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# PRELIMINARY LAUNCH ABORT STUDY FOR APOLLO MISSION "C"/CSM-101

By Mission Operations Section
TRW Systems Group

MSC Task Monitor
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MISSION PLANNING AND ANALYSIS DIVISION

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HOUSTON, TEXAS

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FEBRUARY 16, 1968

Prepared for
MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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## FOREWORD

This report presents the results of a study defining the preliminary launch abort regions for Apollo Mission "C"/CSM-101. It also contains the preliminary abort data and procedures to be used in the event that launch phase anomalies necessitate a mission abort and/or return to earth. Studies are currently being conducted in an effort to design a simple yet reliable set of onboard crew charts to be used in the event that an abort situation develops during the launch phase and communication between the ground and spacecraft is lost. The three proposed charts are not included in this document as a result of delays in final flight crew approval. This document is submitted to NASA/MSC by TRW Systems in partial fulfillment of Task A-162, Contract NAS 9-4810.

CONTENTS

## ILLUSTRATIONS

TABLES

## NOMENCLATURE

| | |
|---|---|
| ADRA | Atlantic Discrete Recovery Area |
| ACRA | Atlantic Continuous Recovery Area |
| B/A | Bank angle |
| $C_D$ | Drag coefficient |
| CM | Command module |
| COI | Contingency orbit insertion |
| CSM | Command service module |
| EDS | Emergency detection system |
| FDAI | Flight director attitude indicator |
| g. e. t. | Ground elapsed time |
| IGM | Iterative guidance mode |
| IORA | Indian Ocean Recovery Area |
| IP | Impact point |
| L/D | Lift to drag ratio |
| LES | Launch escape subsystem |
| LET | Launch escape tower |
| LEV | Launch escape vehicle |
| LSI | Launch site inertial |
| MSC | Manned Spacecraft Center |
| SCS | Stabilization and control system |
| SM | Service module |
| SPS | Service propulsion subsystem |
| $\Delta V$ | Incremental change in velocity |
| $\gamma$ | Inertial flight-path angle |

# 1. INTRODUCTION

## 1.1 PURPOSE

This report defines launch abort regions and procedures for manned Apollo/Saturn flight. Nominal trajectory and spacecraft launch abort data for the ascent-to-orbit phase of Apollo Mission "C" are presented. These data will be used during simulator training to familiarize the crew with the actual values of certain key parameters that they would monitor in either a nominal or contingency situation. The abort modes defined in this document allow flexibility in choosing a course of action in the event that a contingency situation develops during the launch phase. They also provide the capability to return the spacecraft and crew to earth safely following any corrective action taken as the result of a launch abort condition. The results presented herein are preliminary in nature and will be updated in the final operational Apollo Mission "C"/CSM-101 launch abort plan when spacecraft weights, aerodynamics, and propellant loadings are formally documented.

## 1.2 SCOPE

The studies documented here analyzed spacecraft aborts during different phases of the mission from lift-off through insertion. Since the request for abort data specified aborts from the nominal launch trajectory, this study did not consider any off-nominal conditions with the following exceptions:

a) Maximum entry load factor lines

b) Minimum sequence (100 seconds of free fall to 300,000 feet) limit line

c) A near insertion analysis, which includes spacecraft altitude and attitude errors and a service propulsion subsystem (SPS) $\Delta V$ capability study

# 2. PRELIMINARY MISSION PROFILE

## 2.1 SPACECRAFT AND TRAJECTORY DATA

The preliminary spacecraft and trajectory data used in nominal and abort trajectory simulations are listed in Table 1, along with the sequence of events along the nominal launch trajectory. These data were obtained from the Flight Analysis Branch, NASA/MSC, and reflect the best estimates available as of 21 December 1967. Table 2 presents trim lift to drag ratios ($L/D_{trim}$) and drag aerodynamic coefficients as functions of Mach number. This table reflects current Apollo Block II command module (CM) aerodynamic data, Reference 1.

## 2.2 COORDINATE SYSTEM

Several of the graphs representing the Apollo Mission "C" trajectory data illustrate CM Euler pitch angles for both nominal and abort conditions. The purpose of these parameters is to permit the crew to associate actual trajectory conditions with their flight director attitude indicator (FDAI) readings. The body attitudes shown on these graphs will, after conversion to the FDAI coordinate system, provide the crew with this information. The launch site inertial (LSI) reference system used in defining the attitude angles for this report was established as follows: a right-handed orthogonal system centered at the launch site with the positive X-axis extending upward along the astronomical vertical at lift-off, the negative Z-axis extending downrange along the flight azimuth and lying in the horizontal plane, and the positive Y-axis in the direction of the left orthogonal of the flight azimuth. All attitude data presented in this report are referenced to this system, which is shown in Figure 1.

## 2.3 NOMINAL TRAJECTORY ANALYSIS

The nominal AS-205 launch trajectory was obtained from Reference 2. Portions of these data are presented in graphical and tabular form to provide a pictorial representation of the ascent profile. Figure 2 presents nominal altitude, inertial velocity, dynamic pressure, and altitude rate along the nominal trajectory. Figure 3 shows a plot of nominal altitude rate and inertial flight-path angle as functions of ground elapsed time (g. e. t.). The data presented in these curves are also listed in Tables 3 and 4. Figure 4 and Table 5 show spacecraft pitch, roll, and yaw angles along the nominal launch trajectory. These attitudes are referenced to the coordinate system provided in Figure 1.

# 3. LAUNCH ABORT MODES

## 3.1 LAUNCH PHASE - GENERAL

The launch abort modes presently defined for Apollo Mission "C" can be divided into three general categories as follows:

a) Those occurring in the lower atmosphere, which use the launch escape tower (LET) to rocket the spacecraft free of the launch vehicle and effect a safe water landing

b) Those occurring after LET jettison and before the full-lift landing point reaches the Atlantic Discrete Recovery Area (ADRA) (no service propulsion subsystem burn necessary)

c) Those requiring an SPS burn to achieve a safe water landing or safe orbit

A typical abort case consisted of initializing the CSM/S-IVB configuration with a state vector from the launch vehicle trajectory listing (Reference 2) and, using this as the time of abort, performing the necessary spacecraft abort maneuvers. The various launch abort modes are shown in Figure 5 as a function of ground elapsed time from lift-off.

## 3.2 MODE I ABORTS

Mode I aborts are designed for safe recovery of the spacecraft from the launch pad to approximately 2 minutes 46 seconds ground elapsed time. This mode covers the portion of the powered flight trajectory in which an abort is most likely to occur; therefore, it is the most protected region with the LET and the emergency detection system (EDS). These aborts are characterized by high accelerations induced by the launch escape motor and high aerodynamic forces induced by the atmosphere at low altitudes. The launch escape vehicle (LEV) configuration used to accomplish a Mode I abort is shown in Figure 6. Mode I launch abort data were not available for inclusion in this document and will be forthcoming at some future date.

## 3.3 MODE II ABORTS

Following LET jettison (end of Mode I abort region), the CM recovery procedure would be command service module (CSM) separation from the S-IVB and, following CM/service module (SM) and entry preparation, a CM full-lift entry into the Atlantic Continuous Recovery Area (ACRA). Mode II ends when the full-lift landing point reaches the ADRA located 3,200 nautical miles downrange of the launch site. This mode covers a major part of the launch phase (from approximately 2 minutes 46 seconds ground elapsed time to 9 minutes 33 seconds ground elapsed time).

Full-lift landing range and maximum entry load factor for aborts from the nominal ascent trajectory in the Mode II region are shown in Figure 7 and Table 6. Additional Mode II data are presented in Figure 8 and Table 7 where the CM pitch attitude at entry (300,000 ft) and time of free fall to entry following a Mode II abort are shown.

Spacecraft or launch vehicle system malfunctions are the most probable initiators of a launch abort; however, human performance and tolerance levels also dictate certain abort limit lines. Figure 9 shows the proposed maximum entry load factor and time-of-free-fall limit lines.

The maximum entry load factor limit line shows the maximum allowable amount of deceleration that the crew would experience upon entry. A Mode II abort will be initiated upon violation of this limit line. Since Apollo Mission "C" is limited by launch vehicle performance, the total allowable g level was increased from 16 g's to the proposed limit. This tolerance was raised so that many primary mission objectives would not have to be eliminated as a result of a reshaping of the launch trajectory. Results presented in Reference 3 are currently being investigated by the Medical Research and Operations Directorate and the Structures and Mechanics Division to further define the effects of high-g loads on the spacecraft and crew in these abort regions. The time-of-free-fall limit line is a human performance boundary; that is, the crew will need at least 100 seconds from launch vehicle separation to arrest any spacecraft rates and orient the spacecraft heat shield forward for atmospheric entry.

Table 8 lists ground elapsed time to an entry altitude of 400,000 feet and to drogue chute deployment at 23,500 feet. Table 9 presents spacecraft pitch attitude, inertial and relative flight-path angles, and inertial velocity at 400,000 feet altitude for nominal Mode II aborts. These listings are provided for flight control simulations that will use 400,000 feet as entry altitude rather than the 300,000-foot-entry height.

Ionization, induced by aerodynamic heating, eliminates all communication with the spacecraft crew during certain portions of the entry phase of the mission. Figure 10 and Table 10 show ground elapsed time at the entry and exit of the communication blackout region (Reference 5) when contact with the crew will not be possible. A latitude versus longitude plot of full-lift (B/A = 0 degree), half-lift (B/A = 60 degrees), and zero-lift (B/A = 90 degrees) impact points is provided in Figure 11. Figure 12 illustrates landing range as a function of inertial velocity at abort for full-lift (B/A = 0 degree), half-lift (B/A = 60 degrees) and zero-lift (B/A = 90 degrees) entries. The associated data, with the exception of the inertial velocity, are listed in Table 11. These curves show where the spacecraft would have impacted had a no burn Mode II type abort procecure been elected. Land landings in Africa are possible following nominal Mode II type aborts during certain phases of the ascent trajectory. Therefore, additional abort modes were designed to eliminate the possibilities of African landings.

## 3.4 MODE III ABORTS

The Mode III abort region begins at approximately 9 minutes 33 seconds ground elapsed time and continues past insertion (or until Fixed $\Delta V$ aborts can be executed). Abort sequences for Mode III, Fixed $\Delta V$, and Mode IV appear in Table 12, and the corresponding spacecraft orientations at SPS ignition are shown in Figure 13. The Mode III abort procedure consists of performing an SPS fixed inertial attitude retrograde burn and half-lift entry in order to land at the ADRA. Figures 14 and 15 show the spacecraft attitudes at SPS ignition and at entry altitude (300, 000 feet) following nominal Mode III aborts. Table 13 also lists these values as a function of the ground elapsed time of abort. Mode III burns are executed in the stabilization and control system (SCS) $\Delta V$ mode after initially orienting the CSM, in a retrograde attitude, 31.7 degrees below the line of sight to the horizon of the earth.

Figure 16 presents a plot of SPS $\Delta V$ expended and ground elapsed time of abort versus SPS burn time for Mode III and Mode IV aborts. The corresponding tabular data for Mode III appear in Table 14. Because Mode III aborts employ CM half-lift entries as opposed to full-lift for Mode II aborts, early abort times in the Mode III region require no SPS burn and will land short of the ADRA. The Mode III region, requiring an SPS retrograde burn, begins at 9 minutes 36 seconds ground elapsed time and extends through insertion.

Entry acceleration loads experienced by the crew following nominal Mode III aborts are not excessive. Time of free fall to 300,000 feet and entry acceleration are shown in Figure 17 and Table 15 as functions of ground elapsed time of abort. Ground communication with the spacecraft is lost during entry following Mode III aborts, as was the case in the Mode II region. Figure 18 and Table 16 indicate that there exists a period of approximately 2 minutes and 10 seconds during which all contact with the crew is highly improbable.

To further aid in flight simulations, a listing of discrete times and spacecraft orientations at the 400,000-foot entry interface altitude following nominal Mode III aborts appears in Table 17 as a function of ground elapsed time of abort. Launch aborts occurring late in the Mode III region require large SPS retrograde burns to effect a safe water landing in the Atlantic. This is not a desirable situation, for, during the SPS burn, the trace of the spacecraft impact point moves westward across the African continent, and a premature SPS shutdown could result in a land landing. For these reasons, a Fixed $\Delta V$ abort procedure has been defined.

## 3.5 FIXED $\Delta V$ (MODE IIIA) ABORTS

This abort mode covers the near- and post-insertion region where long SPS burns would be required to land at the 3,200-nautical mile landing range (ADRA). This abort sequence involves varying the SPS ignition time with a fixed magnitude $\Delta V$, fixed inertial attitude retrograde burn to land at an Indian Ocean Recovery Area (IORA), assumed for this study to be 8,800 nautical miles downrange of the launch site. This report assumed a Fixed $\Delta V$ of 600 feet per second; however, the magnitude of the Fixed $\Delta V$ burn is still under consideration. Here again, the SPS abort burn is executed in the SCS $\Delta V$ mode with the CSM oriented in a retrograde attitude, 31.7 degrees below the line of sight to the horizon of the earth (Figure 13). The earliest time that a Fixed $\Delta V$ abort can be performed (maximum time delay) is defined by delaying ignition until the time of free fall to an altitude of 300,000 feet after cutoff of the Fixed $\Delta V$ burn is equal to 100 seconds and the half-lift landing point is at the 8,800-nautical mile target. The ground elapsed time of abort corresponding to maximum delay time for Apollo Mission "C" is 9 minutes 51 seconds with SPS ignition occurring at 35 minutes 10.2 seconds, g.e.t. For overspeed trajectories, a Fixed ΔV abort can be performed until the time between S-IVB cutoff and SPS ignition is equal to 2 minutes 5 seconds (minimum time delay). The ground elapsed time at SPS ignition for the overspeed case is 12 minutes 1 second from lift-off. Assuming a nominal insertion into the parking orbit, the latest that a Fixed ΔV abort can be performed corresponds to a ground elapsed time at SPS ignition of 28 minutes 20.6 seconds. Table 18 presents typical results following nominal Fixed ΔV aborts and entries at the 300,000-foot interface altitude.

As part of the ground/spacecraft communication analysis, Table 19 displays ground elapsed time at the entry and exit of the blackout region for representative Fixed ΔV nominal aborts. Flight crew simulation data showing spacecraft orientations and time to the 400,000-foot entry interface altitude appear in Table 20.

## 3.6 MODE IV ABORTS

This abort mode also involves an SPS burn executed in the SCS ΔV mode; however, in this case, the CSM is oriented in a posigrade attitude at 31.7 degrees above the line of sight to the horizon of the earth (Figure 13). The resulting posigrade burn is terminated by a safe orbit condition defined as a perigee altitude equal to or greater than 75 nautical miles. Figure 16 shows ground elapsed time at abort and the amount of SPS ΔV expended as functions of SPS burn time. The associated data are also listed in Table 21. The earliest that a Mode IV abort can be performed corresponds to a ground elapsed time of 9 minutes 26 seconds. Spacecraft pitch attitudes at SPS ignition for nominal Mode IV aborts are presented in Figure 19 and Table 22 as a function of ground elapsed time of abort. An important fact should be noted here in that the Mode IV abort procedure is prime over Mode II or Mode III aborts.

The SPS ΔV capability study and near insertion analysis are presented in Figures 20 and 21. Current SPS propellant loading allows a CSM velocity increase of approximately 3,030 feet per second; 230 feet per second is allotted to arresting spacecraft rates and correcting pitch attitudes and a minimum of 600 feet per second is held in reserve to allow a deorbit from the contingency orbit. This leaves a maximum SPS ΔV capability of 2,200 feet per second for use in attaining contingency orbit insertion (COI). Figure 20 presents a plot of SPS constant ΔV lines and constant apogee lines (perigee equals 75 nautical miles) on an inertial flight-path angle, inertial velocity plot. The constant ΔV lines indicate the amount of ΔV necessary to achieve an orbit with a 75-nautical mile perigee at various velocity flight-path angle conditions.

Constant apogee lines displayed on Figure 20 show the type of orbit (perigee equals 75 nautical miles) which can be expected as a result of the SPS posigrade burn. The currently proposed Mode IV region is shown as a dotted line faired into the ΔV equals 2,200-foot per second line. The area within and to the right of this dotted line defines a zone where a Mode IV abort could be successfully completed. A contingency orbit insertion could not be successfully completed outside the Mode IV region, and a Mode II, Mode III or Fixed ΔV procedure would have to be considered. The curve on the far right-hand side of the plot should be noted. The area to the right of this curve defines the overspeed region where a late S-IVB shutdown would result in an apogee altitude in excess of 300 nautical miles.

Figure 21 presents the regions and boundaries for Modes II, and III, Fixed ΔV, and Mode IV aborts. The area to the right of the line labeled COI defines the theoretical Mode IV region where an orbit with a 75-nautical mile perigee is attainable if an unlimited amount of ΔV is avaliable. The plus and minus 5-degree pitch error and 5-nautical mile error lines show how the theoretical Mode IV region varies with possible attitude and altitude errors. Mode II aborts initiated to the left fo the Mode II/III boundary line will result in full-lift impact points falling short of the ADRA, while those attempted to the right of this line will require an SPS retrograde burn and half-lift entry to land at the ADRA. The area to the right of the apogee kick line defines a region where the resulting apogee, following a nominal Mode IV abort, occurs after the Canary Island tracking station has acquired the spacecraft. This zone is defined so that any spacecraft burn to be performed at apogee can be relayed to the crew via the Canary Island station. The two parallel dotted lines on the right of Figure 21 depict the Fixed $\Delta V$ abort region, where SPS retrograde burns will result in a spacecraft landing in the Indian Ocean Recovery Area, 8,000 nautical miles downrange of the launch pad.

The COI region defined by the dotted lines in Figure 20 is also presented by the shaded area in Figure 21. The overlap between the Mode IV abort regime and the Mode II/Mode III boundaries should be noted. The launch abort modes were purposely designed to allow a continuous ability to return to earth; however, the Mode IV and Apogee Kick procedures are prime in an abort situation where the capability exists.

Table 1. Preliminary Spacecraft and Trajectory Data

a) Preliminary Spacecraft Data

CM Weight = 13, 050 lbs

CSM Weight = 32, 480 lbs

RCS Thrust = 398. 8 lbs

RCS Propellant Flow Rate = 1. 44 lbs/sec

SPS Engine Thrust = 20, 000 lbs

SPS Engine $I_{sp}$ = 313. 4 secs

SPS Usable Propellant = 8, 378 lbs

SPS Propellant Flow Rate = 63. 81 lbs/sec

Total SPS $\Delta V$ Available = 3, 030 ft/sec

SPS $\Delta V$ in reserve to control rates and correct for execution errors = 230 ft/sec

Minimum SPS $\Delta V$ in reserve for deorbit = 600 ft/sec

SPS $\Delta V$ available to attempt COI = 2, 200 ft/sec

b) Sequence of Events Along the Nominal Launch Trajectory

| Nominal Flight Time (Sec) | Events |
|---|---|
| -5. 0 | Guidance reference release |
| 0. 0 | First motion |
| 0. 2 | Lift-off signal; initiate time base 1 |
| 10. 2 | Initiate pitch and roll |
| 137. 0 | Tilt arrest |
| 142. 9 | Inboard engine cutoff |
| 145. 9 | Outboard engine cutoff; initiate time base 3 |
| 147. 3 | Physical separation |
| 148. 6 | J-2 start command |
| 152. 0 | S-IVB 90 percent thrust |
| 159. 2 | Ullage case jettison |
| 165. 9 | LES tower jettison |
| 168. 9 | IGM initiation |
| 592. 6 | Guidance cutoff signal |
| 592. 8 | Initiate time base 4 |
| 602. 6 | Orbit insertion |

Table 2. Block II Spacecraft Aerodynamic Data

| Mach No. | $\alpha_{trim}$ | $C_{L_{trim}}$ | $C_{D_{trim}}$ | $L/D_{trim}$ |
|---|---|---|---|---|
| 0.40 | 167.88 | 0.229 | 0.856 | 0.268 |
| 0.70 | 165.51 | 0.224 | 0.965 | 0.253 |
| 0.90 | 162.91 | 0.303 | 1.074 | 0.282 |
| 1.10 | 156.60 | 0.466 | 1.190 | 0.392 |
| 1.20 | 156.68 | 0.454 | 1.175 | 0.387 |
| 1.35 | 155.49 | 0.535 | 1.296 | 0.413 |
| 1.65 | 154.71 | 0.530 | 1.284 | 0.413 |
| 2.00 | 154.80 | 0.516 | 1.302 | 0.396 |
| 2.40 | 155.42 | 0.489 | 1.274 | 0.384 |
| 3.00 | 155.86 | 0.461 | 1.252 | 0.368 |
| 4.00 | 157.59 | 0.424 | 1.241 | 0.342 |
| 6.00 | 161.45 | 0.368 | 1.316 | 0.280 |
| 10.00 | 161.45 | 0.368 | 1.316 | 0.280 |
| 100.00 | 161.45 | 0.368 | 1.316 | 0.280 |

Table 3. Nominal Launch Trajectory Data

| g. e. t. from Lift-off (min:sec) | Inertial Velocity (ft/sec) | Altitude (n mi) | Altitude Rate (ft/sec) | Dynamic Pressure (lb/ft$^2$) |
|---|---|---|---|---|
| 0:10 | 1, 343. 80 | 0. 08 | 80. 87 | 7. 42 |
| 0:20 | 1, 358. 10 | 0. 30 | 186. 43 | 37. 99 |
| 0:30 | 1, 405. 57 | 0. 71 | 319. 29 | 104. 34 |
| 0:40 | 1, 506. 67 | 1. 36 | 479. 32 | 213. 03 |
| 0:50 | 1, 672. 00 | 2. 30 | 665. 91 | 357. 23 |
| 1:00 | 1, 905. 15 | 3. 56 | 875. 27 | 508. 84 |
| 1:10 | 2, 188. 50 | 5. 18 | 1, 091. 93 | 609. 08 |
| 1:20 | 2, 548. 97 | 7. 18 | 1, 343. 57 | 635. 41 |
| 1:30 | 3, 011. 22 | 9. 63 | 1, 630. 32 | 535. 62 |
| 1:40 | 3, 586. 28 | 12. 56 | 1, 931. 66 | 346. 62 |
| 1:50 | 4, 268. 29 | 16. 00 | 2, 254. 90 | 196. 27 |
| 2:00 | 5, 064. 08 | 19. 99 | 2, 599. 10 | 97. 97 |
| 2:10 | 5, 989. 34 | 24. 57 | 2, 955. 66 | 45. 01 |
| 2:20 | 7, 064. 95 | 29. 74 | 3, 328. 76 | 20. 55 |
| 2:30 | 7, 183. 20 | 37. 85 | 3, 300. 00 | 5. 00 |
| 2:40 | 7, 609. 29 | 40. 78 | 3, 186. 91 | 1. 60 |
| 2:50 | 7, 728. 75 | 45. 91 | 3, 032. 28 | 0. 35 |
| 3:00 | 7, 859. 71 | 50. 79 | 2, 899. 73 | 0. 07 |
| 3:10 | 7, 992. 75 | 55. 48 | 2, 792. 59 | 0. 01 |
| 3:20 | 8, 137. 31 | 60. 00 | 2, 688. 16 | 0. 00 |
| 3:30 | 8, 294. 28 | 64. 34 | 2, 582. 34 | 0. 00 |
| 3:40 | 8, 464. 04 | 68. 51 | 2, 474. 65 | 0. 00 |
| 3:50 | 8, 645. 55 | 72. 50 | 2, 367. 08 | 0. 00 |
| 4:00 | 8, 839. 46 | 76. 32 | 2, 260. 99 | 0. 00 |
| 4:10 | 9, 044. 93 | 79. 96 | 2, 155. 99 | 0. 00 |
| 4:20 | 9, 262. 93 | 83. 43 | 2, 052. 19 | 0. 00 |
| 4:30 | 9, 493. 31 | 86. 73 | 1, 947. 83 | 0. 00 |
| 4:40 | 9, 735. 50 | 89. 73 | 1, 845. 94 | 0. 00 |
| 4:50 | 9, 990. 10 | 92. 83 | 1, 745. 06 | 0. 00 |

Table 3. Nominal Launch Trajectory Data (Continued)

| g.e.t. from Lift-off (min:sec) | Inertial Velocity (ft/sec) | Altitude (n mi) | Altitude Rate (ft/sec) | Dynamic Pressure ($lb/ft^2$) |
|---|---|---|---|---|
| 5:00 | 10,257.74 | 95.63 | 1,647.09 | 0.00 |
| 5:10 | 10,537.90 | 98.26 | 1,548.51 | 0.00 |
| 5:20 | 10,831.42 | 100.74 | 1,453.13 | 0.00 |
| 5:30 | 11,107.63 | 102.84 | 1,369.07 | 0.00 |
| 5:40 | 11,460.60 | 105.24 | 1,267.56 | 0.00 |
| 5:50 | 11,795.98 | 107.26 | 1,175.02 | 0.00 |
| 6:00 | 12,145.98 | 109.13 | 1,088.15 | 0.00 |
| 6:10 | 12,511.57 | 110.86 | 1,001.24 | 0.00 |
| 6:20 | 12,892.96 | 112.45 | 917.32 | 0.00 |
| 6:30 | 13,290.13 | 113.90 | 836.81 | 0.00 |
| 6:40 | 13,704.26 | 115.22 | 760.22 | 0.00 |
| 6:50 | 14,136.38 | 116.42 | 685.63 | 0.00 |
| 7:00 | 14,588.29 | 117.50 | 613.44 | 0.00 |
| 7:10 | 15,060.79 | 118.46 | 546.63 | 0.00 |
| 7:20 | 15,554.34 | 119.32 | 480.43 | 0.00 |
| 7:30 | 16,069.80 | 120.07 | 420.66 | 0.00 |
| 7:40 | 16,607.91 | 120.73 | 361.21 | 0.00 |
| 7:50 | 17,171.41 | 121.30 | 317.66 | 0.00 |
| 8:00 | 17,742.29 | 121.80 | 269.40 | 0.00 |
| 8:10 | 18,305.51 | 122.20 | 214.05 | 0.00 |
| 8:20 | 18,873.59 | 122.53 | 168.00 | 0.00 |
| 8:30 | 19,460.04 | 122.78 | 122.27 | 0.00 |
| 8:40 | 20,070.20 | 122.95 | 75.09 | 0.00 |
| 8:50 | 20,705.37 | 123.07 | 46.98 | 0.00 |
| 9:00 | 21,435.80 | 123.13 | 14.96 | 0.00 |
| 9:10 | 22,062.07 | 123.15 | -3.85 | 0.00 |
| 9:20 | 22,794.51 | 123.15 | -15.91 | 0.00 |
| 9:30 | 23,571.24 | 123.13 | -20.57 | 0.00 |
| 9:40 | 24,397.81 | 123.11 | -17.03 | 0.00 |

Table 3. Nominal Launch Trajectory Data (Continued)

| g. e. t. from Lift-off (min:sec) | Inertial Velocity (ft/sec) | Altitude (n mi) | Altitude Rate (ft/sec) | Dynamic Pressure (lb/ft$^2$) |
|---|---|---|---|---|
| 9:50 | 25, 277. 93 | 123. 09 | -13. 24 | 0. 00 |
| 9:52. 7 | 25, 526. 21 | 123. 09 | 0. 00 | 0. 00 |

Table 4. Nominal Launch Trajectory Data

| g. e. t. (min:sec) | Altitude Rate (ft/sec) | Inertial Flight-path Angle (deg) |
|---|---|---|
| 0:10 | 80.87 | 3.45 |
| 0:20 | 186.43 | 7.89 |
| 0:30 | 319.29 | 13.13 |
| 0:40 | 479.32 | 18.55 |
| 0:50 | 665.91 | 23.47 |
| 1:00 | 875.27 | 27.35 |
| 1:10 | 1091.93 | 29.93 |
| 1:20 | 1343.57 | 31.81 |
| 1:30 | 1630.32 | 32.78 |
| 1:40 | 1931.66 | 32.59 |
| 1:50 | 2254.90 | 31.89 |
| 2:00 | 2599.10 | 30.88 |
| 2:10 | 2955.66 | 29.57 |
| 2:20 | 3328.76 | 28.11 |
| 2:30 | 3300.00 | 26.31 |
| 2:40 | 3186.91 | 24.76 |
| 2:50 | 3032.28 | 23.10 |
| 3:00 | 2899.73 | 21.65 |
| 3:10 | 2792.59 | 20.45 |
| 3:20 | 2688.16 | 19.29 |
| 3:30 | 2582.34 | 18.14 |
| 3:40 | 2474.65 | 17.00 |
| 3:50 | 2367.08 | 15.89 |
| 4:00 | 2260.99 | 14.82 |
| 4:10 | 2155.99 | 13.79 |
| 4:20 | 2052.19 | 12.80 |
| 4:30 | 1947.83 | 11.84 |
| 4:40 | 1845.94 | 10.93 |
| 4:50 | 1745.06 | 10.06 |
| 5:00 | 1647.09 | 9.24 |

Table 4. Nominal Launch Trajectory Data (Continued)

| g. e. t. (min:sec) | Altitude Rate (ft/sec) | Inertial Flight-path Angle (deg) |
|---|---|---|
| 5:10 | 1548.51 | 8.45 |
| 5:20 | 1453.13 | 7.71 |
| 5:30 | 1369.07 | 7.08 |
| 5:40 | 1267.56 | 6.35 |
| 5:50 | 1175.02 | 5.75 |
| 6:00 | 1088.15 | 5.14 |
| 6:10 | 1001.24 | 4.59 |
| 6:20 | 917.32 | 4.08 |
| 6:30 | 836.81 | 3.61 |
| 6:40 | 760.22 | 3.18 |
| 6:50 | 685.63 | 2.78 |
| 7:00 | 613.44 | 2.41 |
| 7:10 | 546.63 | 2.08 |
| 7:20 | 480.43 | 1.77 |
| 7:30 | 420.66 | 1.50 |
| 7:40 | 361.21 | 1.25 |
| 7:50 | 317.66 | 1.06 |
| 8:00 | 269.40 | 0.87 |
| 8:10 | 214.05 | 0.67 |
| 8:20 | 168.00 | 0.51 |
| 8:30 | 122.27 | 0.36 |
| 8:40 | 75.09 | 0.28 |
| 8:50 | 46.98 | 0.13 |
| 9:00 | 14.96 | 0.04 |
| 9:10 | -3.85 | -0.01 |
| 9:20 | -15.91 | -0.04 |
| 9:30 | -20.57 | -0.05 |
| 9:40 | -17.03 | -0.04 |
| 9:50 | -13.24 | -0.03 |
| 9:52.7 | 0.00 | 0.00 |

Table 5. Spacecraft Pitch, Roll, and Yaw Attitudes Along the Nominal Launch Trajectory*

| g. e. t. from Lift-off (min:sec) | Pitch (deg) | Roll (deg) | Yaw (deg) |
|---|---|---|---|
| 0:00 | 0.00 | -28.00 | 0.00 |
| 0:10 | 0.00 | -28.00 | 0.00 |
| 0:20 | 1.81 | -18.20 | 0.00 |
| 0:30 | 5.56 | -8.20 | 0.00 |
| 0:40 | 10.30 | 0.00 | 0.00 |
| 0:50 | 15.28 | 0.00 | 0.00 |
| 1:00 | 20.00 | 0.00 | 0.00 |
| 1:10 | 24.36 | 0.00 | 0.00 |
| 1:20 | 29.17 | 0.00 | 0.00 |
| 1:30 | 36.44 | 0.00 | 0.00 |
| 1:40 | 42.43 | 0.00 | 0.00 |
| 1:50 | 46.67 | 0.00 | 0.00 |
| 2:00 | 51.38 | 0.00 | 0.00 |
| 2:10 | 55.79 | 0.00 | 0.00 |
| 2:20 | 58.69 | 0.00 | 0.00 |
| 2:30 | 58.69 | 0.00 | 0.00 |
| 2:40 | 58.69 | 0.00 | 0.00 |
| 2:50 | 57.69 | 0.00 | -1.00 |
| 3:00 | 48.68 | 0.00 | -5.87 |
| 3:10 | 49.84 | 0.00 | -5.75 |
| 3:20 | 51.46 | 0.00 | -5.66 |
| 3:30 | 54.04 | 0.00 | -6.03 |
| 3:40 | 55.47 | 0.00 | -5.82 |
| 3:50 | 57.04 | 0.00 | -5.77 |
| 4:00 | 58.59 | 0.00 | -5.65 |
| 4:10 | 60.06 | 0.00 | -5.57 |
| 4:20 | 61.43 | 0.00 | -5.43 |
| 4:30 | 62.91 | 0.00 | -5.32 |
| 4:40 | 64.27 | 0.00 | -5.21 |

*Attitudes referenced to Figure 1

Table 5. Spacecraft Pitch, Roll, and Yaw Attitudes Along the Nominal Launch Trajectory (Continued)

| g. e. t. from Lift-off (min:sec) | Pitch (deg) | Roll (deg) | Yaw (deg) |
|---|---|---|---|
| 4:50 | 65. 54 | 0. 00 | -5. 07 |
| 5:00 | 66. 95 | 0. 00 | -4. 94 |
| 5:10 | 68. 31 | 0. 00 | -4. 83 |
| 5:20 | 69. 59 | 0. 00 | -4. 70 |
| 5:30 | 71. 00 | 0. 00 | -4. 56 |
| 5:40 | 72. 38 | 0. 00 | -4. 45 |
| 5:50 | 73. 67 | 0. 00 | -4. 33 |
| 6:00 | 74. 88 | 0. 00 | -4. 20 |
| 6:10 | 76. 20 | 0. 00 | -4. 06 |
| 6:20 | 77. 53 | 0. 00 | -3. 94 |
| 6:30 | 78. 84 | 0. 00 | -3. 81 |
| 6:40 | 80. 12 | 0. 00 | -3. 68 |
| 6:50 | 81. 43 | 0. 00 | -3. 55 |
| 7:00 | 82. 77 | 0. 00 | -3. 42 |
| 7:10 | 84. 12 | 0. 00 | -3. 29 |
| 7:20 | 85. 45 | 0. 00 | -3. 17 |
| 7:30 | 86. 75 | 0. 00 | -3. 04 |
| 7:40 | 88. 03 | 0. 00 | -2. 91 |
| 7:50 | 89. 33 | 0. 00 | -2. 77 |
| 8:00 | 91. 85 | 0. 00 | -2. 01 |
| 8:10 | 91. 82 | 0. 00 | -2. 86 |
| 8:20 | 93. 64 | 0. 00 | -2. 44 |
| 8:30 | 95. 00 | 0. 00 | -2. 30 |
| 8:40 | 96. 16 | 0. 00 | -1. 97 |
| 8:50 | 97. 43 | 0. 00 | -1. 88 |
| 9:00 | 98. 80 | 0. 00 | -1. 77 |
| 9:10 | 100. 17 | 0. 00 | -1. 68 |
| 9:20 | 101. 59 | 0. 00 | -1. 61 |
| 9:30 | 103. 05 | 0. 00 | -1. 51 |

Table 5. Spacecraft Pitch, Roll, and Yaw Attitudes Along the Nominal Launch Trajectory (Continued)

| g. e. t. from Lift-off (min:sec) | Pitch (deg) | Roll (deg) | Yaw (deg) |
|---|---|---|---|
| 9:40 | 105.65 | 0.00 | -0.88 |
| 9:50 | 104.41 | 0.00 | -1.13 |
| 9:52.7 | 104.21 | 0.00 | -1.17 |

Table 6. Full-lift Landing Range and Maximum Entry Load Factor Following Nominal Mode II Aborts

| g. e. t. of Abort (min:sec) | Full-lift Landing Range (n mi) | Maximum Entry Load Factor (g) |
|---|---|---|
| 2:46 | 316. 25 | 8. 25 |
| 3:00 | 334. 78 | 8. 82 |
| 3:10 | 354. 09 | 9. 29 |
| 3:20 | 374. 00 | 9. 72 |
| 3:40 | 415. 63 | 10. 50 |
| 4:00 | 459. 84 | 11. 42 |
| 4:20 | 506. 93 | 12. 17 |
| 4:40 | 557. 22 | 12. 85 |
| 5:00 | 611. 13 | 13. 59 |
| 5:20 | 669. 00 | 14. 27 |
| 5:40 | 731. 83 | 14. 90 |
| 6:00 | 799. 95 | 15. 41 |
| 6:20 | 874. 78 | 15. 91 |
| 6:40 | 957. 54 | 16. 27 |
| 7:00 | 1050. 64 | 16. 46 |
| 7:20 | 1157. 33 | 16. 41 |
| 7:40 | 1282. 35 | 16. 23 |
| 8:00 | 1431. 66 | 15. 67 |
| 8:20 | 1600. 08 | 14. 70 |
| 8:40 | 1813. 21 | 13. 38 |
| 9:00 | 2111. 93 | 11. 42 |
| 9:20 | 2609. 68 | 8. 49 |
| 9:33 | 3200. 00 | 5. 62 |
| 9:40 | 3928. 02 | 4. 00 |
| 9:50 | 9127. 50 | 2. 50 |
| 9:52 | Orbit | Orbit |
| 9:52. 7 | Orbit | Orbit |

Table 7. Spacecraft Pitch Attitude at Entry Interface Altitude (300, 000 Feet) and Time of Free Fall to 300, 000 Feet for Nominal Mode II Aborts

| g. e. t. of Abort (min:sec) | Time of Free Fall (sec) | Pitch Attitude (deg)* |
|---|---|---|
| 2:46 | 201. 52 | -41. 82 |
| 3:00 | 205. 00 | -39. 14 |
| 3:20 | 212. 13 | -37. 50 |
| 3:40 | 216. 05 | -36. 62 |
| 4:00 | 219. 83 | -36. 10 |
| 4:20 | 221. 05 | -35. 83 |
| 4:40 | 222. 31 | -35. 78 |
| 5:00 | 224. 83 | -35. 84 |
| 5:20 | 225. 00 | -36. 00 |
| 5:40 | 226. 21 | -36. 19 |
| 6:00 | 227. 33 | -36. 39 |
| 6:20 | 228. 42 | -36. 60 |
| 6:40 | 230. 08 | -36. 72 |
| 7:00 | 234. 77 | -36. 78 |
| 7:20 | 237. 27 | -36. 69 |
| 7:40 | 245. 00 | -36. 40 |
| 8:00 | 255. 03 | -35. 82 |
| 8:20 | 270. 00 | -34. 95 |
| 8:40 | 286. 85 | -34. 18 |
| 9:00 | 315. 28 | -31. 72 |
| 9:20 | 383. 14 | -27. 02 |
| 9:40 | 600. 00 | -12. 30 |
| 9:50 | - | 53. 90 |
| 9:52 | - | Orbit |
| 9:52. 7 | - | Orbit |

*Attitudes referenced to Figure 1.

Table 8. Ground Elapsed Time from Lift-off to Entry Interface Altitude at 400, 000 Feet and Drogue Chute Deployment Following Nominal Mode II Aborts

| g. e. t. of Abort (min:sec) | g. e. t. at 400, 000 ft (min:sec) | g. e. t. at Drogue Chute Deployment (min:sec) |
|---|---|---|
| 2:46 | 5:22 | 8:47 |
| 3:00 | 5:49 | 9:08 |
| 3:20 | 6:17 | 9:36 |
| 3:40 | 6:45 | 19:59 |
| 4:00 | 7:11 | 10:23 |
| 4:20 | 7:35 | 10:47 |
| 4:40 | 7:57 | 11:10 |
| 5:00 | 8:19 | 11:34 |
| 5:20 | 8:41 | 11:59 |
| 5:40 | 9:02 | 12:25 |
| 6:00 | 9:23 | 12:51 |
| 6:20 | 9:45 | 13:19 |
| 6:40 | 10:06 | 13:49 |
| 7:00 | 10:29 | 14:21 |
| 7:20 | 10:53 | 14:57 |
| 7:40 | 11:19 | 15:37 |
| 8:00 | 11:48 | 16:23 |
| 8:20 | 12:18 | 17:14 |
| 8:40 | 12:54 | 18:15 |
| 9:00 | 13:42 | 19:39 |
| 9:20 | 15:00 | 21:54 |
| 9:40 | 18:29 | 27:40 |
| 9:50 | 31:49 | 49:56 |

Table 9. Spacecraft Pitch Attitude, Inertial and Relative Flight-path Angles, and Inertial Velocity at 400,000-Foot Entry Altitude Following Nominal Mode II Aborts

| g.e.t. of Abort (min:sec) | Pitch Attitude at Entry (deg)* | Inertial Flight-path Angle at Entry (deg) | Relative Flight-path Angle at Entry (deg) | Inertial Velocity (ft/sec) |
|---|---|---|---|---|
| 2:46 | -53.87 | -13.17 | -16.49 | 7,150.00 |
| 3:00 | -51.85 | -14.79 | -18.00 | 7,518.23 |
| 3:20 | -48.97 | -18.90 | -19.92 | 8,016.32 |
| 3:40 | -46.68 | -18.21 | -22.70 | 8,538.97 |
| 4:00 | -45.12 | -18.97 | -22.45 | 9,075.25 |
| 4:20 | -43.00 | -19.24 | -22.22 | 9,628.38 |
| 4:40 | -42.26 | -19.16 | -21.94 | 10,203.02 |
| 5:00 | -42.71 | -18.83 | -21.40 | 10,803.17 |
| 5:20 | -42.32 | -18.31 | -20.65 | 11,433.72 |
| 5:40 | -42.03 | -17.62 | -19.74 | 12,101.56 |
| 6:00 | -41.80 | -16.80 | -18.71 | 12,810.09 |
| 6:20 | -41.59 | -15.89 | -17.58 | 13,587.08 |
| 6:40 | -41.37 | -14.89 | -16.38 | 14,377.57 |
| 7:00 | -41.09 | -13.83 | -15.13 | 15,251.91 |
| 7:20 | -40.72 | -12.69 | -13.82 | 16,201.13 |
| 7:40 | -40.20 | -11.51 | -12.46 | 17,232.54 |
| 8:00 | -39.43 | -10.28 | -11.07 | 18,340.64 |
| 8:20 | -38.42 | -9.09 | -9.75 | 19,445.53 |
| 8:40 | -37.00 | -7.86 | -8.39 | 20,615.08 |
| 9:00 | -34.76 | -6.52 | -6.94 | 21,884.62 |
| 9:20 | -30.54 | -4.98 | -5.28 | 23,282.80 |
| 9:40 | -17.59 | -2.89 | -3.05 | 24,856.71 |
| 9:50 | +35.78 | -0.86 | -0.91 | 25,713.65 |

*Attitudes referenced to Figure 1.

Table 10. Ground Elapsed Time to Enter and Exit from VHF Communications Blackout Region Following Nominal Mode II Aborts

| g. e. t. of Abort (min:sec) | g. e. t. (Enter Blackout Region) (min:sec) | g. e. t. (Exit Blackout Region) (min:sec) |
|---|---|---|
| 2:46 | -- | -- |
| 3:00 | -- | -- |
| 3:20 | -- | -- |
| 3:40 | -- | -- |
| 4:00 | -- | -- |
| 4:20 | -- | -- |
| 4:40 | 9:06 | 9:08 |
| 5:00 | 9:23 | 9:31 |
| 5:20 | 9:41 | 9:52 |
| 5:40 | 9:59 | 10:14 |
| 6:00 | 10:18 | 10:35 |
| 6:20 | 10:37 | 10:58 |
| 6:40 | 10:56 | 11:21 |
| 7:00 | 11:17 | 11:45 |
| 7:20 | 11:40 | 12:12 |
| 7:40 | 12:04 | 12:42 |
| 8:00 | 12:32 | 13:16 |
| 8:20 | 13:02 | 13:54 |
| 8:40 | 13:38 | 14:40 |
| 9:00 | 14:29 | 15:44 |
| 9:20 | 15:52 | 17:35 |
| 9:40 | 19:46 | 22:58 |
| 9:50 | 36:08 | 45:46 |

Table 11. Spacecraft Landing Range and Longitude and Latitude of Impact Points for Full-lift (B/A = 0 Degree), Half-lift (B/A = 60 Degrees), and Zero-lift (B/A = 90 Degrees) Entries Following Nominal Mode II Type Aborts

| g. e. t. of Abort (min:sec) | Geodetic Latitude (deg) | Longitude (deg) | Landing Range (n mi) |
|---|---|---|---|
| B/A = 0 Degree (Full-lift Entry) | | | |
| 9:30 | 27.28 | -22.52 | 2995.72 |
| 9:32 | 26.64 | -20.33 | 3154.51 |
| 9:34 | 25.86 | -17.84 | 3300.28 |
| 9:36 | 24.89 | -14.97 | 3486.53 |
| 9:38 | 23.65 | -11.61 | 3684.89 |
| 9:40 | 22.03 | -7.59 | 3928.03 |
| 9:42 | 19.84 | -2.70 | 4232.11 |
| 9:46 | 11.63 | 12.56 | 5239.42 |
| 9:48 | 2.22 | 27.32 | 6281.08 |
| 9:49 | -6.47 | 40.50 | 7113.72 |
| 9:50 | -22.17 | 69.16 | 9127.42 |
| B/A = 60 Degrees (Half-lift Entry) | | | |
| 9:30 | 27.48 | -25.92 | 2847.75 |
| 9:32 | 26.93 | -23.91 | 2983.75 |
| 9:34 | 26.26 | -21.62 | 3117.43 |
| 9:36 | 25.41 | -18.96 | 3270.76 |
| 9:38 | 24.34 | -15.83 | 3453.22 |
| 9:40 | 22.91 | -12.06 | 3677.75 |
| 9:42 | 20.98 | -7.44 | 3959.54 |
| 9:44 | 17.75 | -0.75 | 4338.76 |
| 9:46 | 13.60 | 7.09 | 4901.33 |
| 9:48 | 4.89 | 21.19 | 5883.36 |
| 9:49 | -3.40 | 33.63 | 6637.51 |
| 9:50 | -19.29 | 59.80 | 8577.06 |

Table 11. Spacecraft Landing Range and Longitude and Latitude of Impact Points for Full-lift (B/A = 0 Degree), Half-lift (B/A = 60 Degrees), and Zero-lift (B/A = 90 Degrees) Entries Following Nominal Mode II Type Aborts (Continued)

B/A = 90 Degrees (Zero-lift Entry)

| g. e. t. of Abort (min:sec) | Geodetic Latitude (deg) | Longitude (deg) | Landing Range (n mi) |
|---|---|---|---|
| 9:30 | 28.06 | -27.10 | 2758.62 |
| 9:32 | 27.57 | -25.16 | 2843.19 |
| 9:34 | 26.96 | -22.96 | 3020.83 |
| 9:36 | 26.20 | -20.40 | 3182.37 |
| 9:38 | 25.22 | -17.38 | 3355.92 |
| 9:40 | 23.93 | -13.74 | 3569.55 |
| 9:42 | 22.17 | -9.28 | 3837.58 |
| 9:44 | 19.58 | -3.46 | 4198.67 |
| 9:46 | 15.35 | 4.81 | 4735.59 |
| 9:48 | 7.16 | 18.47 | 5675.38 |
| 9:49 | -0.75 | 30.43 | 6410.02 |
| 9:50 | -16.27 | 55.05 | 8253.49 |

Table 12. Sequence of Events for Mode III, Fixed ΔV, and Mode IV Launch Aborts

| Time from Booster Shutdown (min:sec) | Event |
|---|---|
| | Mode III-Fixed ΔV Mode |
| 0:00. 00 | Launch vehicle cutoff |
| 0:01. 85 | End of S-IVB tailoff |
| 0: 03. 00 | CSM/S-IVB separation, RCS direct ullage (Four jets) ON |
| 0:23. 00 | Mode III-Fixed ΔV Mode maneuver to retrograde attitude - RCS direct ullage (Four jets) OFF |
| 2:05. 00* | SPS thrust ON - SPS thrust OFF when IP = 3200 n mi from pad** |
| | Mode IV |
| 0:00. 00 | Launch vehicle cutoff |
| 0:01. 85 | End of S-IVB tailoff |
| 0:03. 00 | CSM/S-IVB separation, RCS direct ullage ON |
| 0:23. 00 | RCS direct ullage OFF - maneuver to posigrade attitude |
| 1:50. 00 | RCS direct ullage ON*** |
| 2:05. 00 | RCS direct ullage OFF, SPS thrust ON - SPS thrust OFF when resulting $h_p \geq 75$ nautical miles |

*Variable for Fixed ΔV Aborts.

**For Fixed ΔV Aborts, ΔV = 600 ft/sec, IP = 8800 n mi.

***Not simulated.

Table 13. Spacecraft Pitch Attitude at SPS Ignition and at Entry Interface Altitude (300,000 Feet) Following Nominal Mode III Aborts**

| g.e.t. (min:sec) | Pitch Attitude at SPS Ignition (deg) | Pitch Attitude at Entry (deg) |
|---|---|---|
| 9:35 | * | -18.16 |
| 9:36 | 247.55 | -18.28 |
| 9:38 | 247.70 | -18.38 |
| 9:40 | 247.85 | -18.51 |
| 9:42 | 248.00 | -18.62 |
| 9:44 | 248.13 | -18.77 |
| 9:46 | 248.33 | -18.55 |
| 9:48 | 248.49 | -18.76 |
| 9:50 | 248.65 | -18.72 |
| 9:52 | 248.80 | -18.62 |

*Half-lift landing range less than 3200 nautical miles, no SPS burn required.

**Attitudes referenced to Figure 1.

Table 14. SPS ΔV Expended and SPS Burn Time Following Nominal Mode III Aborts

| g. e. t. of Abort (min:sec) | ΔV Necessary to Achieve Half-lift Landing Range = 3200 n mi (ft/sec) | SPS Burn Time (sec) |
|---|---|---|
| 9:36 | 66.21 | 3.34 |
| 9:38 | 218.82 | 10.97 |
| 9:40 | 380.23 | 18.73 |
| 9:42 | 535.13 | 26.13 |
| 9:44 | 699.12 | 34.00 |
| 9:46 | 870.63 | 42.12 |
| 9:48 | 1,052.30 | 50.65 |
| 9:50 | 1,244.24 | 59.33 |
| 9:52 | 1,570.62 | 73.75 |

Table 15. Maximum Entry Load Factor and Time of Free Fall to Entry Interface Altitude Following Nominal Mode III Aborts

| g. e. t. of Abort (min:sec) | Entry Acceleration Load (g) | Time of Free Fall to 300,000-Foot Entry Altitude (min:sec)* |
|---|---|---|
| 9:36 | 7.95 | 6:21 |
| 9:38 | 7.84 | 6:09 |
| 9:40 | 7.75 | 5:55 |
| 9:42 | 7.68 | 5:42 |
| 9:44 | 7.62 | 5:29 |
| 9:46 | 7.59 | 5:17 |
| 9:48 | 7.59 | 5:04 |
| 9:50 | 7.63 | 4:51 |
| 9:52 | 7.72 | 4:39 |

*From SPS cutoff to entry interface altitude.

Table 16. Ground Elapsed Time from Lift-off to Enter and Exit from the VHF Communications Blackout Region Following Nominal Mode III Aborts

| Mode III | | |
|---|---|---|
| g. e. t. of Abort (min:sec) | g. e. t. (Enter Blackout Region) (min:sec) | g. e. t. (Exit Blackout Region) (min:sec) |
| 9:36 | 18:18 | 20:18 |
| 9:38 | 18:07 | 20:16 |
| 9:40 | 18:03 | 20:14 |
| 9:42 | 18:00 | 20:12 |
| 9:44 | 17:56 | 20:09 |
| 9:46 | 17:53 | 20:07 |
| 9:48 | 17:51 | 20:04 |
| 9:50 | 17:49 | 20:02 |
| 9:52 | 17:47 | 20:00 |

Table 17. Discrete Times at 400, 000-Foot Entry Interface Altitude and Drogue Chute Deployment and Spacecraft Orientation and Inertial Velocity at 400, 000 Feet Following Nominal Mode III Aborts

| Mode III | | | | | | |
|---|---|---|---|---|---|---|
| g. e. t. of Abort (min:sec) | g. e. t. at 400, 000 ft (sec) | g. e. t. Drogue Chute Deployment (min:sec) | Pitch Attitude at Entry (deg)* | Inertial Flight-path Angle (deg) | Relative Flight-path Angle (deg) | Inertial Velocity (ft/sec) |
| 9. 36 | 17:04 | 23:17 | -22. 99 | -3. 50 | -3. 70 | 24, 482. 34 |
| 9:38 | 17:00 | 23:16 | -23. 14 | -3. 48 | -3. 68 | 24, 546. 80 |
| 9:40 | 16:56 | 23:15 | -23. 26 | -3. 48 | -3. 68 | 24, 611. 59 |
| 9:42 | 16:53 | 23:13 | -23. 35 | -3. 48 | -3. 68 | 24, 679. 41 |
| 9:44 | 16:50 | 23:11 | -23. 42 | -3. 49 | -3. 69 | 24, 746. 34 |
| 9:46 | 16:48 | 23:09 | -23. 43 | -3. 52 | -3. 72 | 24, 812. 49 |
| 9:48 | 16:46 | 23:07 | -23. 37 | -3. 56 | -3. 76 | 24, 876. 57 |
| 9:50 | 16:45 | 23:05 | -23. 25 | -3. 62 | -3. 82 | 24, 938. 22 |
| 9:52 | 16:45 | 23:00 | -23. 07 | -3. 70 | -3. 90 | 24, 997. 34 |

*Attitudes referenced to Figure 1.

Table 18. Fixed $\Delta V$ Mode Nominal Launch Abort Data

| g. e. t. of Abort (min:sec) | Inertial Velocity (ft/sec) | Altitude Rate (ft/sec) | Delay Time* (min:sec) | Pitch Attitude at SPS Ignition (deg)** | Pitch Attitude at Entry (deg)*** | Time of Free Fall (min:sec)**** |
|---|---|---|---|---|---|---|
| 9:51 | 25, 368. 93 | -9. 08 | 25:19. 6 | -14. 49 | 71. 02 | 4:49 |
| 9:52 | 25, 460. 50 | -4. 37 | 19:40. 8 | -38. 17 | 70. 83 | 10:05 |
| 9:52. 7 | 25, 526. 21 | -0. 69 | 16:42. 2 | -52. 21 | 69. 94 | 13:26 |
| 10:02 | 25, 551. 52 | 1. 97 | 16:32. 4 | -52. 51 | 69. 89 | 13:30 |
| 26:15. 6 | 25, 503. 04 | 45. 80 | 2:05 | -45. 00 | 70. 59 | 11:49 |

*From time of abort to SPS ignition.

**Pitch attitudes referenced to Figure 1.

***Entry altitude = 300, 000 feet above launch pad radius.

****To 300, 000 feet altitude above launch pad radius.
Based on predicted time of free fall.

Table 19. Ground Elapsed Time from Lift-off to Enter and Exit from the VHF Communications Blackout Region Following Nominal Fixed $\Delta V$ Aborts

| g. e. t. of Abort (min:sec) | g. e. t. (Enter Blackout Region) (min:sec) | g. e. t. (Exit Blackout Region) (min:sec) |
|---|---|---|
| 9:51 | 40:13 | 44:18 |
| 9:52 | 40:19 | 44:25 |
| 9:52.7 | 40:05 | 44:28 |
| 10:02 | 40:04 | 44:28 |
| 26:15.6 | 40:13 | 44:27 |

Table 20. Discrete Times at 400, 000-Foot Entry Interface Altitude and Drogue Chute Deployment and Spacecraft Orientation and Inertial Velocity at 400, 000 Feet Following Nominal Fixed $\Delta V$ Aborts

| g. e. t. of Abort (min:sec) | g. e. t. at 400, 000 ft (sec) | g. e. t. at Drogue Chute Deployment (min:sec) | Pitch Attitude at Entry* (deg) | Inertial Flight-path Angle (deg) | Relative Flight-path Angle (deg) | Inertial Velocity (ft/sec) |
|---|---|---|---|---|---|---|
| 9:51 | 38:07 | 47:20 | 65:25 | -1. 734 | -1. 828 | 25, 392. 67 |
| 9:52 | 38:01 | 47:25 | 62. 79 | -1. 763 | -1. 858 | 25, 569. 78 |
| 9:52. 7 | 37:58 | 47:29 | 61:15 | -1. 763 | -1. 868 | 25, 569. 78 |
| 10:02 | 37:57 | 47:29 | 61:08 | -1. 758 | -1. 852 | 25, 571. 34 |

*Attitudes referenced to Figure 1.

Table 21. SPS Burn Time and SPS $\Delta V$ Increase Necessary to Increase Perigee Altitude to 75 Nautical Miles for Nominal Mode IV Aborts

| g. e. t. of Abort (min:sec) | $\Delta V$ Necessary to Increase Perigee Altitude to 75 n mi (ft/sec) | SPS Burn Time (sec) |
|---|---|---|
| 8:50 | 5,710.66 | 221.00 |
| 8:54 | 5,077.23 | 202.19 |
| 8:58 | 4,665.40 | 189.32 |
| 9:02 | 4,304.61 | 177.59 |
| 9:06 | 3,960.17 | 166.00 |
| 9:10 | 3,622.01 | 154.23 |
| 9:14 | 3,285.77 | 142.13 |
| 9:18 | 2,948.85 | 129.60 |
| 9:22 | 2,609.73 | 116.54 |
| 9:26 | 2,245.72 | 102.15 |
| 9:26.3 | 2,200.00 | 96.02 |
| 9:30 | 1,920.21 | 88.63 |
| 9:34 | 1,552.13 | 72.63 |
| 9:38 | 1,211.74 | 57.87 |
| 9:42 | 849.09 | 41.28 |
| 9:46 | 480.44 | 23.78 |
| 9:50 | 105.27 | 5.31 |

Table 22. Pitch Angle at SPS Ignition for Nominal Mode IV Aborts*

| g. e. t. of Abort (min:sec) | Pitch Attitude at SPS Ignition (deg) |
|---|---|
| 8:50 | 92. 91 |
| 8:54 | 93. 24 |
| 8:58 | 93. 58 |
| 9:02 | 93. 93 |
| 9:06 | 94. 29 |
| 9:10 | 94. 65 |
| 9:14 | 95. 02 |
| 9:18 | 95. 40 |
| 9:22 | 95. 78 |
| 9:24 | 96. 18 |
| 9:30 | 96. 58 |
| 9:34 | 97. 00 |
| 9:38 | 97. 42 |
| 9:42 | 97. 85 |
| 9:46 | 98. 28 |
| 9:50 | 98. 74 |

*Attitudes referenced to Figure 1.

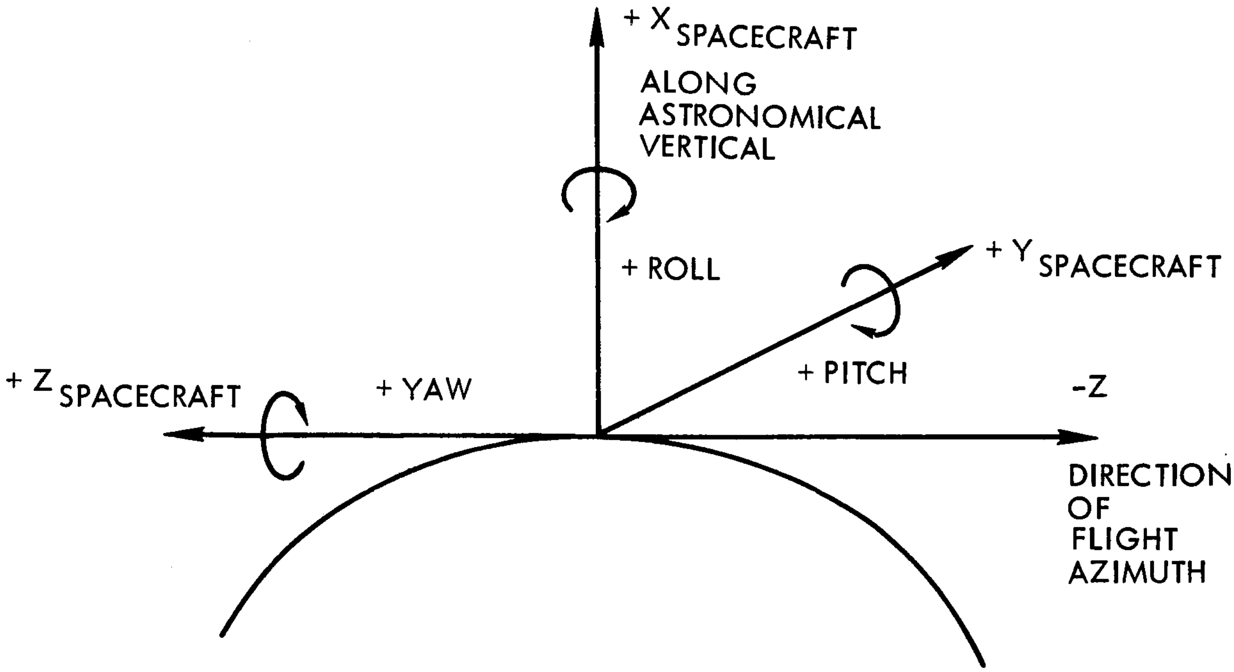



**Figure 1.** Launch Site Inertial Coordinate System Used to Define Spacecraft Attitudes

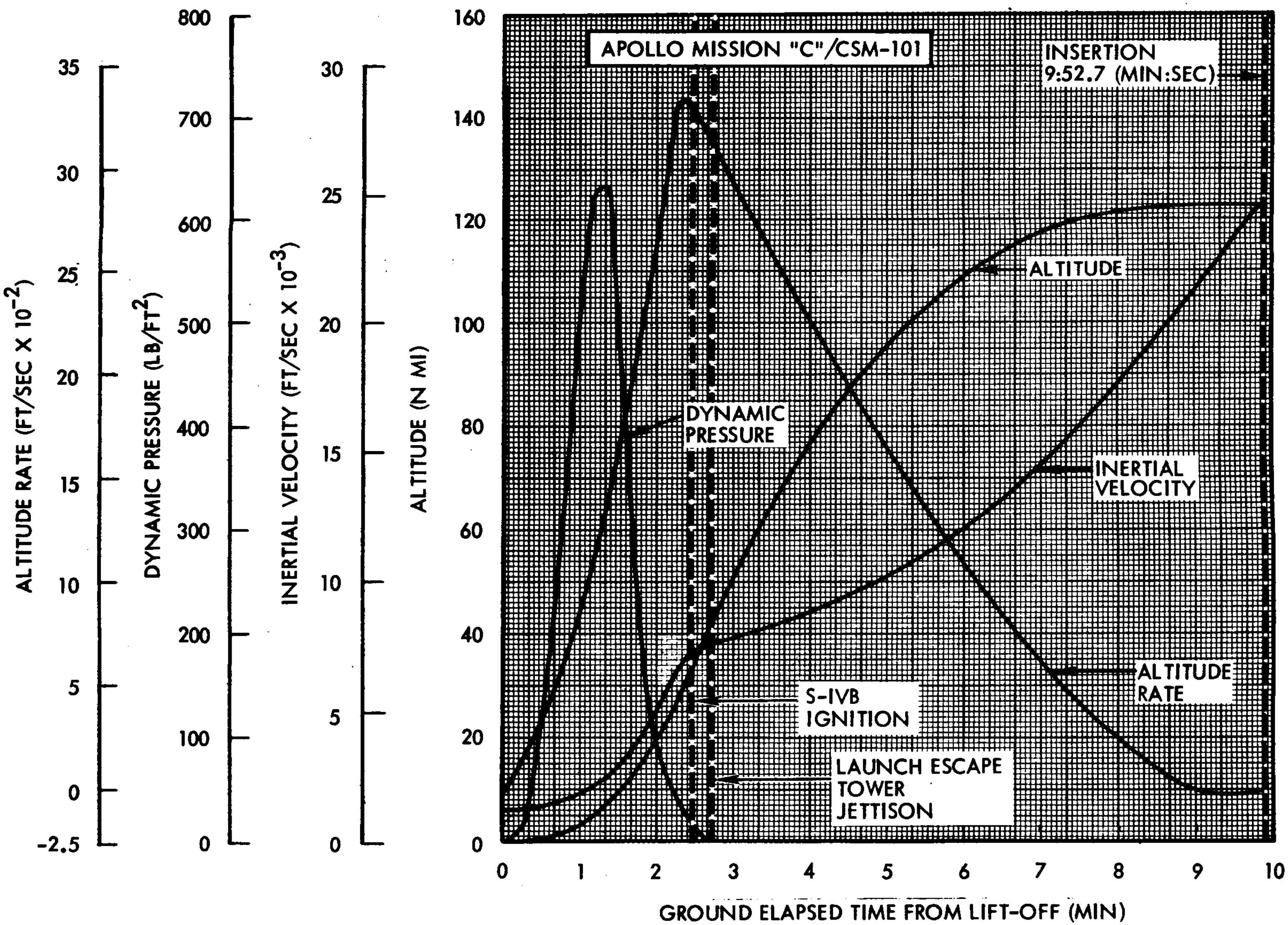



Figure 2. Nominal Launch Trajectory Altitude, Inertial Velocity, Dynamic Pressure, and Altitude Rate versus Ground Elapsed Time from Lift-off

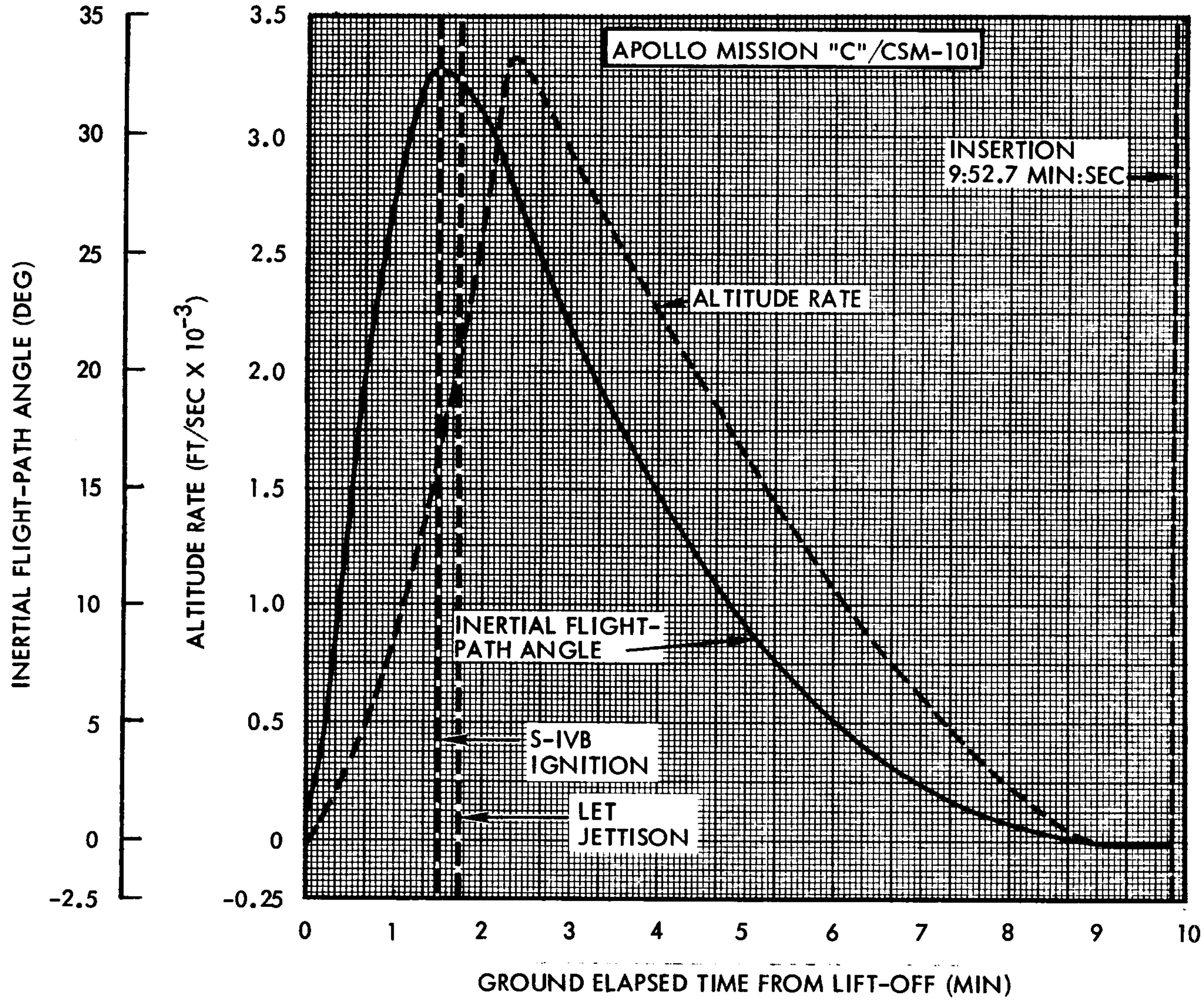



Figure 3. Nominal Launch Trajectory Altitude Rate and Inertial Flight-path Angle versus Ground Elapsed Time from Lift-off

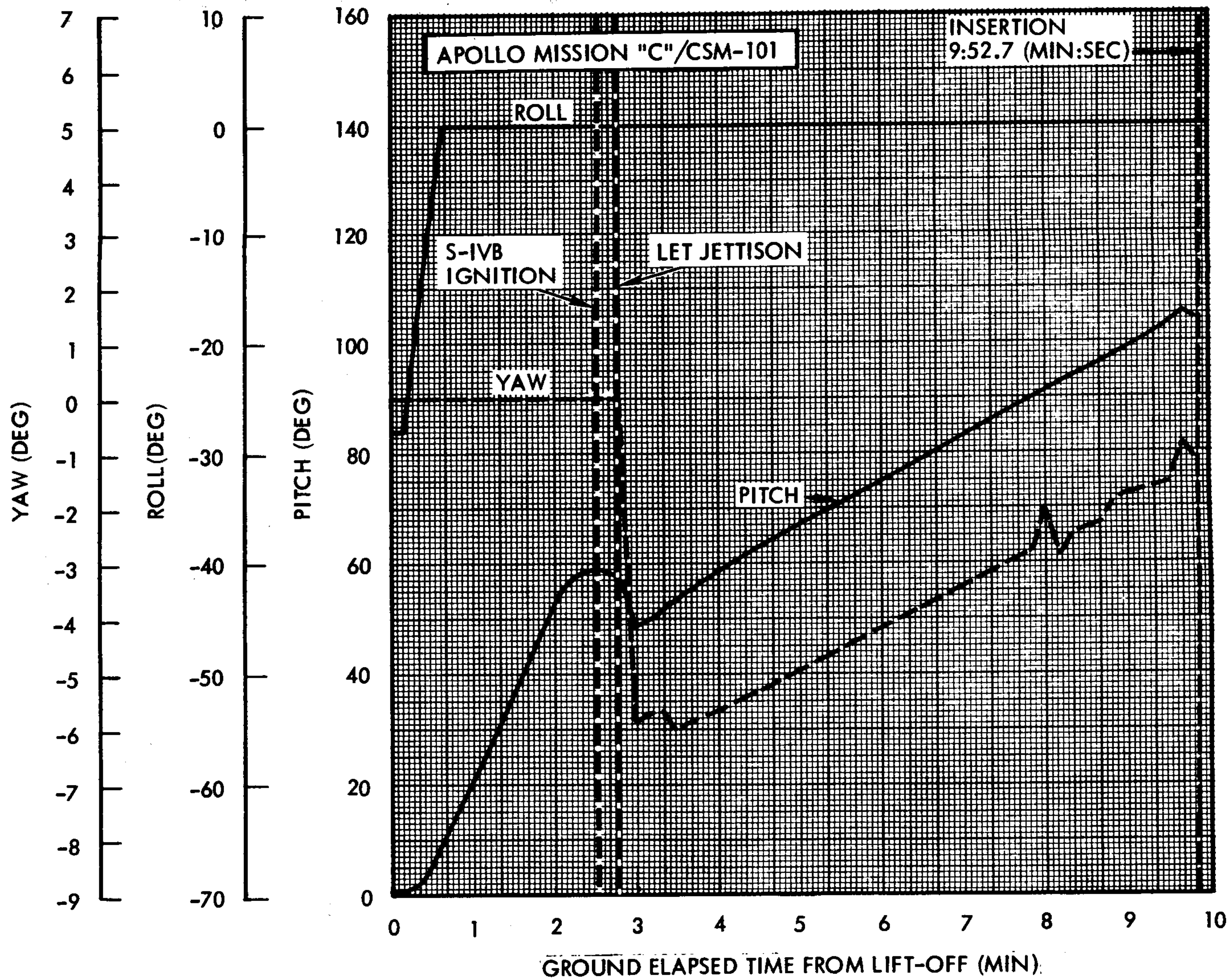



Figure 4. Spacecraft Pitch, Roll, and Yaw Attitude versus Ground Elapsed Time from Lift-off

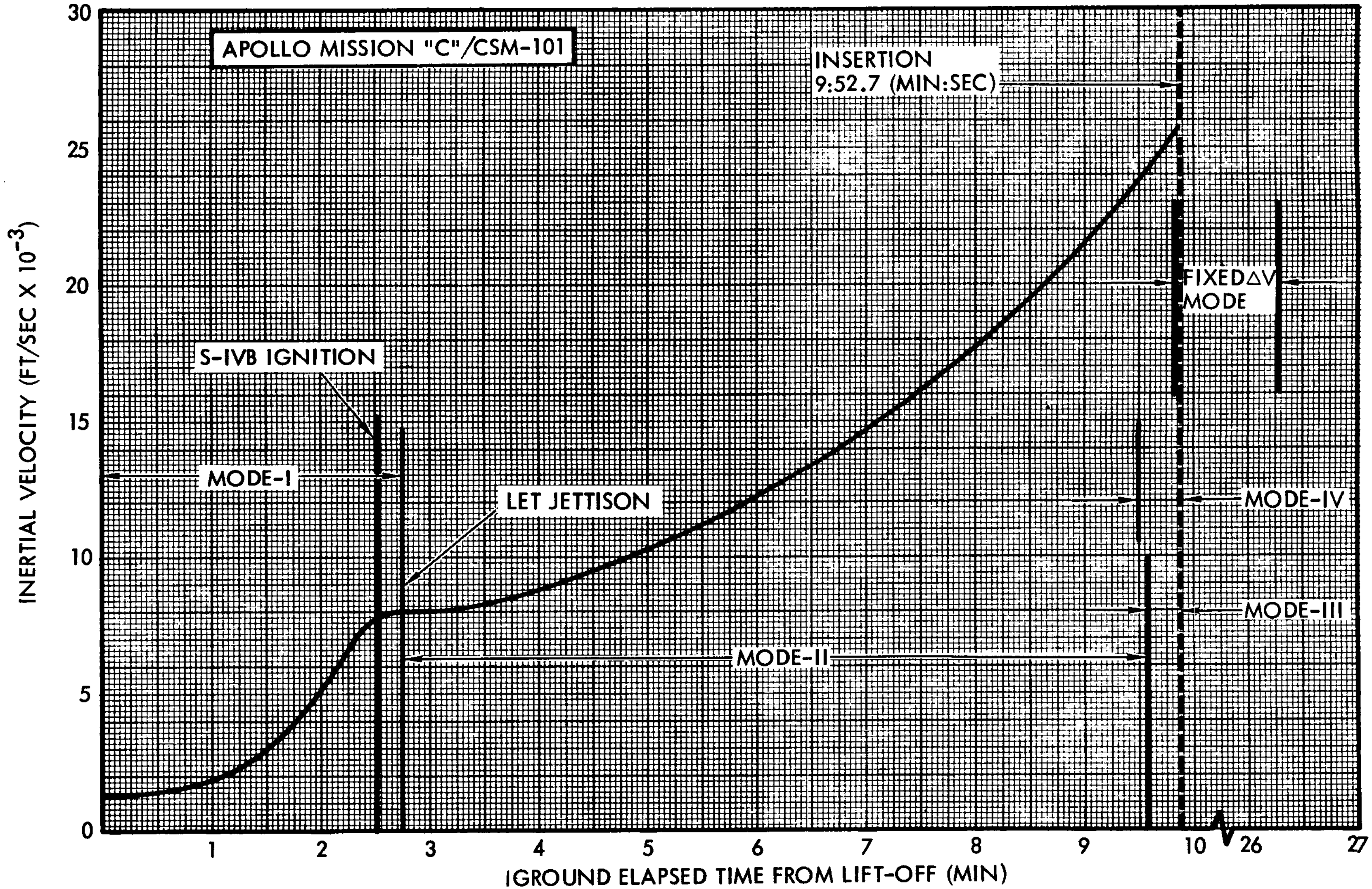



Figure 5. Nominal Launch Abort Regions and Inertial Velocity versus Ground Elapsed Time from Lift-off

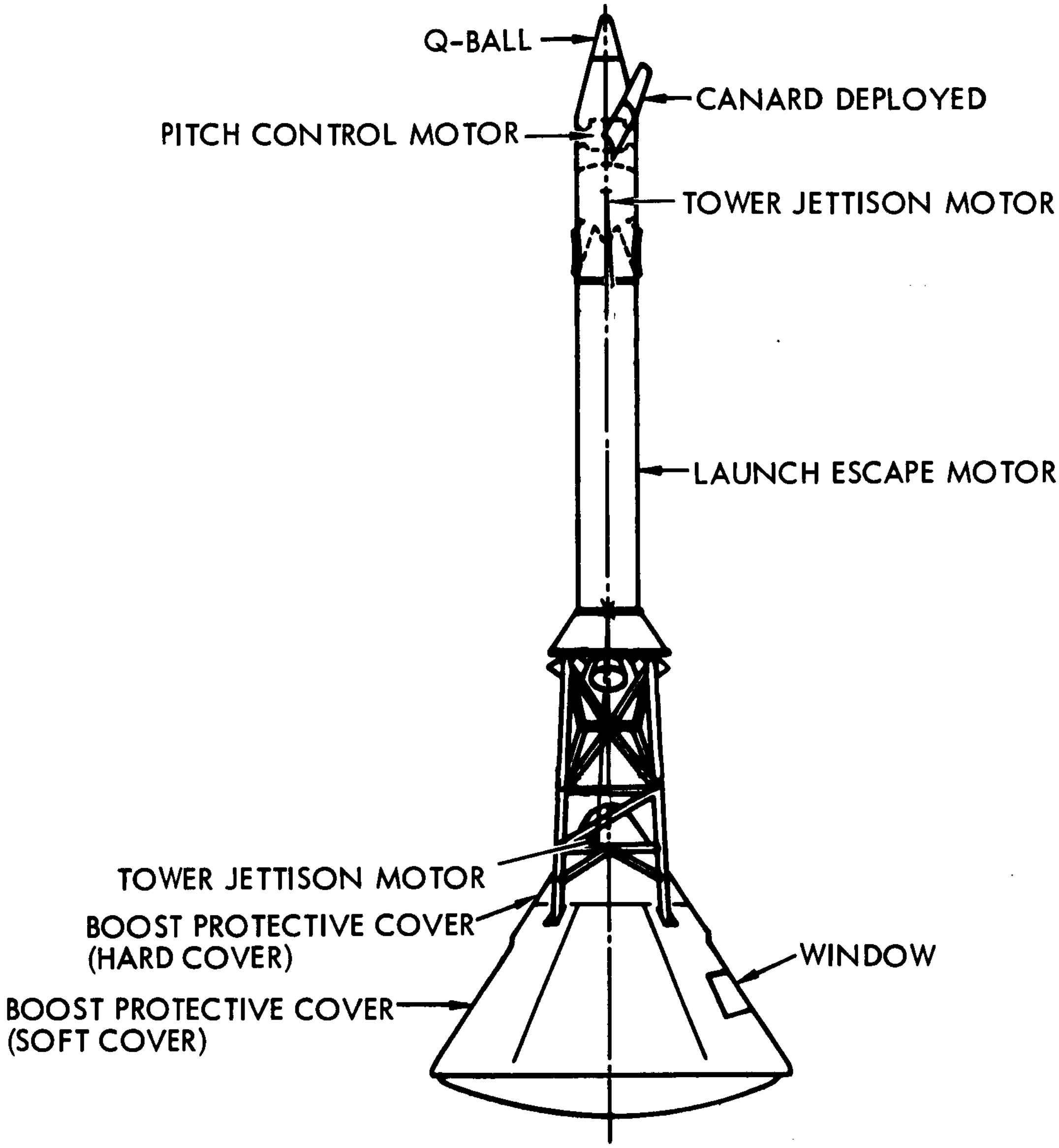



Figure 6. Launch Escape Vehicle Configuration for Mode I Aborts

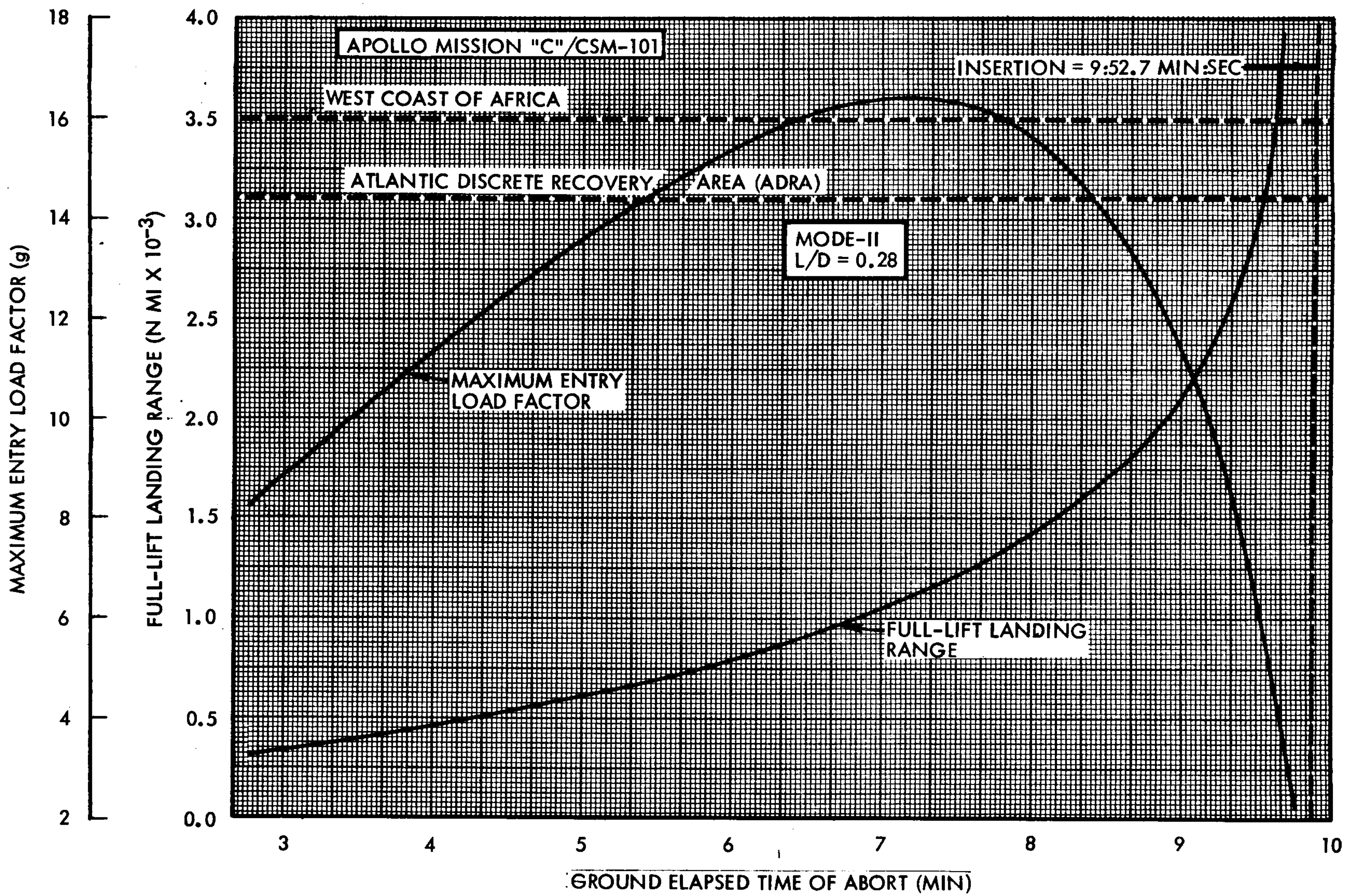



Figure 7. Full-lift Landing Range and Maximum Entry Load Factor Following Nominal Mode II Aborts versus Ground Elapsed Time of Abort

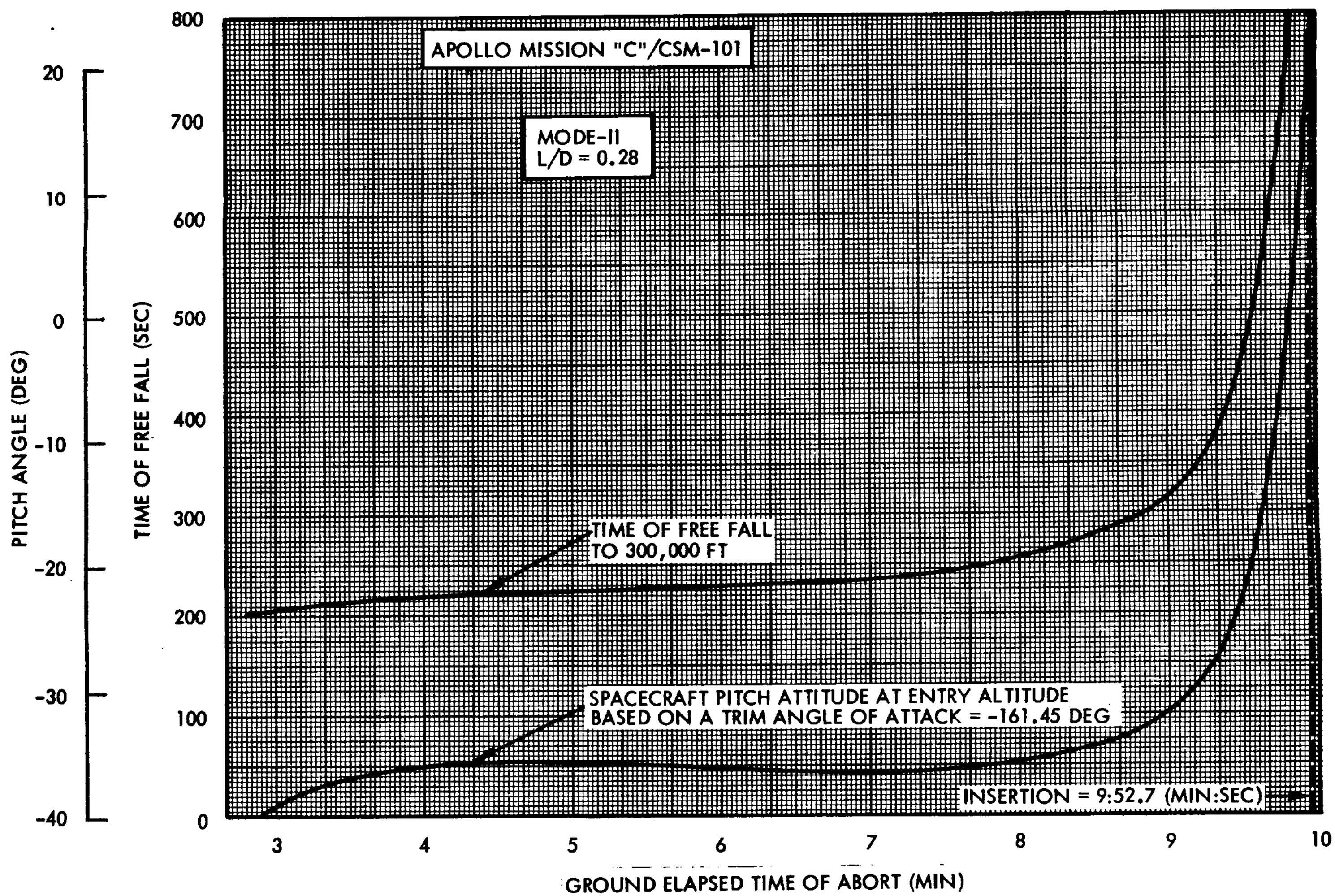



Figure 8. Time of Free Fall to 300,000 Feet and Spacecraft Pitch Attitude at Entry Interface Altitude Following Nominal Mode II Aborts versus Ground Elapsed Time of Abort

Note: Pitch Attitudes Referenced to Figure 1.

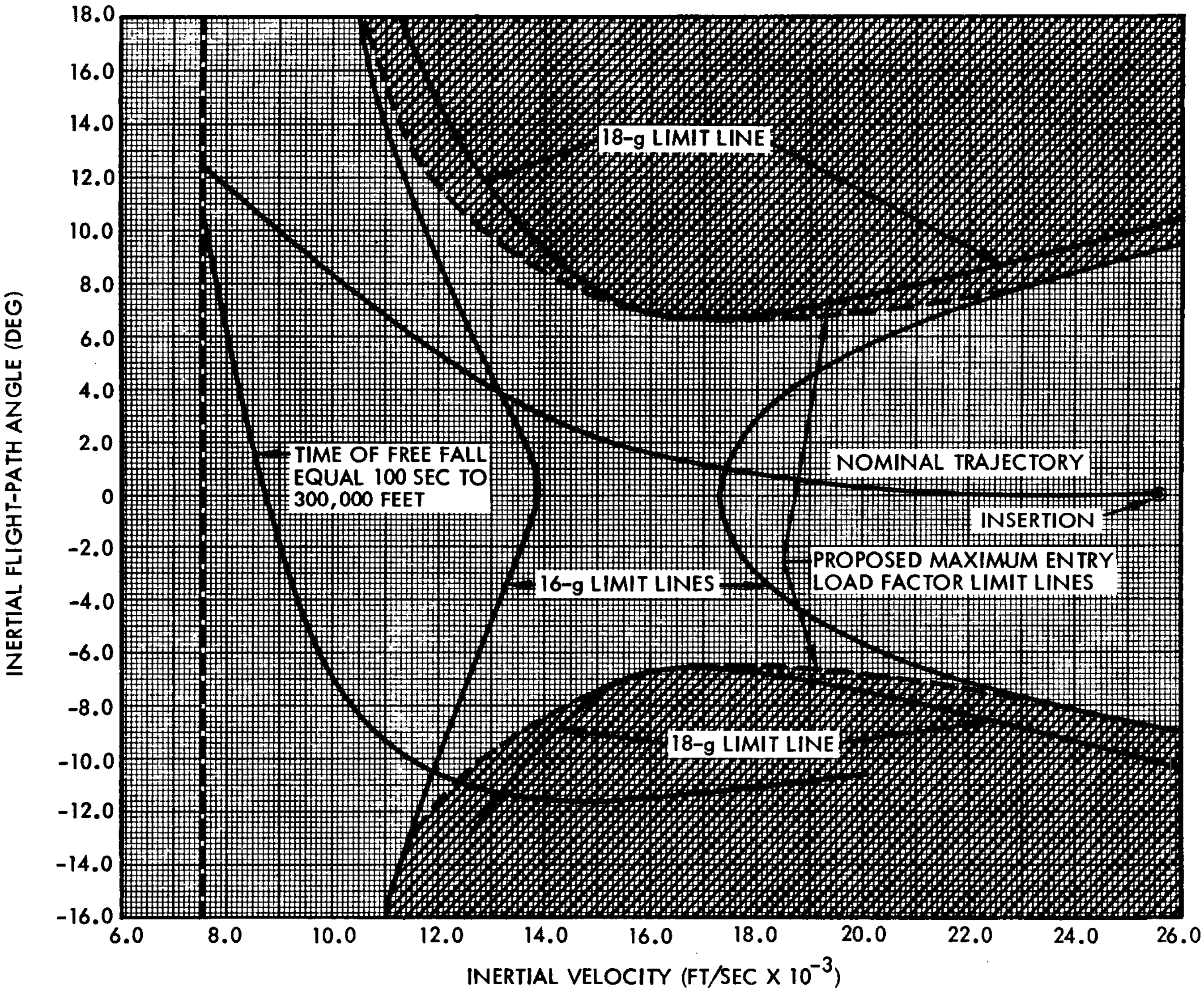



Figure 9. Maximum Entry Load Factor Limit Lines and Time-of-free-fall Limit Line

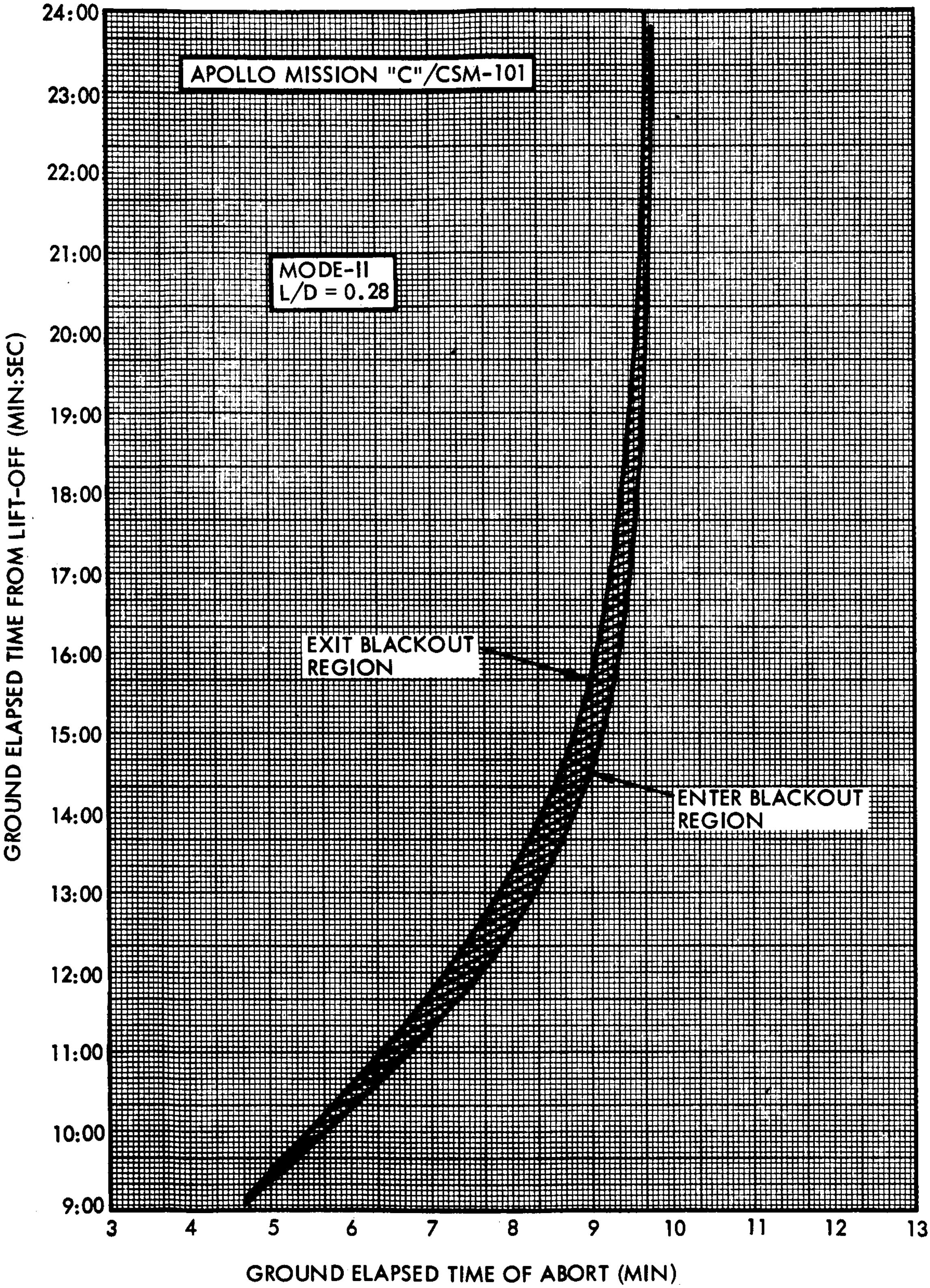



Figure 10. Ground Elapsed Time from Lift-off at the Entry and Exit from the VHF Communication Blackout Region Following Nominal Mode II Aborts versus Ground Elapsed Time of Abort

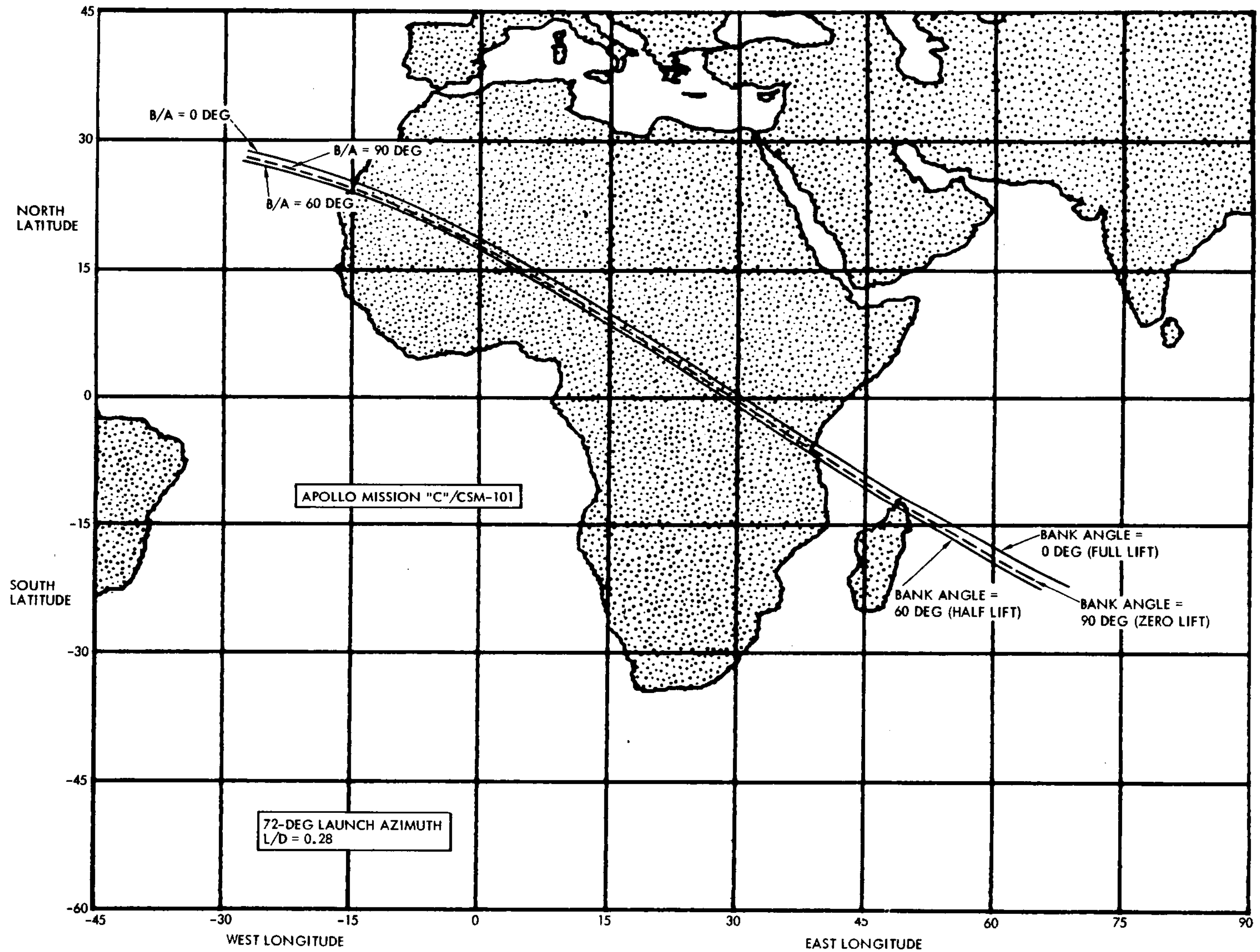



Figure 11. Latitude and Longitude Traces of Spacecraft Impact Points for Full-lift (B/A=0 degree), Half-lift (B/A=60 degrees), and Zero-lift (B/A=90 degrees) Entries Following Nominal Mode II Type Aborts

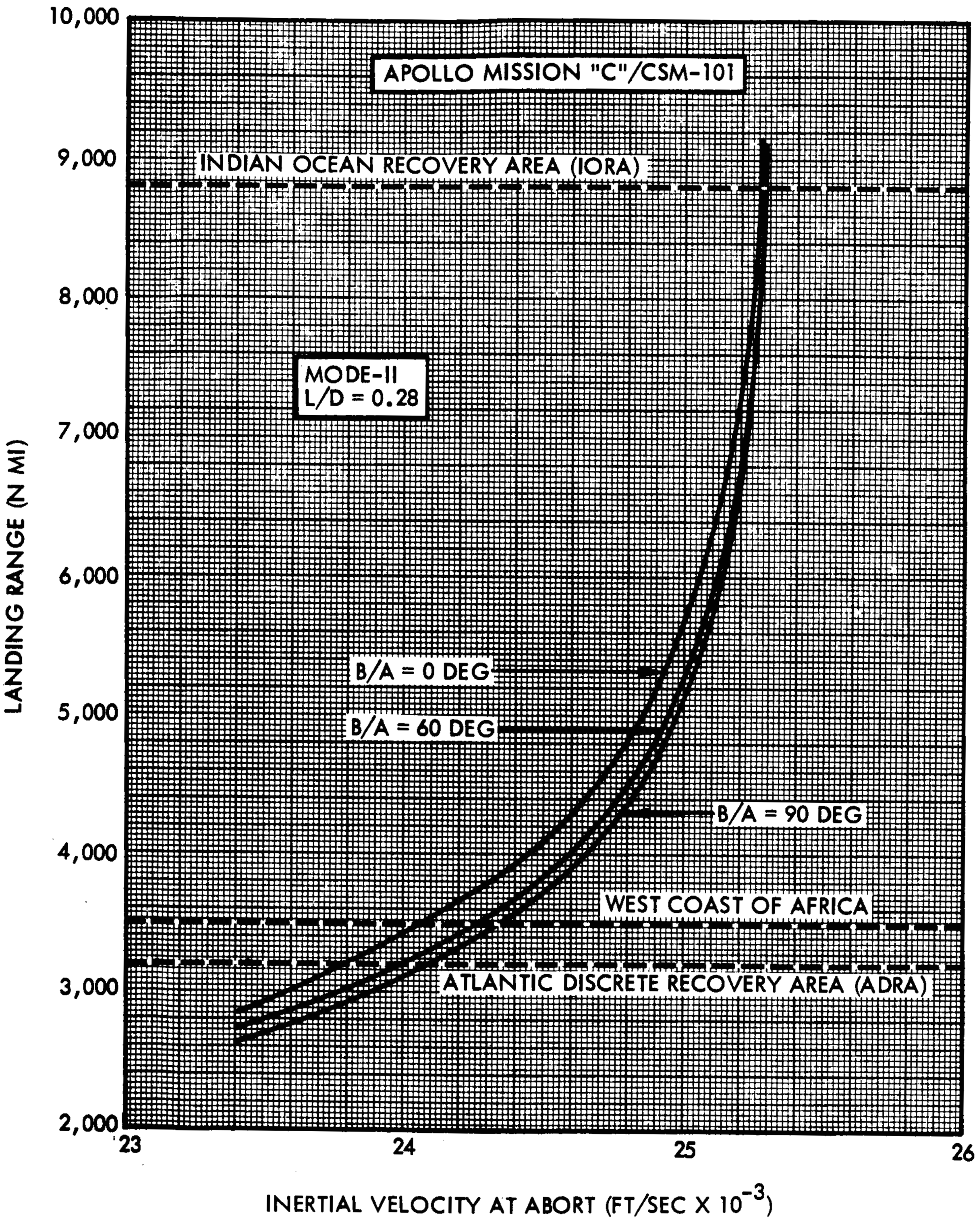
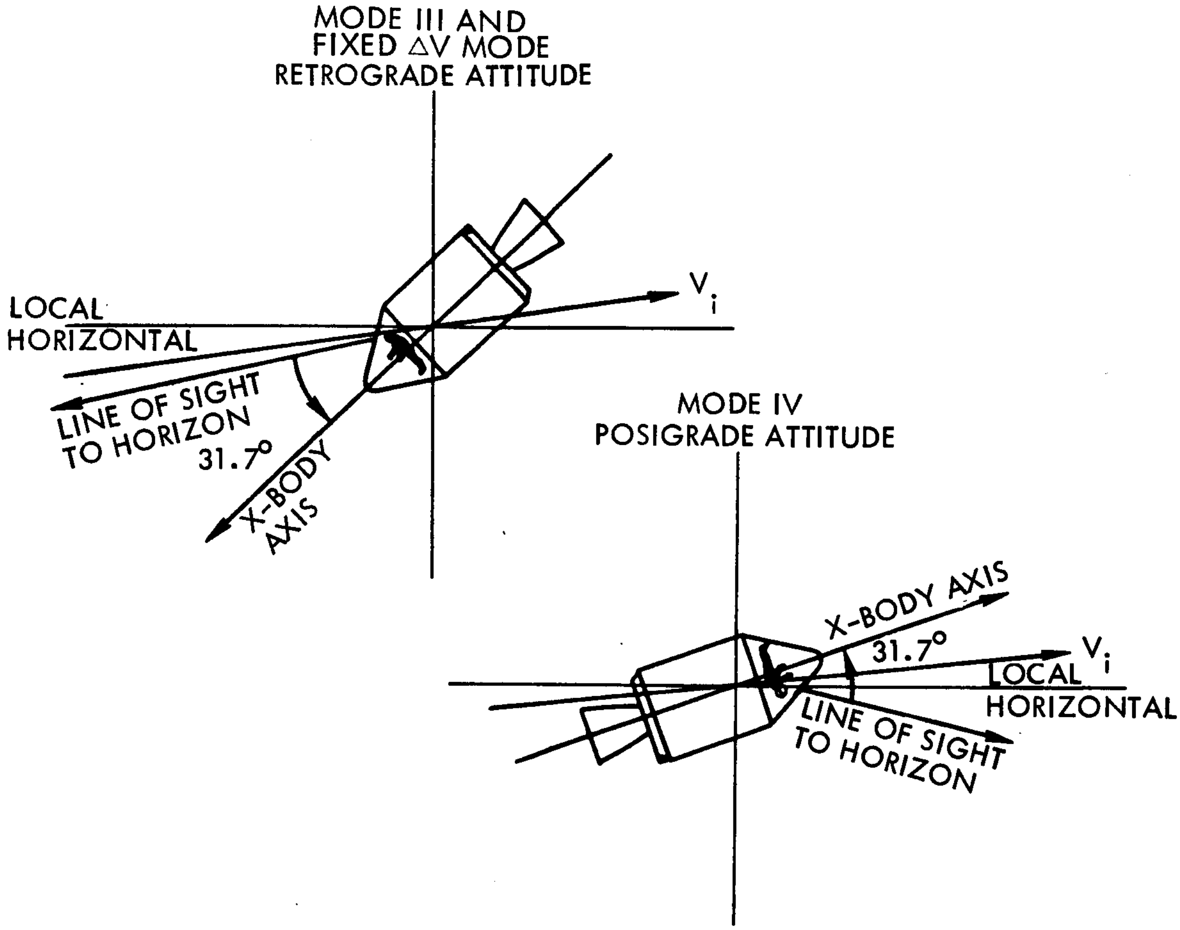



Figure 12. Landing Range versus Inertial Velocity for Full-lift (B/A = 0 degree), Half-lift (B/A = 60 degrees), and Zero-lift (B/A = 90 degrees) Entries Following Nominal Mode II Aborts




NOTE: SPS RETROGRADE AND POSIGRADE MANEUVERS WILL NORMALLY BE INITIATED AT BOOSTER CUTOFF PLUS 125 SECONDS FOR ALL LAUNCH ABORTS REQUIRING SPS MANEUVERS. THE ATTITUDES PRESENTED ABOVE ARE THE REQUIRED SPACECRAFT ORIENTATIONS AT SPS IGNITION. THE SUBSEQUENT ABORT MANEUVER WILL BE CONTROLLED VIA THE SCS; WHEREBY, THE SCS SHALL MAINTAIN THE INERTIAL ATTITUDE WHICH CORRESPONDS TO THE RELATIVE ATTITUDE AT SPS IGNITION.

Figure 13. Spacecraft Orientations at SPS Ignition for Mode III, Fixed ΔV, and Mode IV Launch Aborts

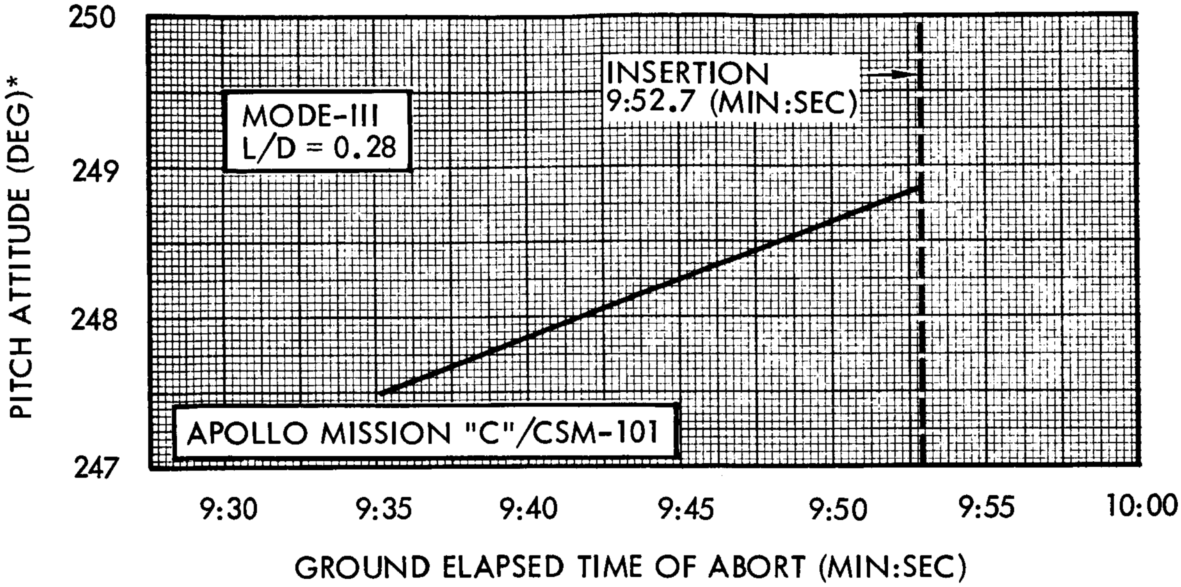



Figure 14. Spacecraft Pitch Attitude at SPS Ignition for Nominal Mode III Aborts versus Ground Elapsed Time of Abort

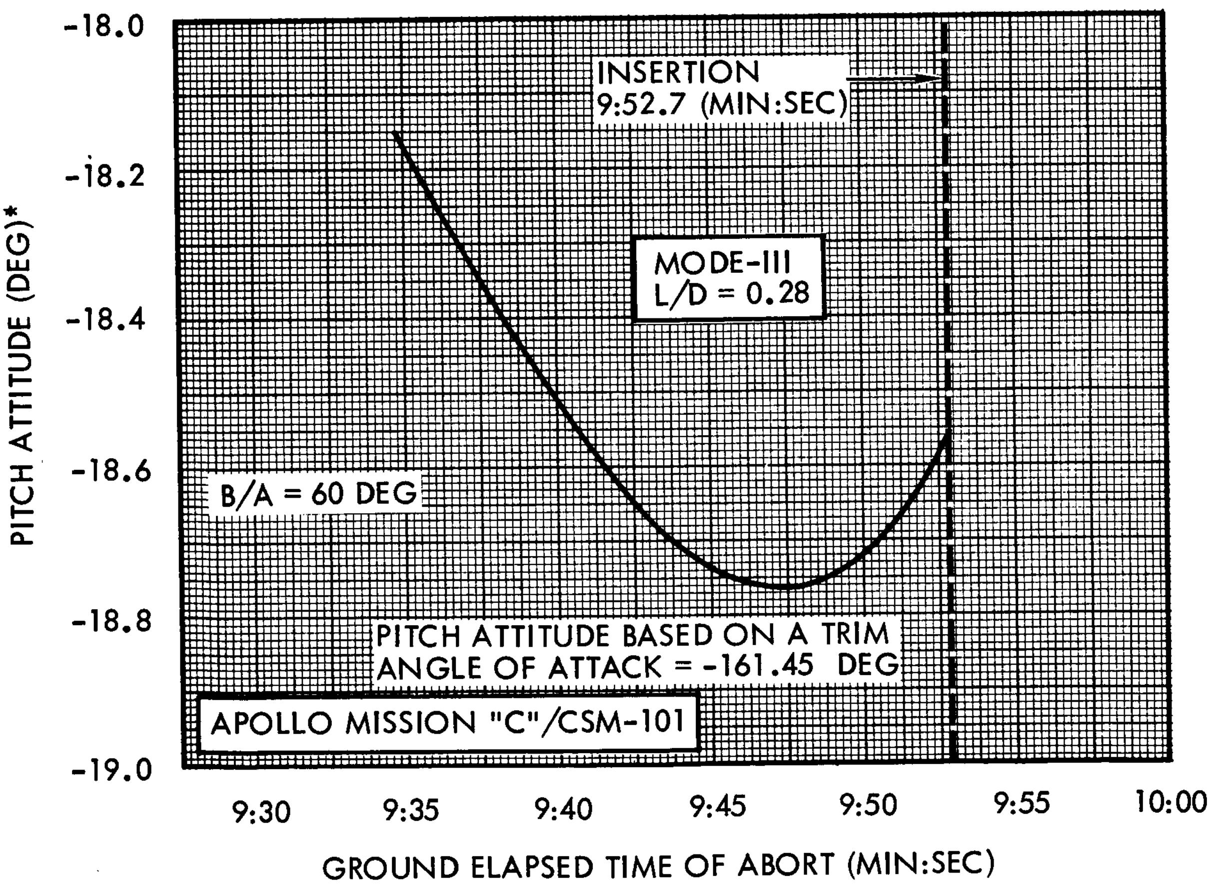



Figure 15. Spacecraft Pitch Attitude at Entry Interface Altitude (300,000 Feet) Following Nominal Mode III Aborts versus Ground Elapsed Time of Abort



*ATTITUDES REFERENCED TO FIGURE 1.

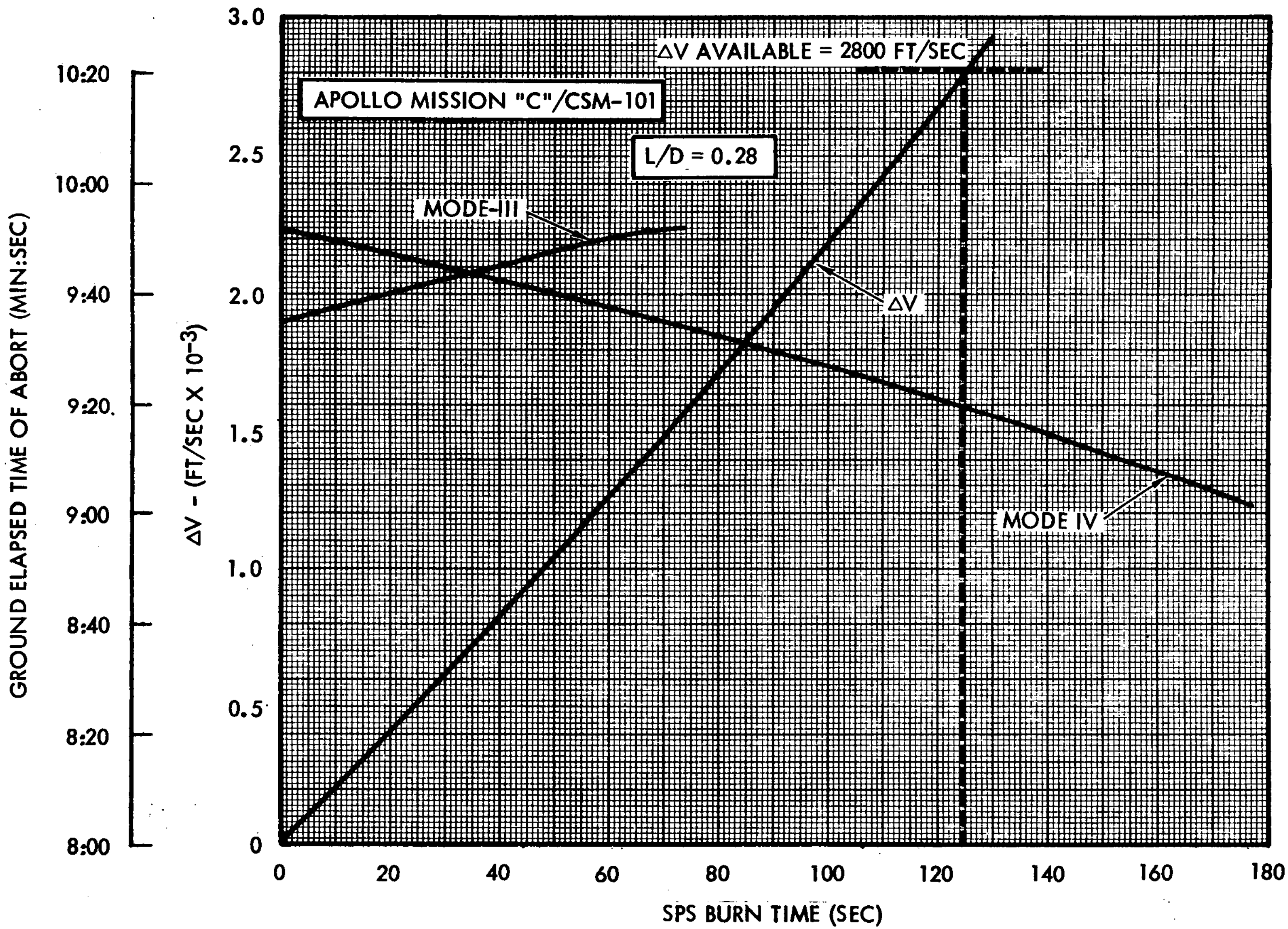



Figure 16. Ground Elapsed Time of Abort and SPS $\Delta V$ Expended versus SPS Burn Time for Nominal Mode III and Mode IV Aborts

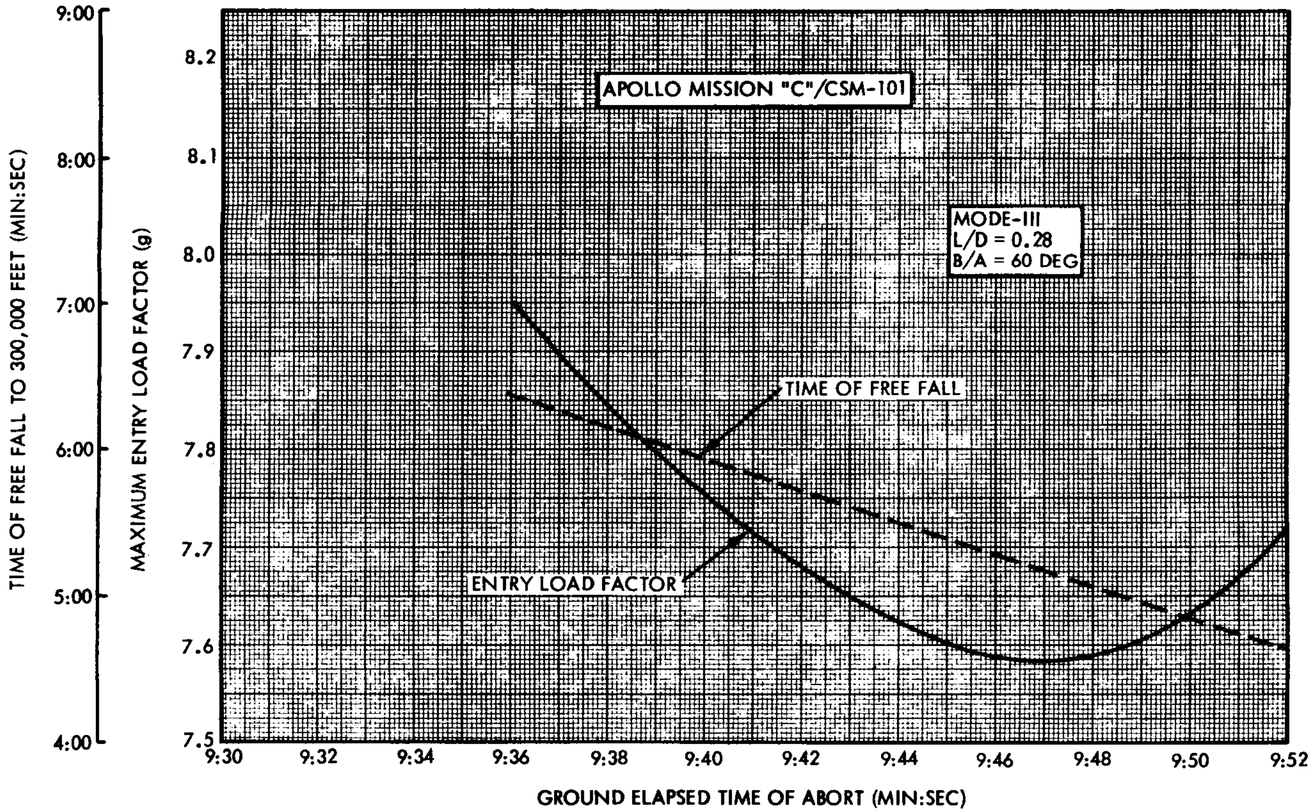



Figure 17. Maximum Entry Load Factor and Time of Free Fall to Entry Interface Altitude Following Nominal Mode III Aborts versus Ground Elapsed Time of Abort

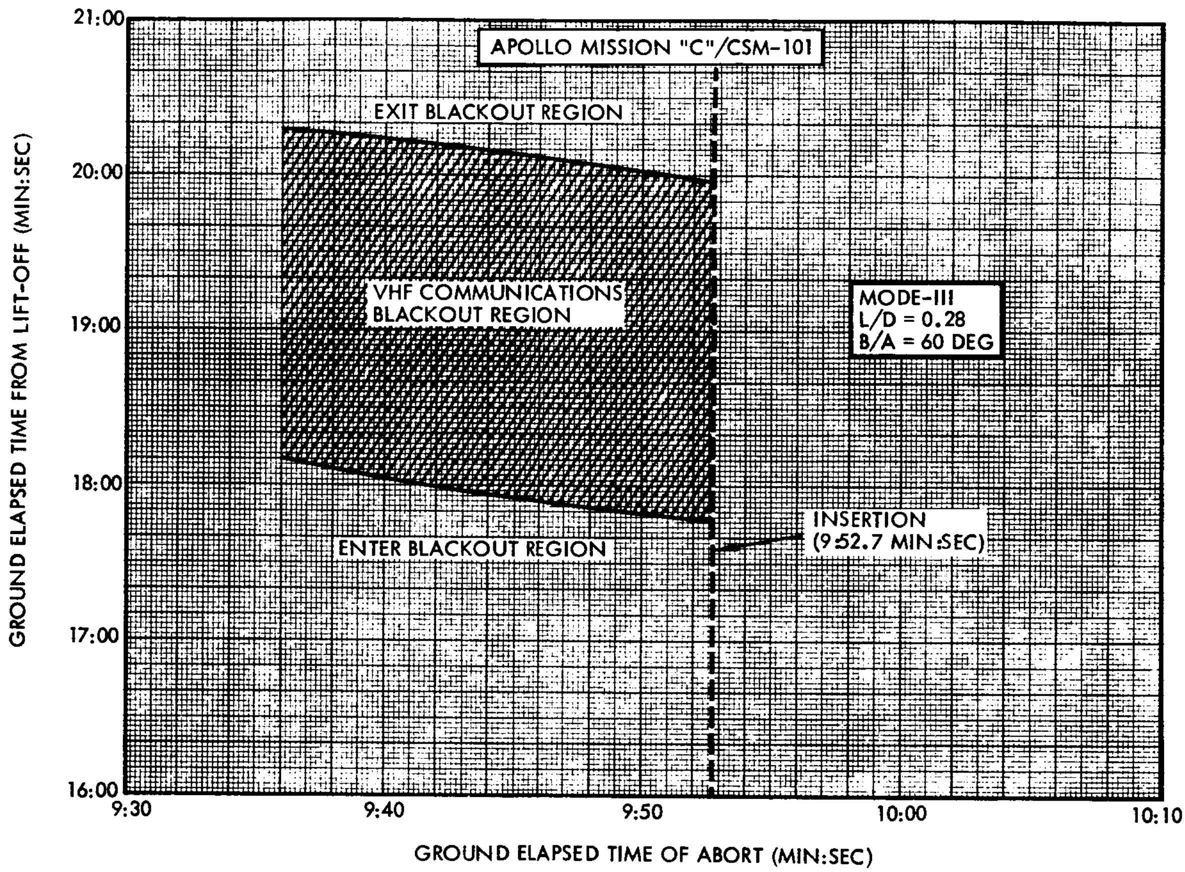
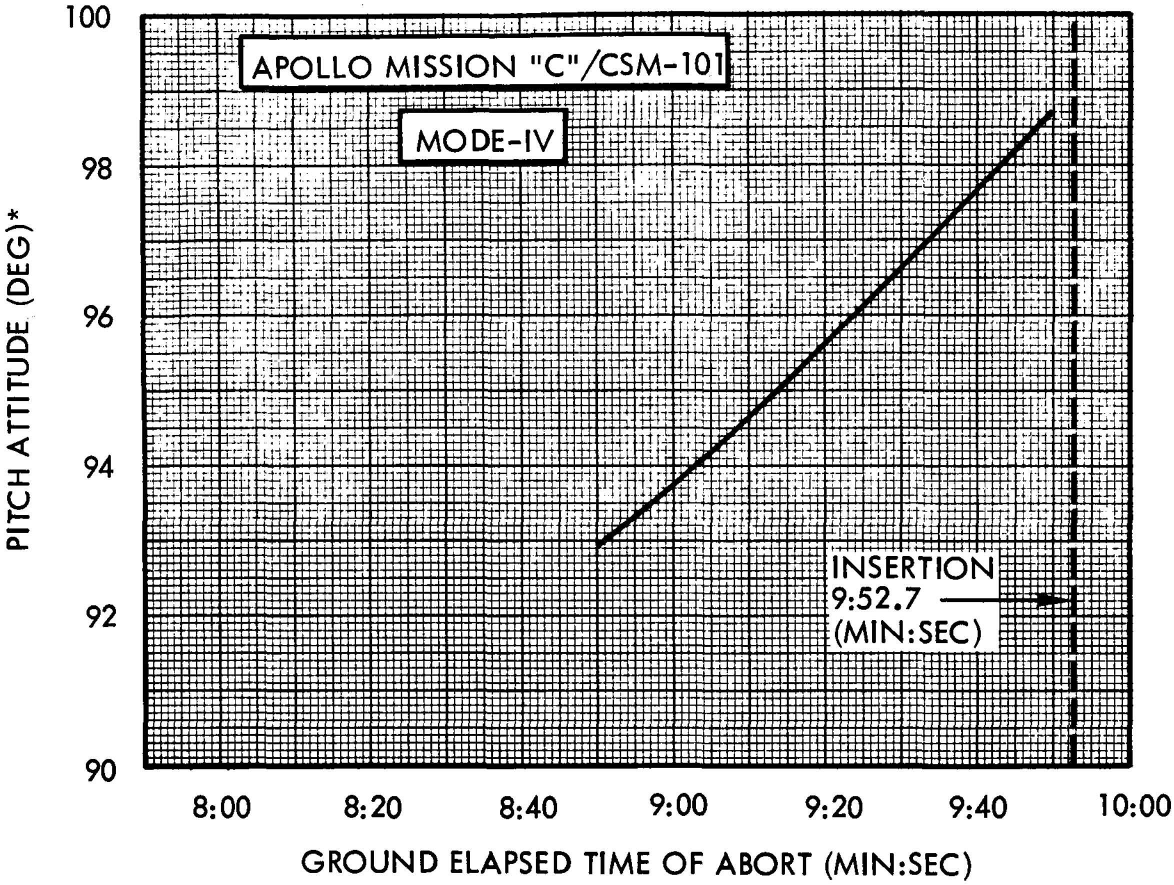



Figure 18. Ground Elapsed Time from Lift-off to Enter and Exit from the VHF Communication Blackout Region Following Nominal Mode III Aborts versus Ground Elapsed Time of Abort




*ATTITUDES REFERENCED TO FIGURE 1.

Figure 19. Spacecraft Pitch Attitude at SPS Ignition for Nominal Mode IV Aborts versus Ground Elapsed Time of Abort

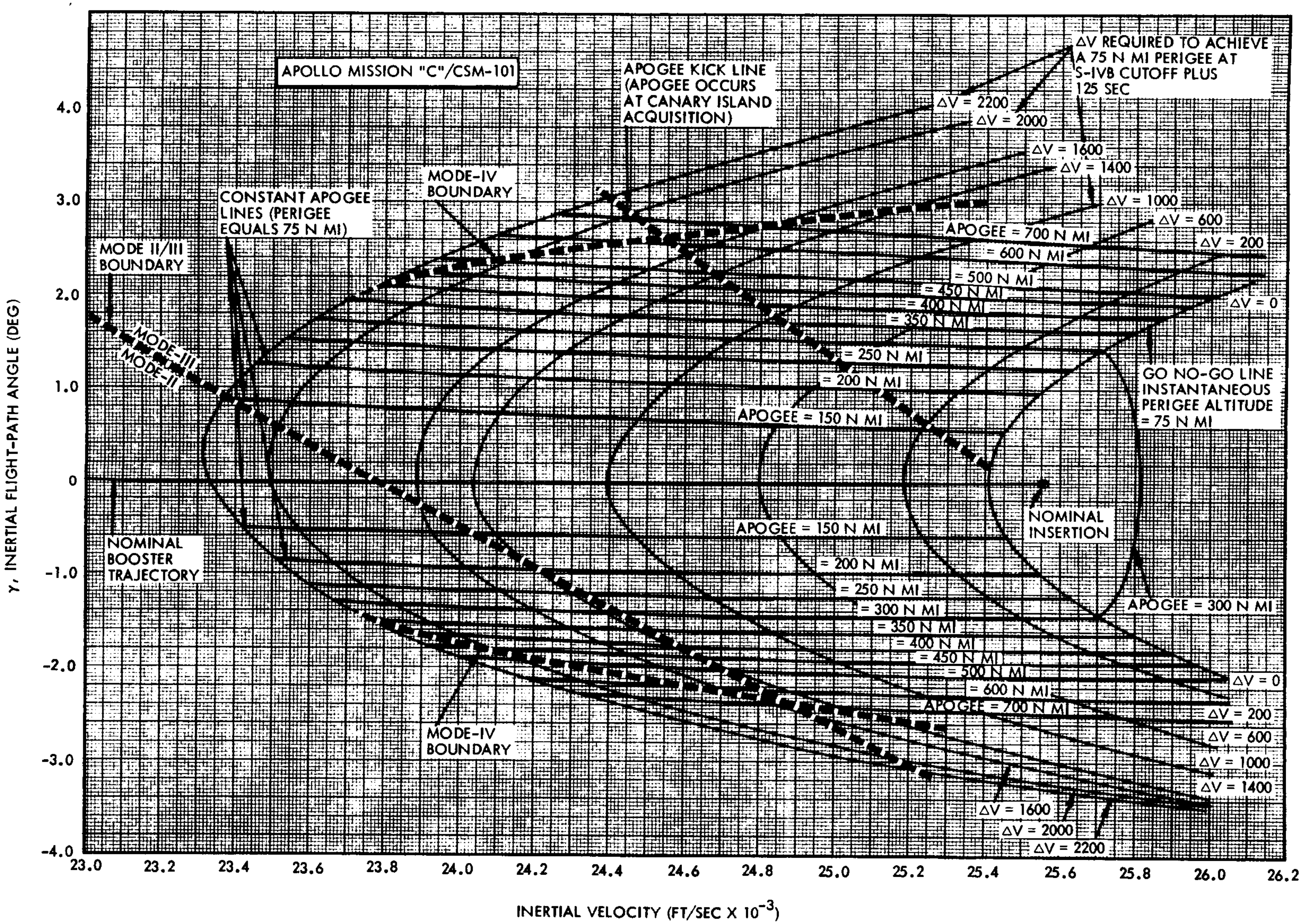



Figure 20. SPS Constant $\Delta V$ Lines, Constant Apogee Altitude Lines, and the Contingency Orbit Insertion Region

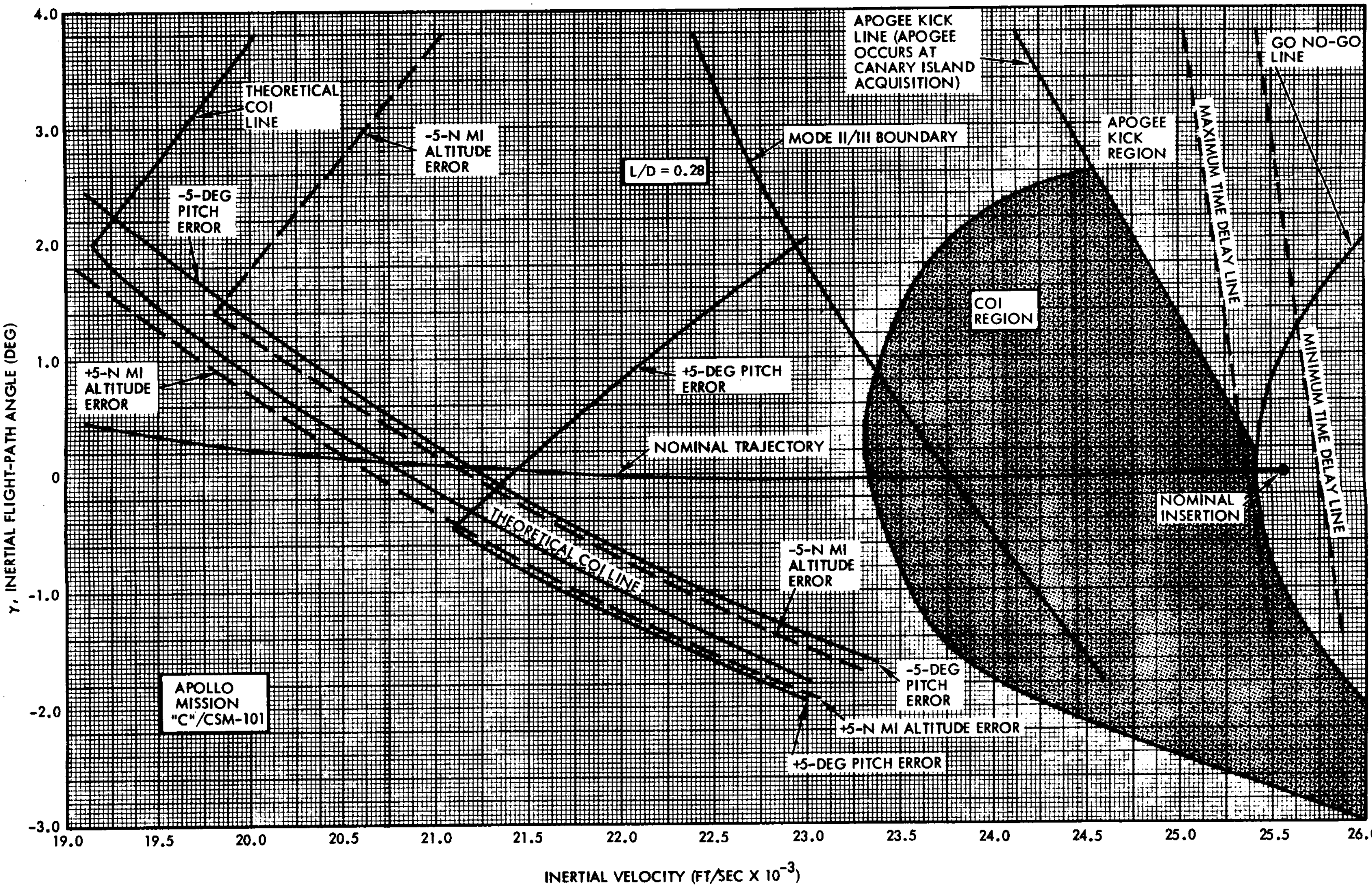



Figure 21. Pictorial View of the Near Insertion Regime Showing the Various Launch Abort Regions on an Inertial Velocity - Inertial Flight-path Angle Plot

## REFERENCES


1. "Trim Aerodynamics for the Apollo Block II Command Module," TRW IOC 3423.5-187, 1 November 1967.

2. "AS-205 Typical Trajectory Profile to the 120 by 150 Nautical Mile Elliptic Orbit," MSFC Memorandum R-AERO-FMR-199-67, 25 August 1967.

3. "Launch Abort Trajectory Data for Determining the Abort Load Limit for the AS-205/101 Mission," MSC Internal Note 67-FM-178, 17 November 1967.

4. "Task Agreement for Spacecraft Operational Abort Analysis and Documentation for Launch and Orbit Phases of Manned Apollo Missions," Task MSC/TRW A-162, 2 January 1968.

5. "Blackout Curve for Apollo Spacecraft Reentries," MSC Memorandum 66-FM31-54, 1 June 1966.