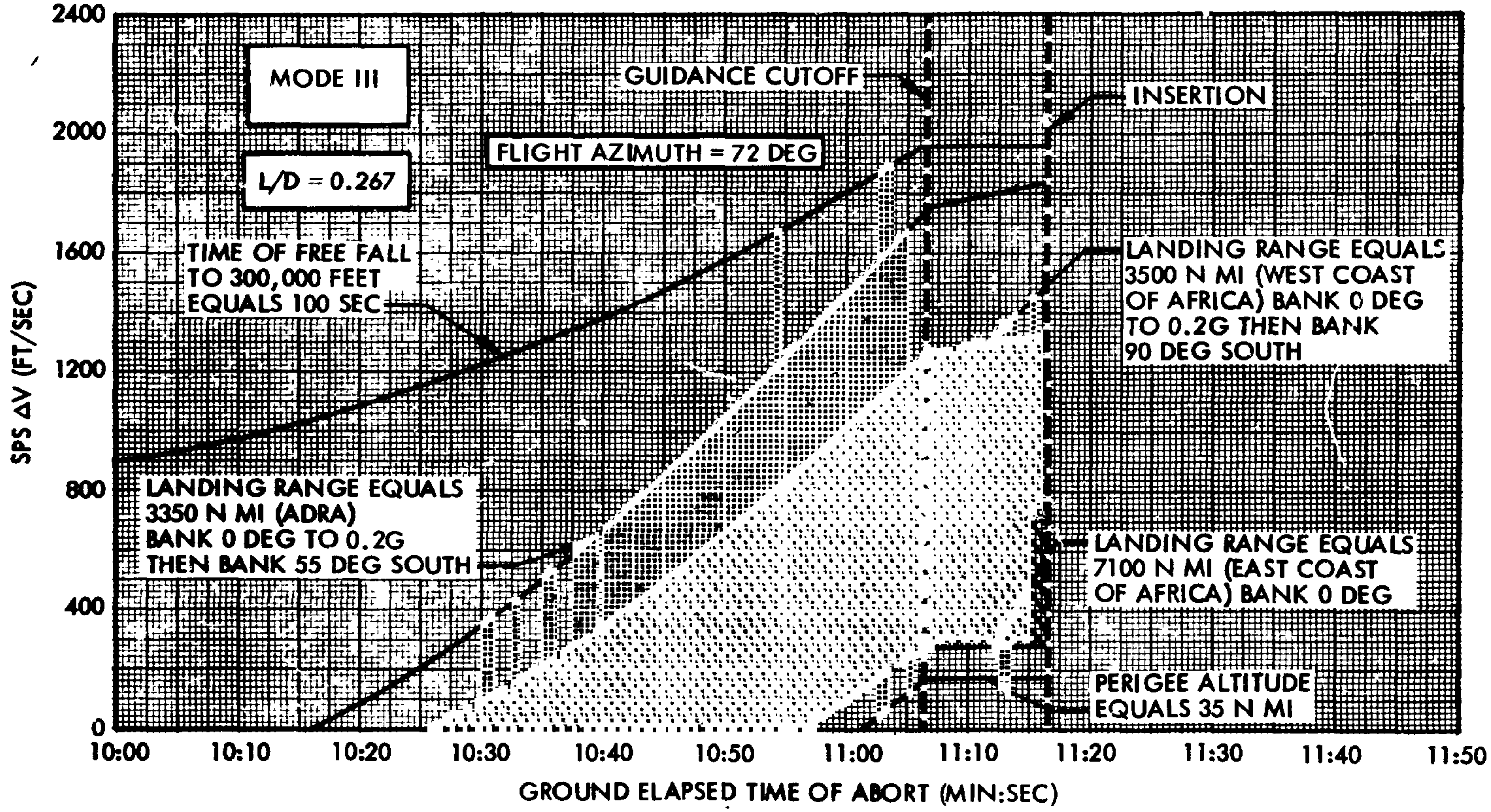

Figure 52.- Landing location following mode III aborts for a typical Saturn V mission with SPS failure during the SPS burn.

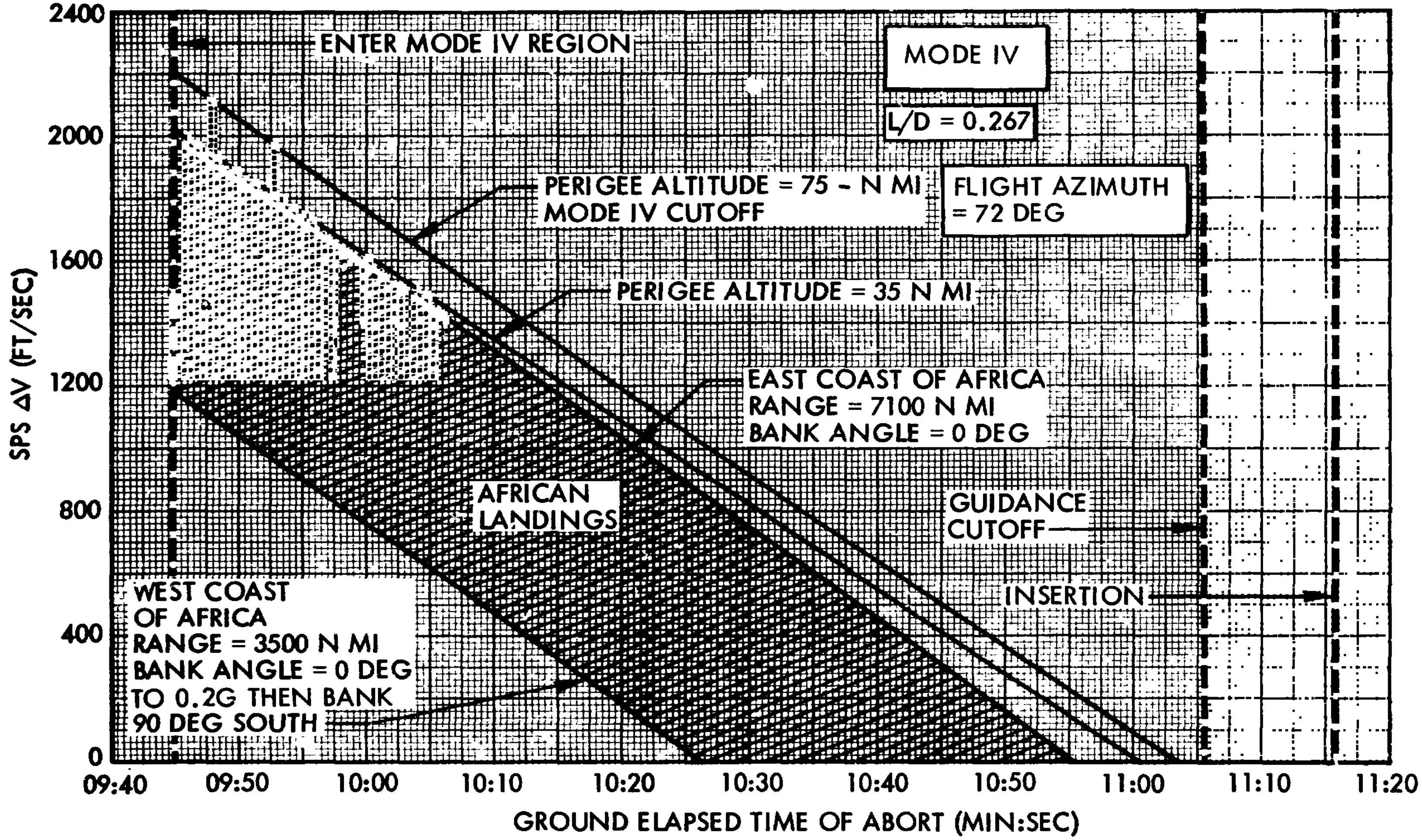

Figure 53.- Landing location for mode IV aborts with SPS failure during the SPS burn.

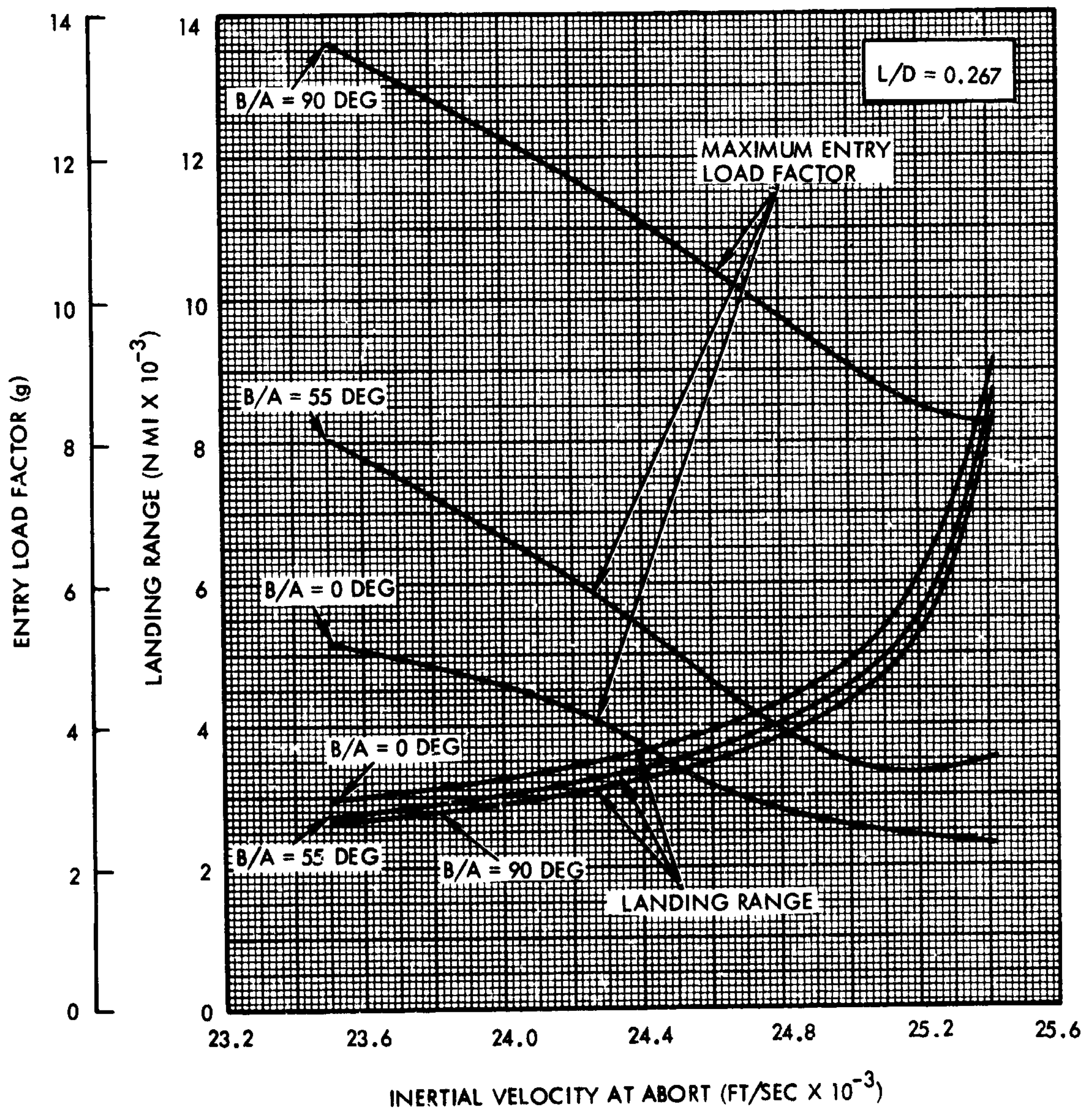

Figure 54.- Landing range control capability and associated entry load factors for a typical Saturn V mission.

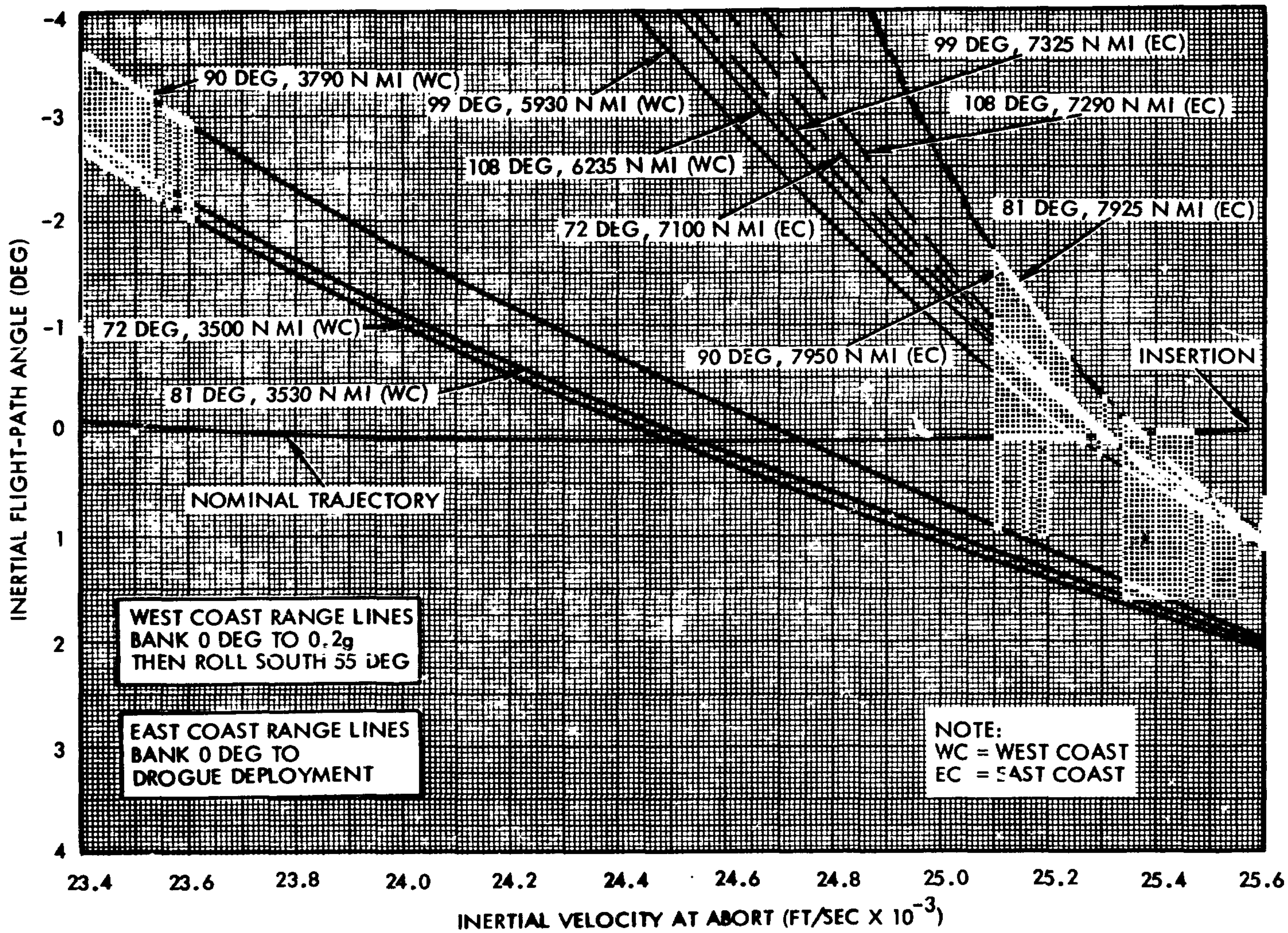

Figure 55.- Constant range lines to the east and west coasts of Africa for a typical Saturn V mission on variable flight azimuths.

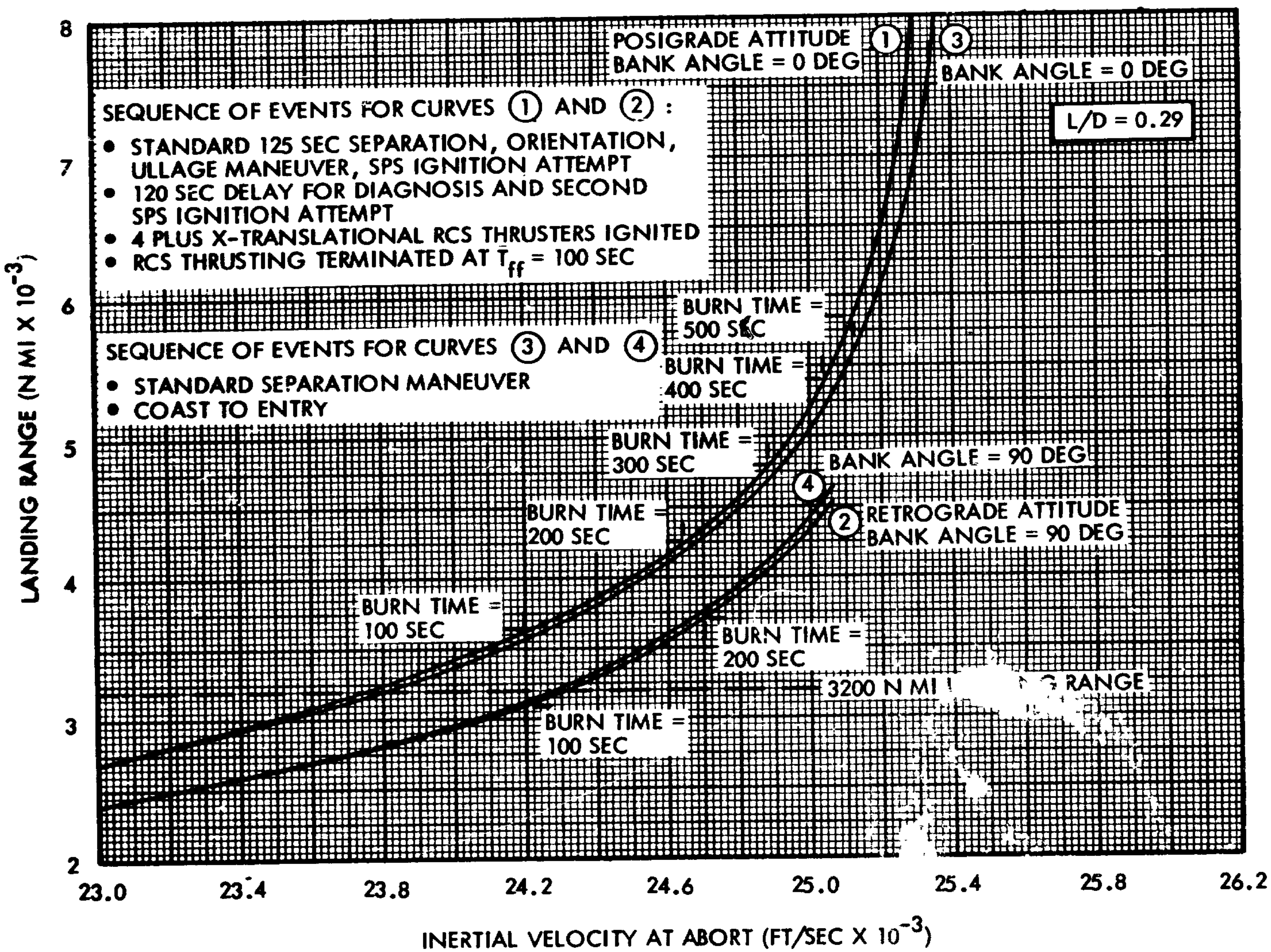

Figure 56.- SM/RCS landing range control capability for a typical Saturn V mission.

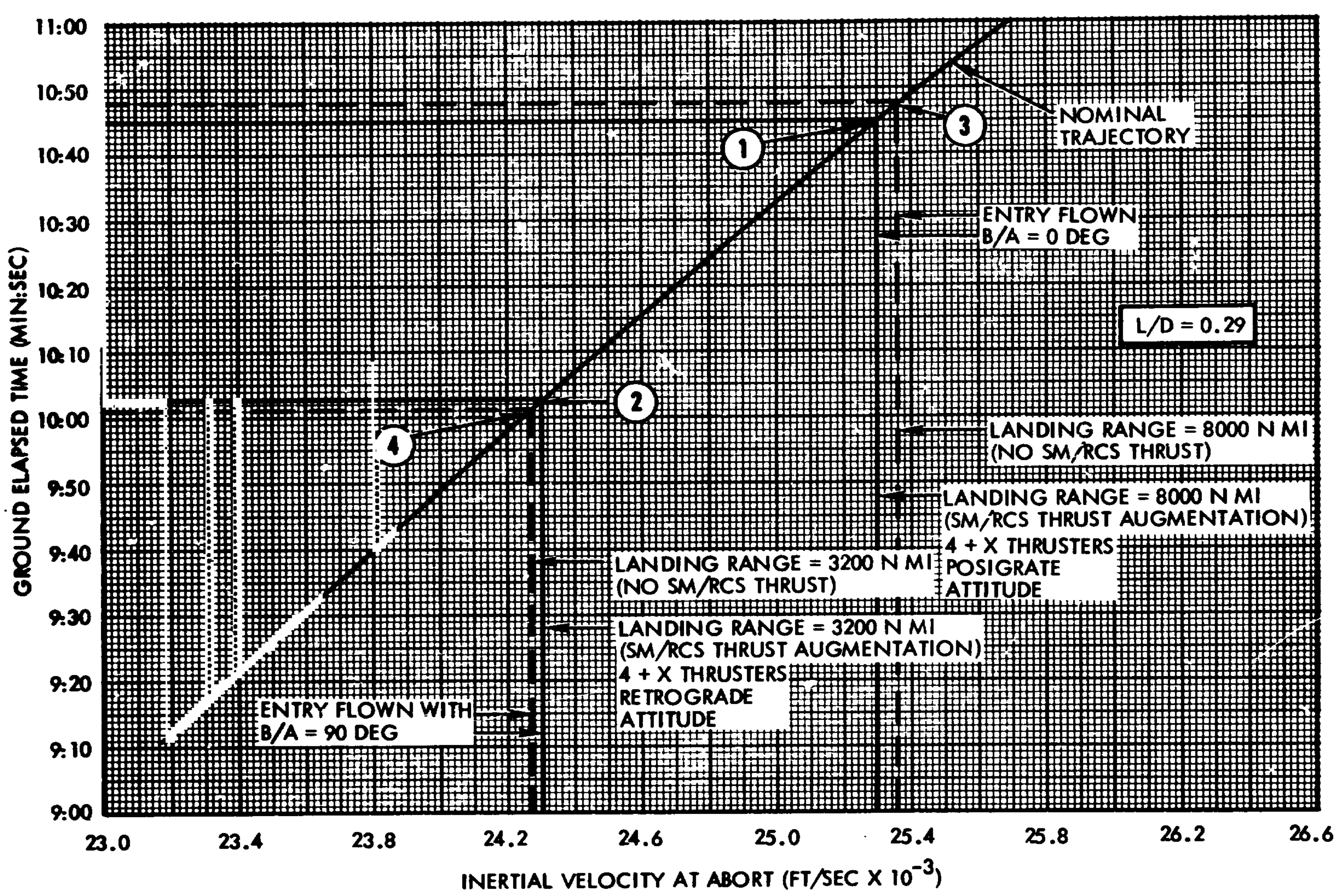

Figure 57.- Additional African overfly capability available from the SM/RCS thrusters for a typical Saturn V mission.

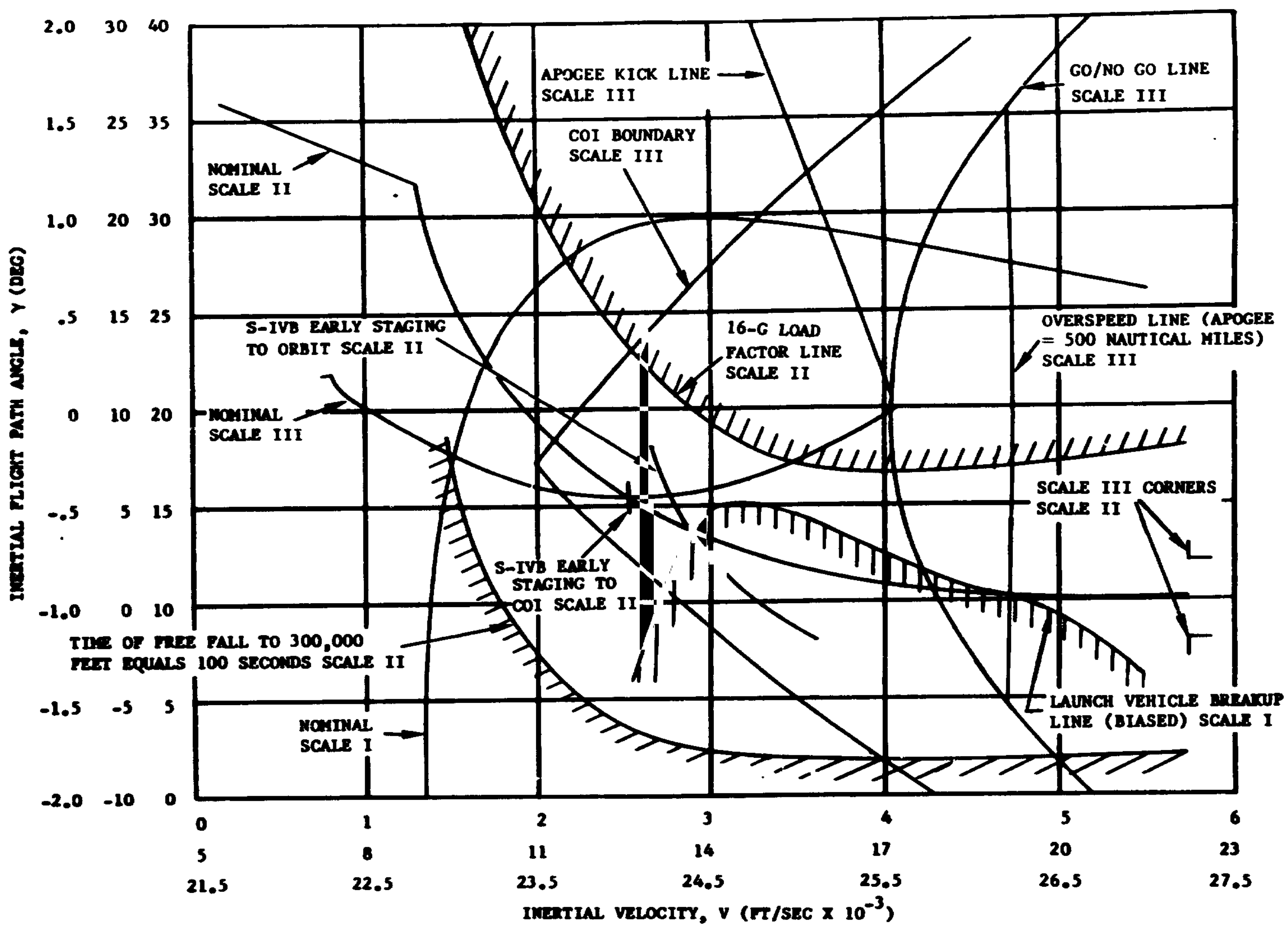

Figure 58.- Inertial flight-path angle versus inertial velocity (γ - V).

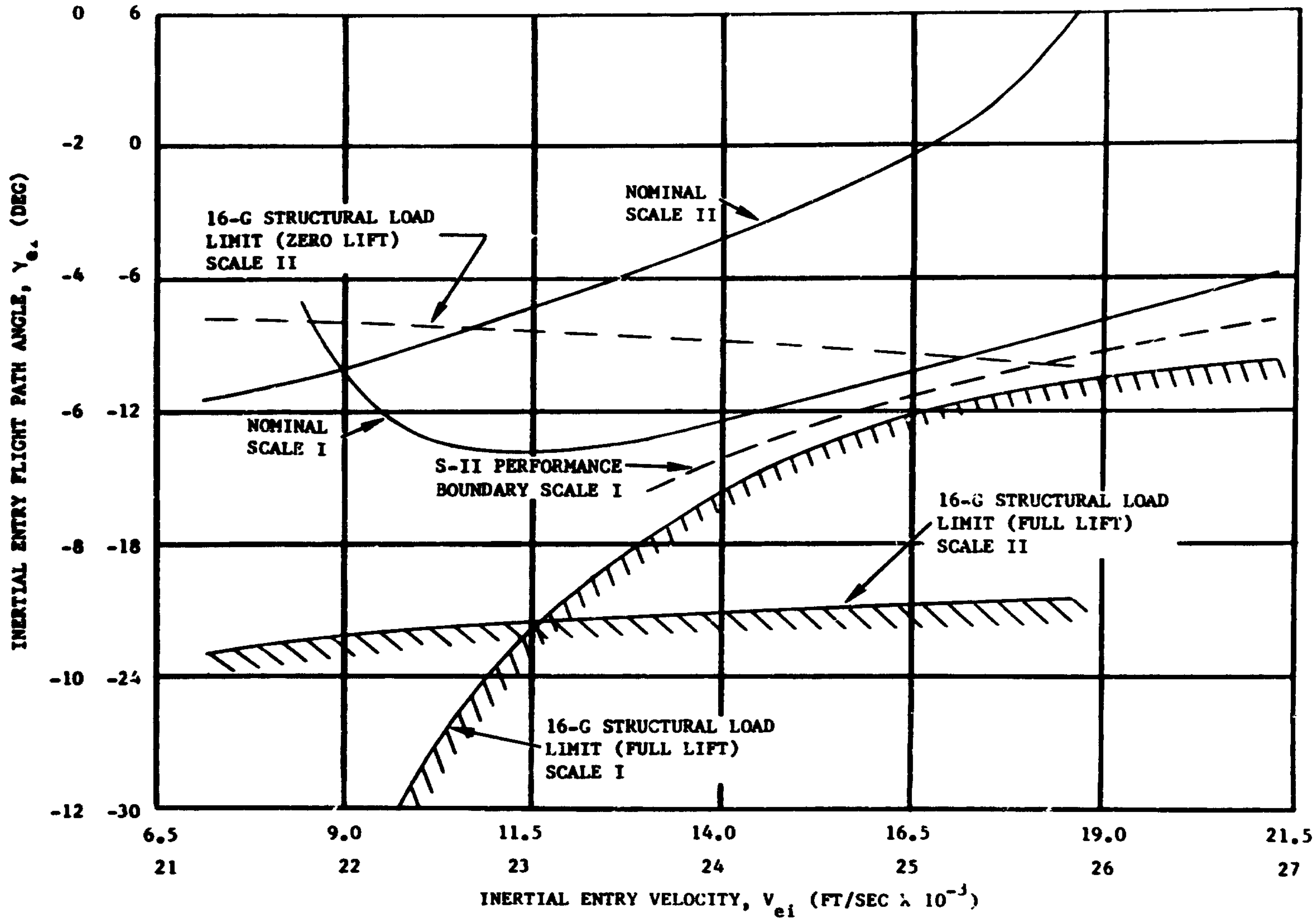

Figure 59.- Inertial flight-path angle at entry interface versus inertial velocity at entry interface (γ_{ei} - V_{ei}).

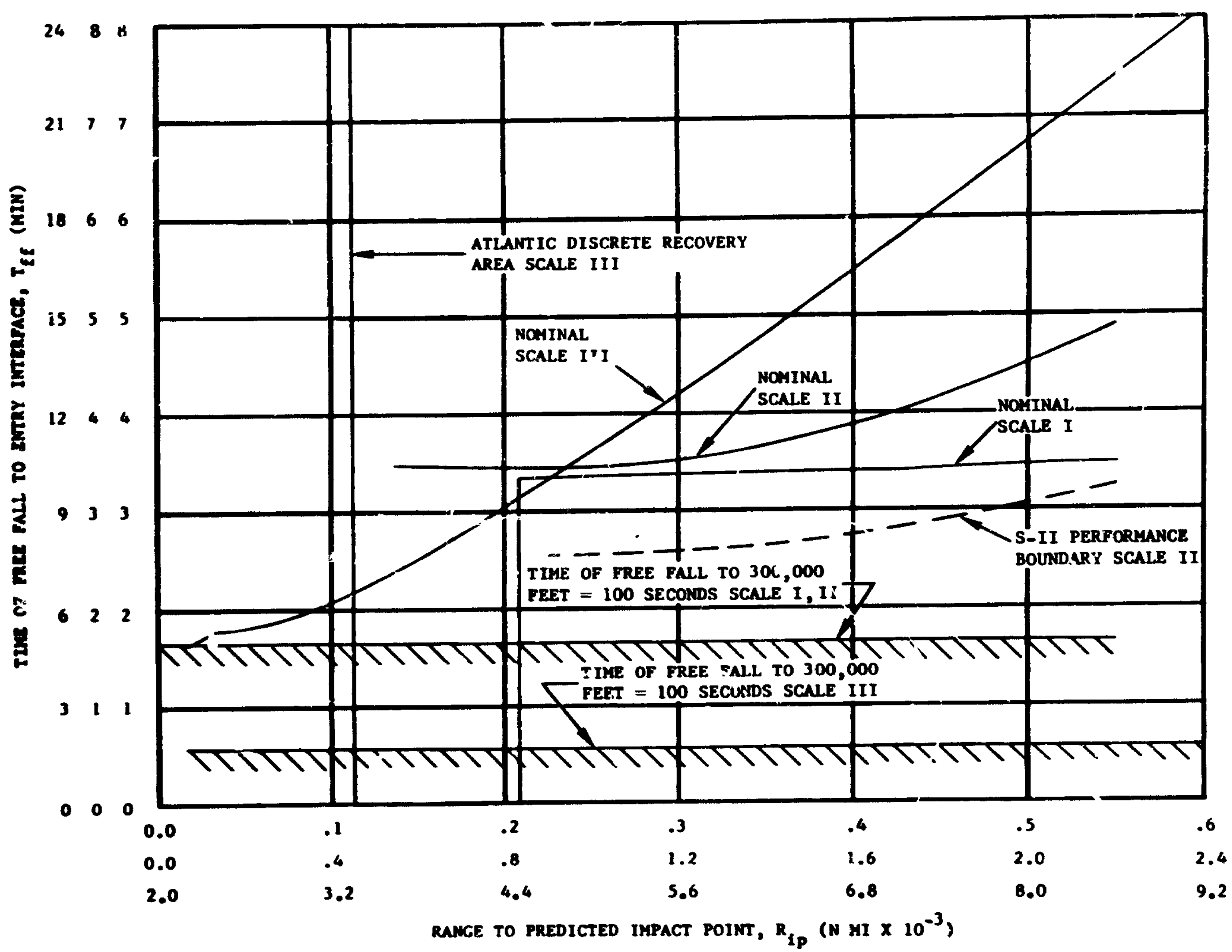

Figure 60.- Time of free fall to entry interface versus range to predicted impact point (T_{ff} - R_{ip}).

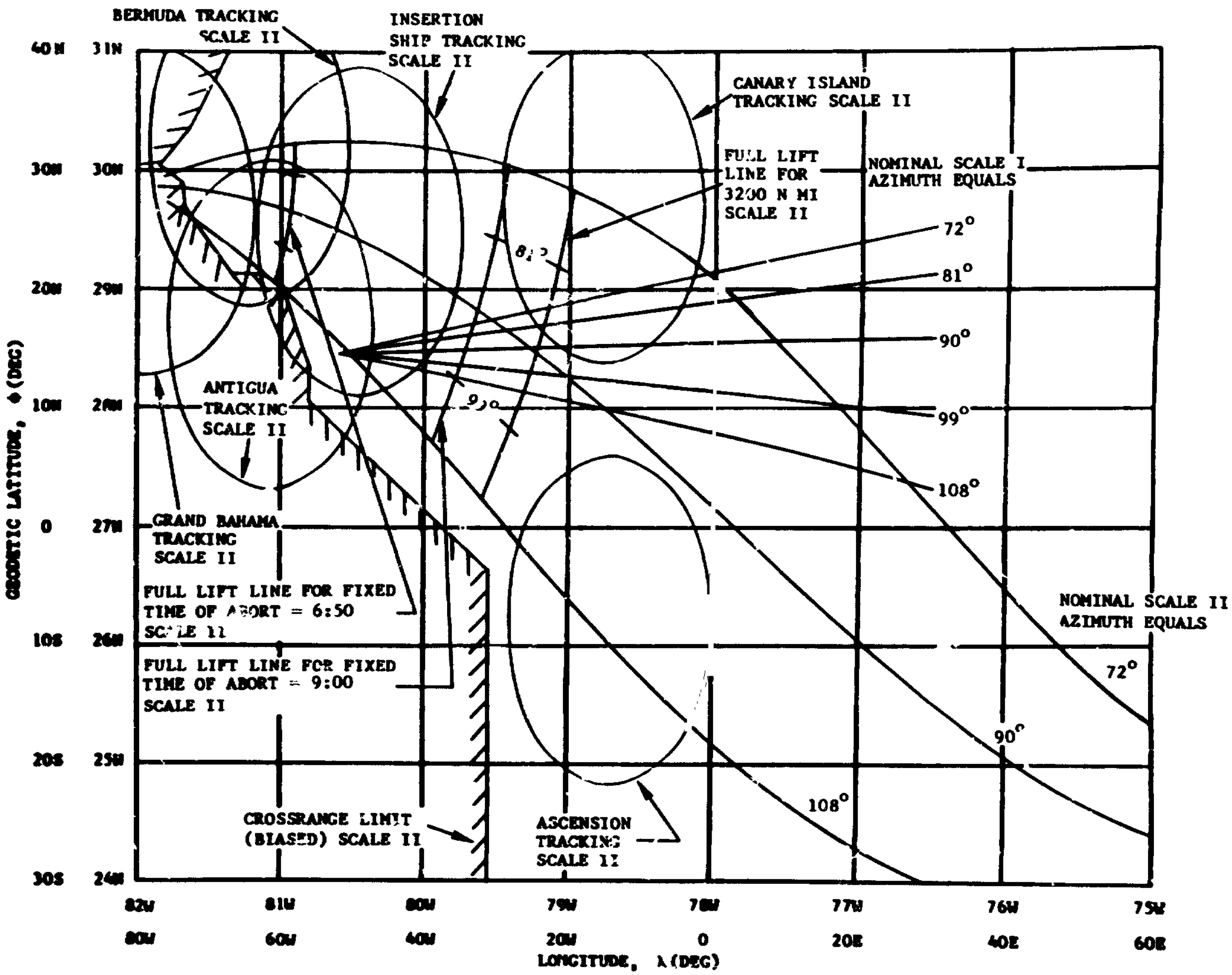

Figure 61.- Geodetic latitude versus longitude (ϕ - γ).

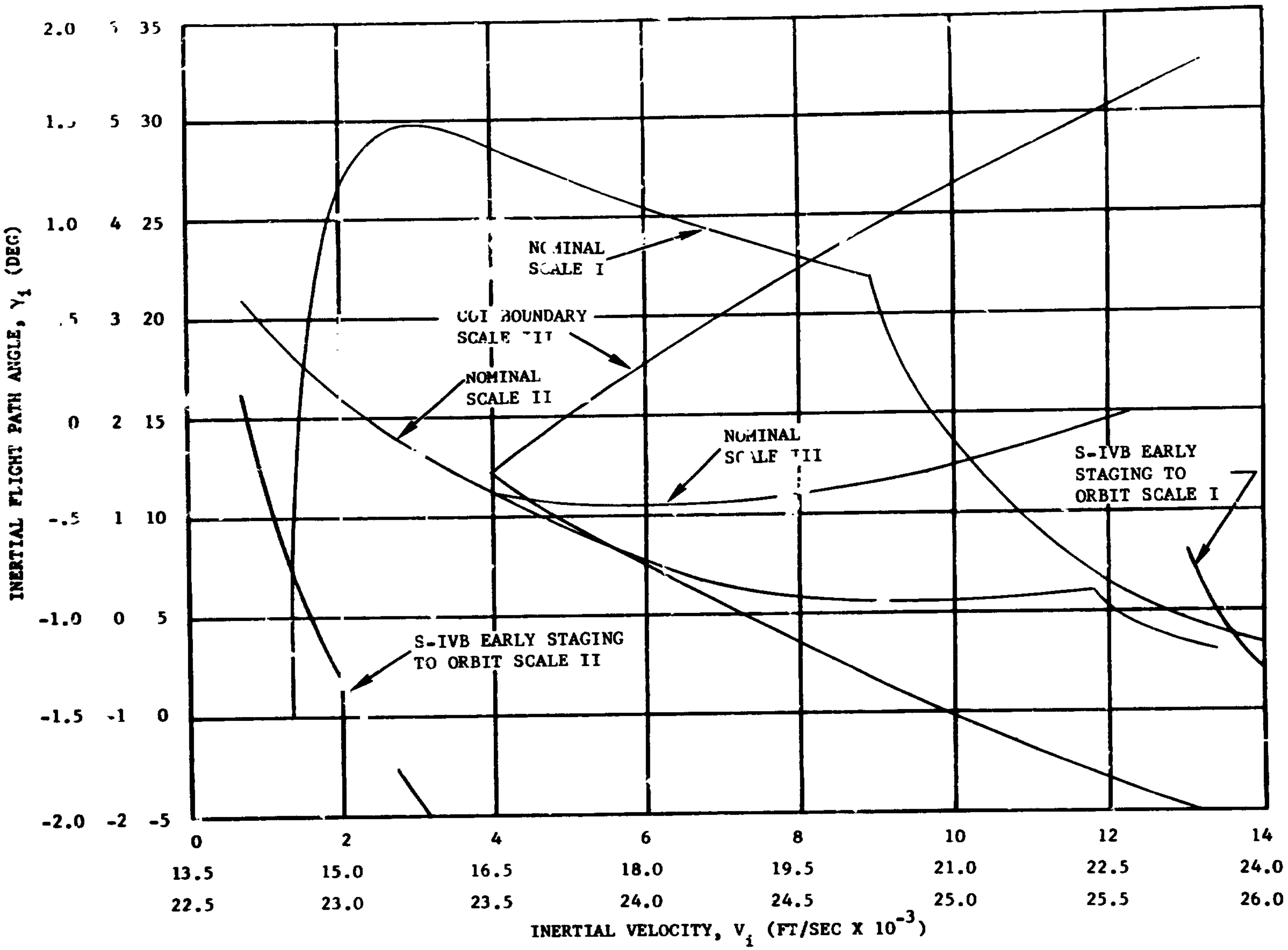

Figure 62.- Inertial flight-path angle versus inertial velocity (AGC dynamic status) (γ_i - V_i).

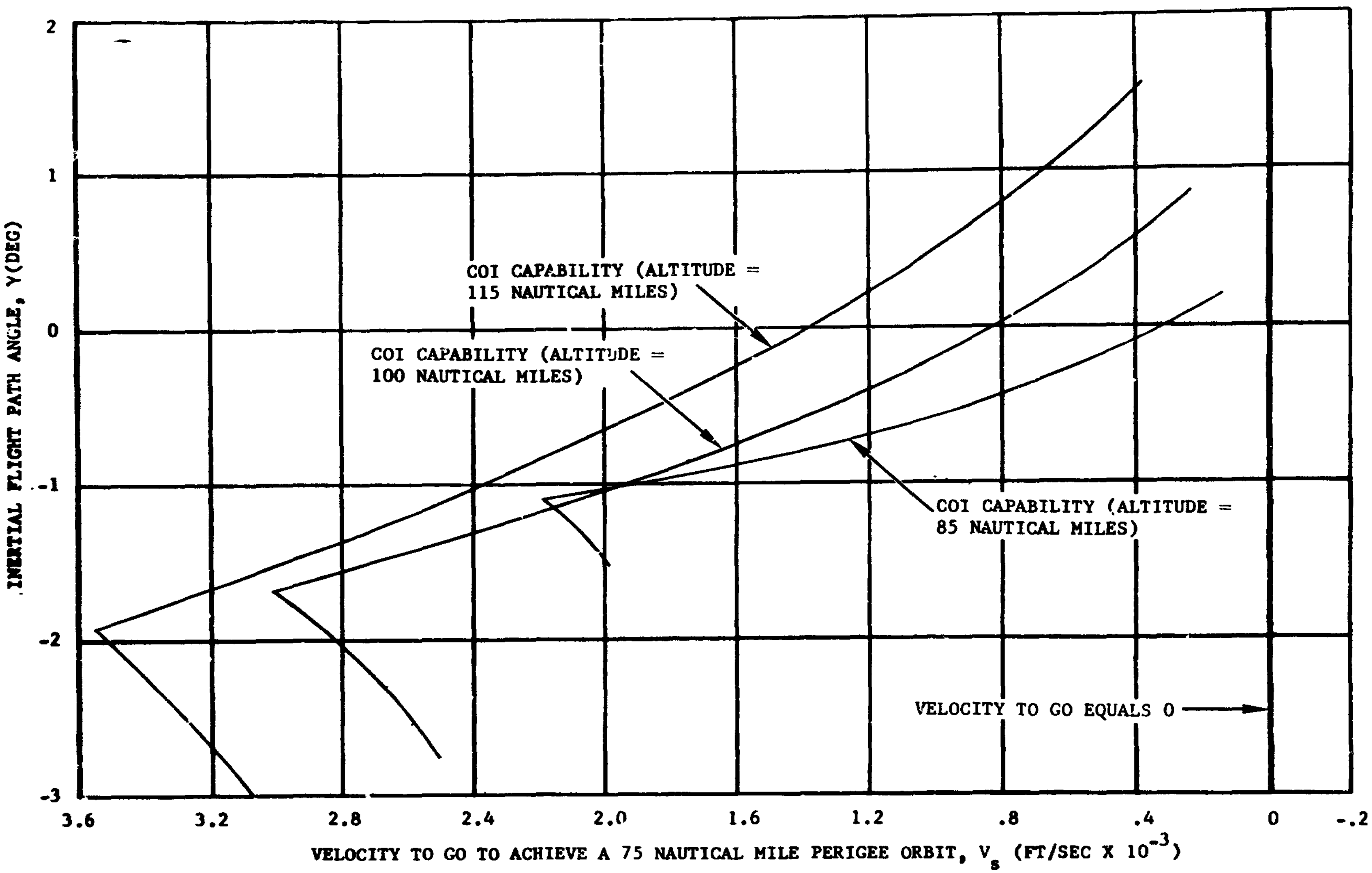

Figure 63.- Inertial flight-path angle versus velocity to go to achieve a 75-nautical mile perigee orbit (γ - V_s).

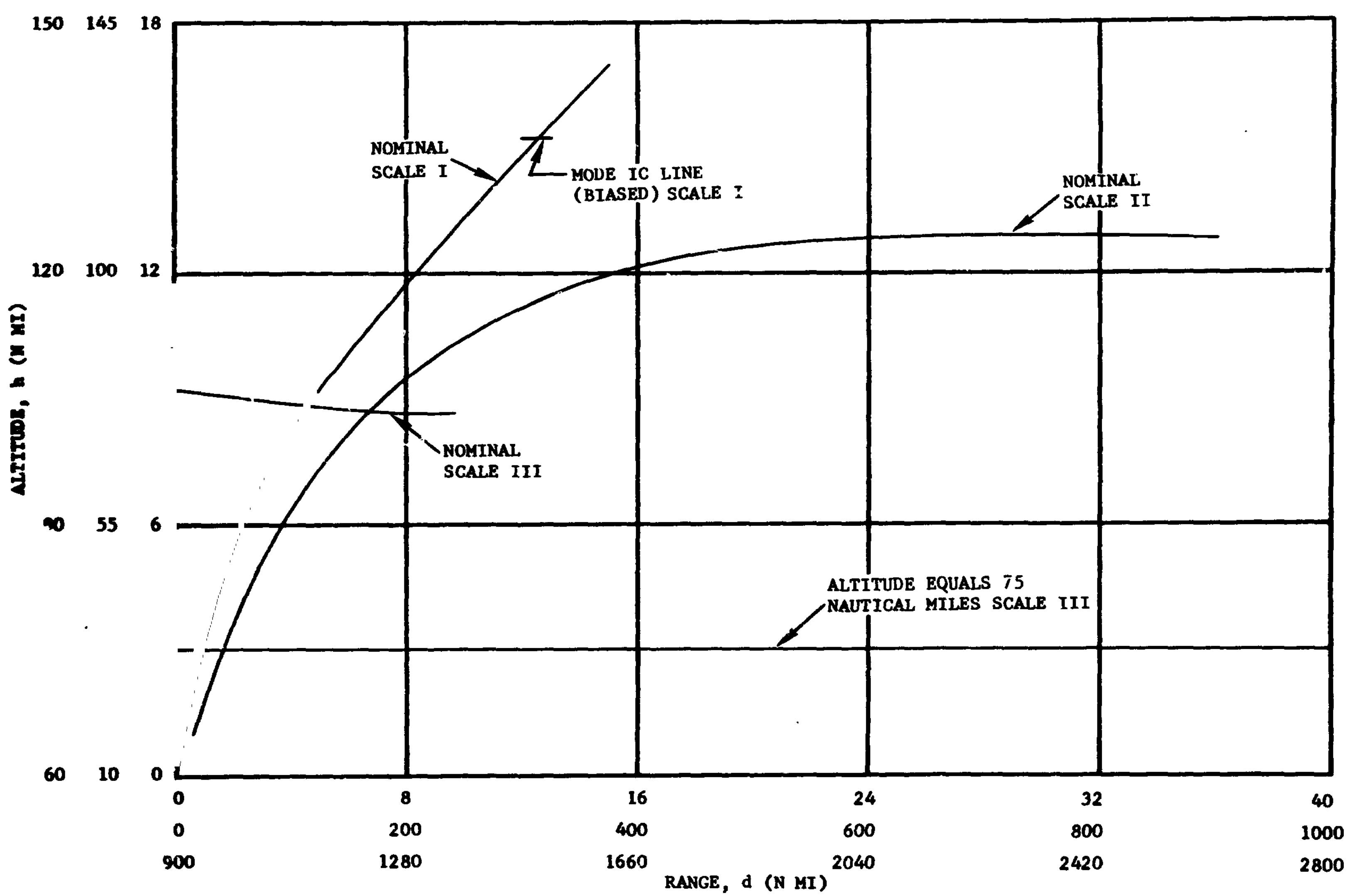

Figure 64.- Altitude versus range (h - d).

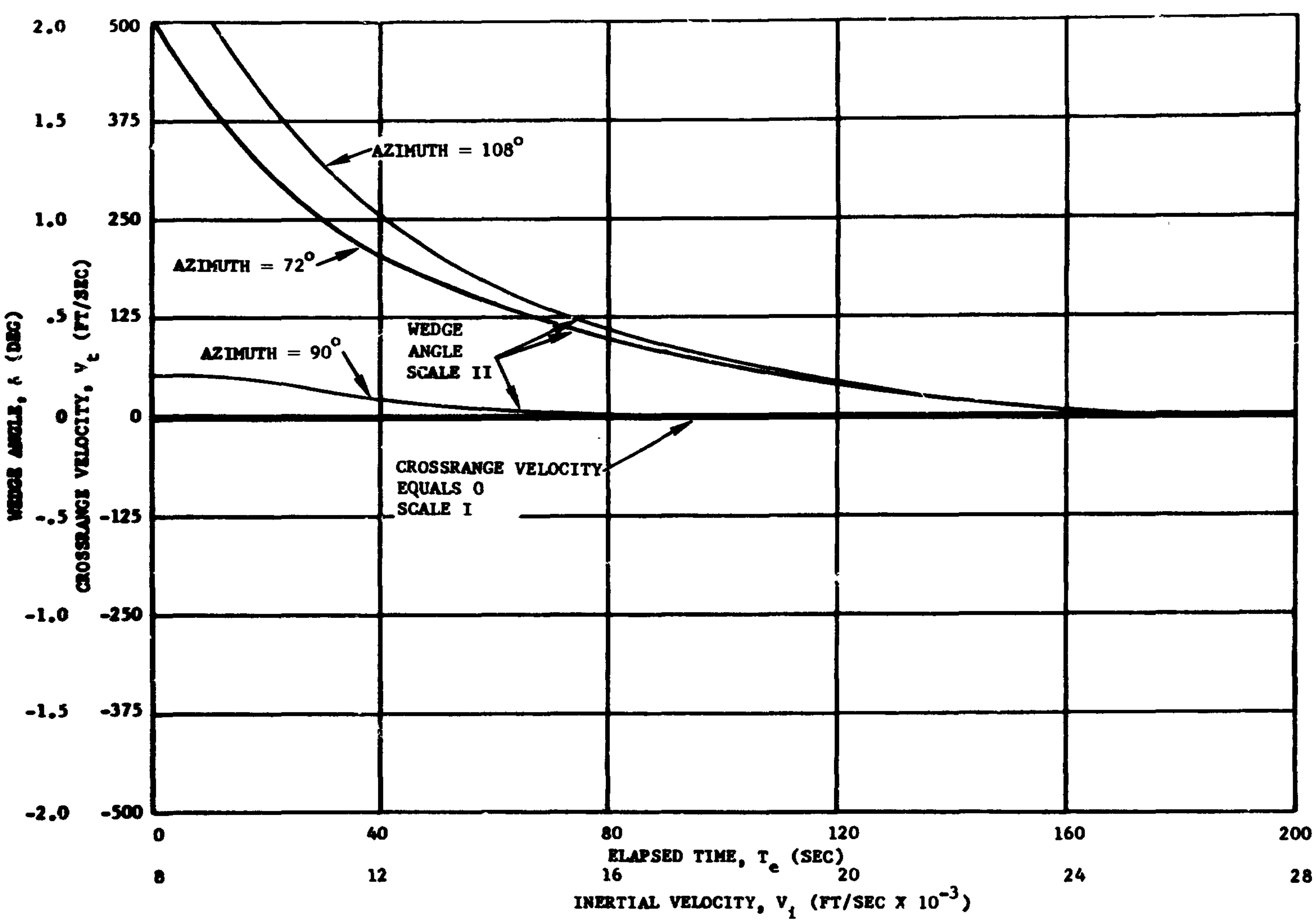

Figure 65.- Cross-range velocity versus elapsed time (V_t - T_e) and wedge angle versus inertial velocity (t - V_i).

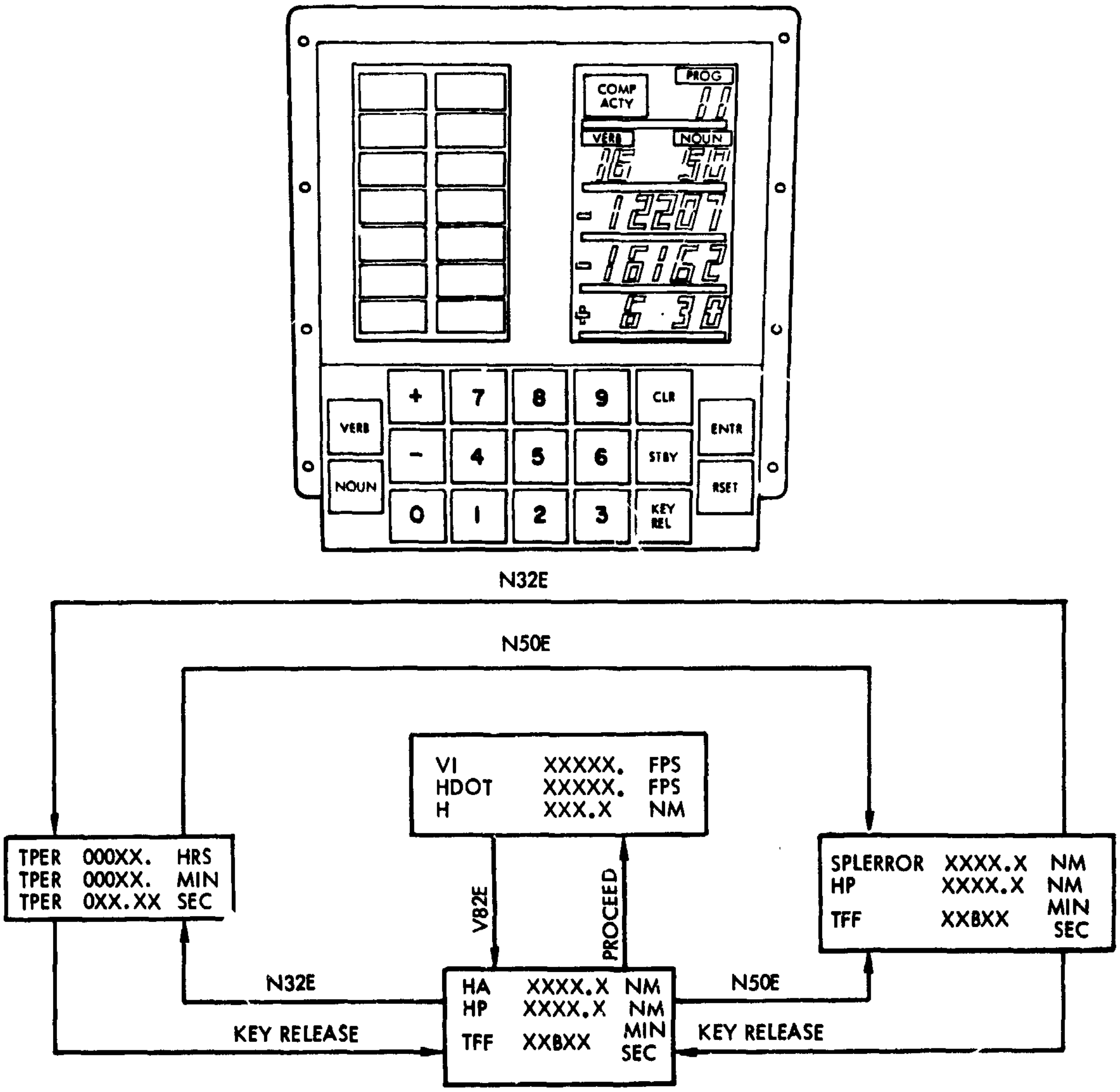

Figure 66.- DSKY panel layout and display switching pattern.

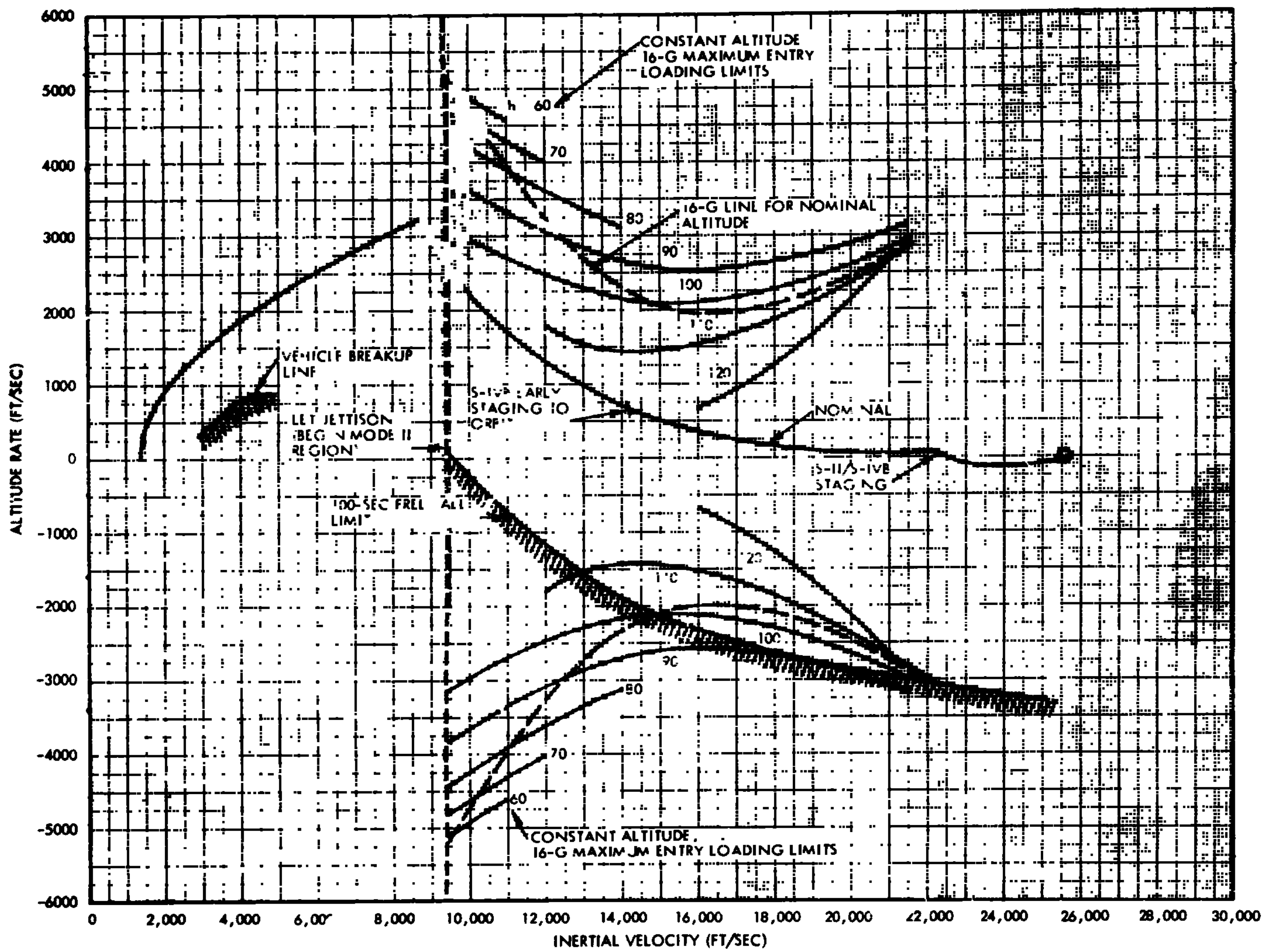

Figure 67.- No voice on board crew chart 1.

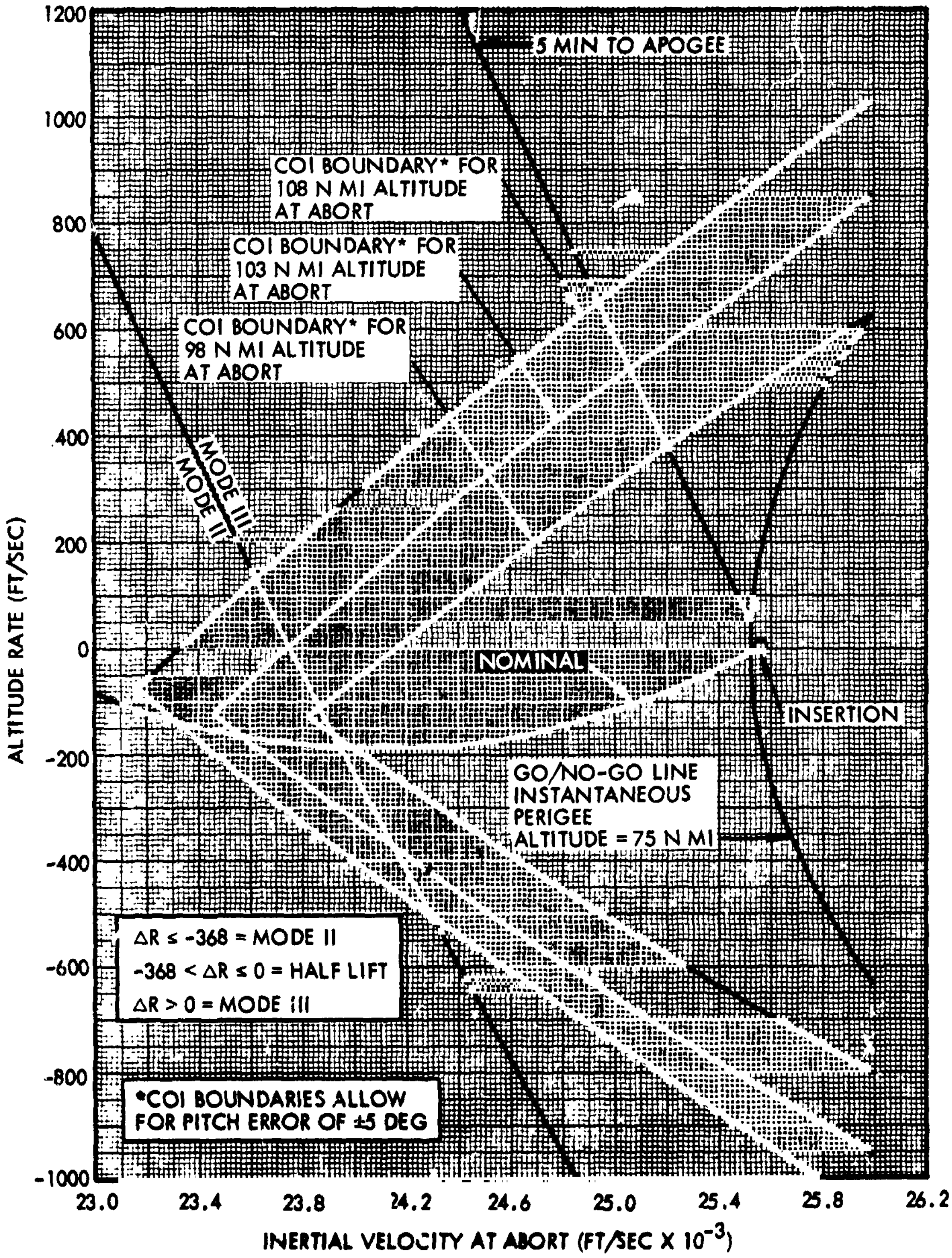

Figure 68.- No voice on board crew chart 2.

7.0 REFERENCES

1. Task Agreement Amendment for Launch Phase Operational Abort Analysis, Amendment no. 1. MSC/TRW Task A-162, October 1, 1968.

2. TRW: TRW Portion of the General Saturn V Launch Abort Document. TRW letter no. 3423.8-42, November 15, 1968.

3. TRW: Apollo Saturn IB Earth Launch Phase Abort Study. TRW note 68-FMT-629, May 1968.

4. Henderson, E. M., FAB; and Schutt, R. W., TRW Systems Group: Preliminary Launch Abort Study for Apollo Mission D/CSM-103/LM-3. MSC IN 68-FM-217, September 3, 1968.

5. Weber, Bobbie D.: Preliminary Launch Abort Analysis for Manned Apollo S-V Missions. MSC IN 67-FM-7, January 18, 1967.

6. Apollo Mission Techniques Saturn V/Apollo Launch Phase Aborts. MSC IN S-PA-8T-026, October 22, 1968.

7. CSM/LM Spacecraft Operational Data, Volumes I, II, and III. MSC report SNA-8-D-027, March 1968.

8. Goddard Space Flight Center: Apollo Missions and Navigation Systems Characteristics. Goddard Space Flight Center technical report no. AN-1.3, December 15, 1967.

9. MSC: Directory of Standard Geodetic and Geophysical Constants for Gemini and Apollo. MSC NASA General Working Paper 10020B, April 6, 1966.

10. Contract Change Authorization (CCA) 1546 directs 31.7° marking on SC-103 window. Master Change Record (MCR) 4092 implements this change with NR.

11. Range Safety Section, MSFC: B7 Tape for Unbiased Mission D Operational Trajectory Transmitted with Tape Number 17829 to John McAnulty of MSC. July 1, 1968.

12. Boeing Company: Saturn V AS-504 Launch Vehicle Reference Trajectory, Book 1, Volume II of II. The Boeing Company, D5-15481, May 15, 1967.

13. MSFC: Saturn V Launch Vehicle Emergency Detection System Analysis, AS-503 Mission D. MSFC memorandum R-AERO-FF-45-68, April 22, 1968.

14. Lunar Mission Design Section, LMAB: Apollo Mission C' Spacecraft Operational Trajectory, Alternate 1, Lunar Orbit Mission Profile for a Mission Launched December 21, 1968. MSC IN 68-FM-252, October 25, 1968.

15. TRW Systems Multi-Vehicle N-Stage (MVNS) Digital Computer Program. CDRC report 9830.4-23, August 2, 1965.

16. North American Aviation, Inc.: Performance Data Supplement to Mission Modular Data Book (Block II Earth Orbital Mission). North American Aviation, Inc. SID 66-1501-A, Part 3, revised March 15, 1967.

17. MIT/IL: Guidance System Operations Plan for Manned CM Earth Orbital and Lunar Missions using Program COLOSSUS, Section 5 - Guidance Equations (Rev. 1). MIT/IL Document, May 1968.