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DESIGN ANALYSIS FOR THE MALFUNCTION DETECTION SYSTEM SATURN S-IVB-501 STAGE

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PREFACE

The purpose of this report is to present overall stage/vehicle failure modes and other technical data applicable to Saturn S-IVB-501 which can be used for the design of a Malfunction Detection System (MDS) or can be used to assess the effectiveness of an existing MDS or Emergency Detection System. This document is one of a series of reports prepared in conjunction with the Reliability Engineering Model for each S-IVB Stage. The data in this document revises that which was previously presented in the preliminary edition of the Design Analysis for the Malfunction Detection System, Saturn S-IVB-501 Stage, dated April, 1966. This report includes the addition of information which was not previously issued and is now available.

This document was prepared by the Reliability Analysis Section of Saturn Mechanics and Reliability Department, Saturn Development Engineering, of the Missile and Space System Division, Douglas Aircraft Company, Inc. It was prepared for the National Aeronautics and Space Administration under Contract No. NAS7-101, Change Order 388.

ABSTRACT

This final Design Analysis for the Saturn S-IVB-501 Stage Malfunction Detection System, Report SM-53156, consists of technical analysis and data required for the design of a malfunction detection system. The design analysis is composed of three interdependent sections: 1) Failure Effect Analysis Data; 2) Malfunction Detection System Summary; and 3) Malfunction Detection System Single Thread Cause/Effect Analysis. The first section is designed to present a detailed description of stage overall failure modes, the contributing systems, the various time constraints involved, the parameters to be monitored, and their respective failure mode consequences. This section contains recommendations for the detection of critical stage malfunctions during flight. It supplies supporting data required for determining type, location, redline values, and response time of sensors, from liftoff to, and including, the end of the period during which the stage must provide a stable platform. The second section both summarizes the failure effect data and presents information necessary to determine telemetry signals best suited to transmit parameter information. It also presents the time dependency of failure occurrence and effect, criticality of failure type, and decisive damage resulting from failure. The third section traces each failure type from the item level, through the overall failure mode level, to the stage loss level.

DESCRIPTORS

Saturn S-IVB-501 Stage
Failure Effect Analysis
Single Thread Diagram
Failure Mode Criticality
Malfunction Detection System Analysis

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INTRODUCTION

Malfunction Detection System

The requirements for a Malfunction Detection System (MDS) dictate that it be designed to sense trouble and, where practical, provide the indication that permits decision. An MDS is also required to identify the most probable cause of a given stage malfunction sufficiently early to permit, where possible, the flight or ground crew to select an alternate mission, or to initiate corrective action that would preclude the necessity for abort and possible destruction of the vehicle. An MDS may also include automatic reaction capabilities when time constraints require rapid correction. During the boost phase, the S-IVB MDS may operate in parallel with, or serve as a backup to the Emergency Detection System (EDS).

Design Analysis for the Malfunction Detection System

The design analysis presented in this document provides detailed information on stage/vehicle failure modes and other technical data which can be used for the design of an MDS or to evaluate the effectiveness of an existing EDS. This information is arranged in three parts or sections. Each respective section is discussed in the following three paragraphs.

The Failure Effects Analysis Data section, whose format is shown in Figure A, presents a detailed description of the overall failure mode, contributing systems, the failure mode consequence, various time constraints involved, and the parameters to be monitored. Also presented in this section are normal parameter operating levels, maximum and minimum parameter levels expected during normal flight, and a listing of the sensors that monitor the various parameters. The overall failure mode criticality, along with EDS information and recommendations and pertinent discussions are presented, where possible.

The MDS Summary section, using the format shown in Figure B, summarizes the failure effect analysis data and presents information necessary to determine the telemetry signals best suited to transmit parameter information. Where possible, launch vehicle (L/V) limits, launch escape system (LES) limits, and abort modes are also presented.

The MDS Single Thread Cause/Effect Analysis section, using the format as shown in Figure C, traces each failure type from the item level, through the overall failure mode level, to the stage loss level. The criticalities for the various failure types of each flight critical item, along with the time phases during which the failure types can contribute to the overall failure modes, are also presented. In this manner the analysis points out all the failure modes that the MDS could be designed to detect, the items that can cause the failure modes, the time periods during which the failure modes can occur, and the probability of stage loss resulting from the occurrence of a given failure mode.

General Information

The failure effect analysis of the flight critical items is taken from information contained in the Reliability Engineering Model Douglas Report SM-47406. The analysis of the J-2 Engine is taken from NASA Internal Note IN-P & VE-V-65-7 and from the Rocketdyne J-2 Engine Manual, and is considered at the engine subsystem level. Sensor and parameter information is derived from various analytical studies which have been performed in Douglas Saturn Development Engineering. The Propulsion System Configuration & Instrumentation schematic, as shown in Figure D, is provided as an aid in determining the location and position within the configuration of various propulsion system sensors.

FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: General description of the overall failure mode which may result in stage or vehicle loss with identification of specific contributing failure modes/types.

2. STAGE: Stage within which all components are located which could cause overall failure mode.

3. SYSTEM: System(s) which contain components within stage that could cause overall failure mode. By name and number as appearing in Reliability Engineering Model.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Total time span during which failure of each component, with respect to described failure mode, may cause stage or vehicle loss.

5. FAILURE MODE CONSEQUENCE: Failure effect which is most closely related to stage or vehicle loss.

6. TIME DEPENDENCY OF FAILURE: All time dependent relationships between failure and failure effect are described. Where necessary, critical parameters, those parameters most closely associated with failure effect, are plotted versus flight time and presented.

7. OVERALL FAILURE MODE CRITICALITY: Overall failure mode criticality as determined from failure effect analysis and failure type summary.

8. MSFC RECOMMENDATION FOR EDS MONITOR: Made only on approval of MSFC. Such approval obtained by submission of formal recommendation to MSFC and approved for entry by R-P&VE-VO.

9. MSC RECOMMENDATION FOR EDS MONITOR: Provided to DAC by MSFC.

10. MEASURING PARAMETER: Reflects that parameter most directly associated with overall failure mode.

11. SENSOR LOCATION: Lists all sensors associated with measurement of measuring parameter. Consists of Measurement Number as listed in Instrumentation Program and Components List for specific stage.

12. EDS TIME DELAY: Reaction time allowable between failure occurrence and necessary safety and/or corrective action. For purpose of determining type and location of sensor and parameter to be monitored.

13. NORMAL PARAMETER OPERATING LEVEL: Normal design operation level of all critical parameters.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: All normal deviations of critical parameters, within specified tolerances, which may occur during normal flight.

15. EDS MONITOR SETTING: Furnished by R-P&VE-VO in accordance with MSFC-MSC requirements for providing flight crew with optimum information.

16. FAILURE EFFECT ANALYSIS: Complete description of all possible deviations from normal operating conditions which may occur as the result of sustaining critical failure mode. Where applicable, plots of critical parameters versus time are used.

17. FLIGHT HISTORY: Complete description for all critical parameters under normal operating conditions, i.e. no failure. Where applicable, plots of critical parameters versus time are used.

18. DISCUSSION: Data, remarks, and discussion pertinent to description of failure and effects, display of failure detection data for control purposes, human factors, etc., not described elsewhere.

19. INFORMATION DEFICIENCY: Information required not available due to lack of test data, incomplete analysis, lack of design definition, etc.

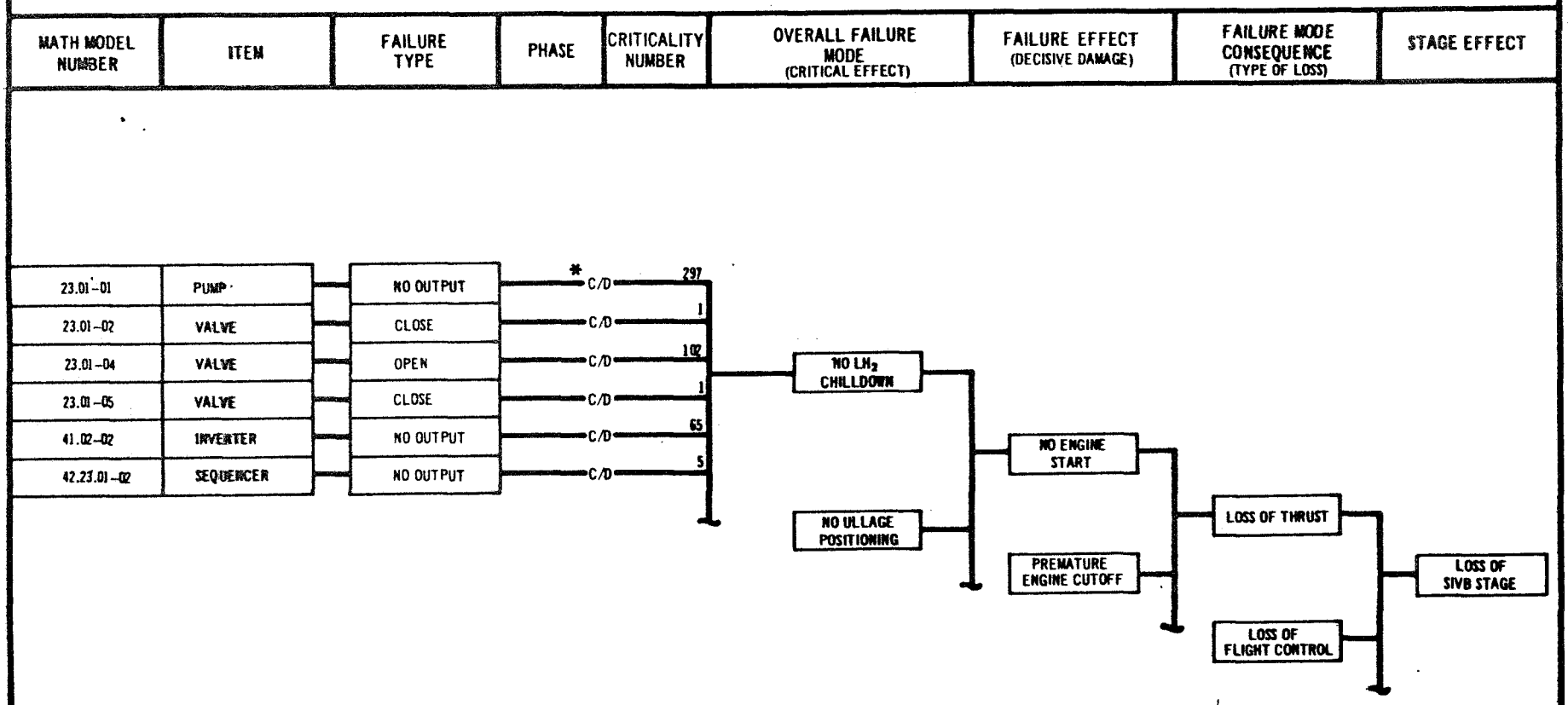
Figure A.

MALFUNCTION DETECTION SYSTEM SUMMARY

REMARKS		Remarks - Pertinent remarks and information not tabulated elsewhere on the MDS Summary Sheet is tabulated in the remarks column.
SIGNAL		Signal - The characteristics of the sensor which is chosen for use in the malfunction system design is supplied to DAC by MSFC; however, DAC's recommendation is shown prior to decision by the responsible design group.
ABORT MODE		Abort Mode - The final abort mode entry is supplied to DAC by MSFC; however, DAC's recommendation is shown prior to a joint decision by MSFC and MSC.
TIME DEPENDENCY OF FAILURE	FLIGHT TIME	Flight Time - The time during which the failure mode described in the failure column is critical (could cause stage, vehicle, and/or mission loss) is listed as shown on the Failure Effect Analysis Data Form.
	LES LIMIT	LES Limit - The amount of time available to obtain a satisfactory separation from the vehicle with the launch escape system is listed (The LES limit is supplied by MSFC/MSC since it requires detailed technical information with repect to LES characteristics).
	L/V LIMIT	LV Limit - The minimum permissible time which can elapse from occurrence of failure to sustained failure effect (from the Failure Analysis Data Form) is listed.
MEASURING PARAMETER		Measuring Parameter - The measuring parameter shown on the Failure Effect Analysis Data Form is listed.
CRITI-CALITY NUMBER		Criticality Number - The criticality number shown on the Failure Effect Analysis Data Form is listed.
FAILURE	EFFECT	Effect - The failure effect as reflected by the failure mode consequence entry on the Failure Effect Analysis Data Form is described briefly.
	TYPE/MODE	Type/Mode - The overall failure mode as listed on the Failure Effect Analysis Data Form is listed.

FIGURE B.

MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS



* REPRESENTS PHASE OF FAILURE OCCURANCE AND PHASE OF FAILURE EFFECT AS DEFINED IN THE RELIABILITY MATHEMATICAL MODEL

(TYPICAL EXAMPLE)

Figure C

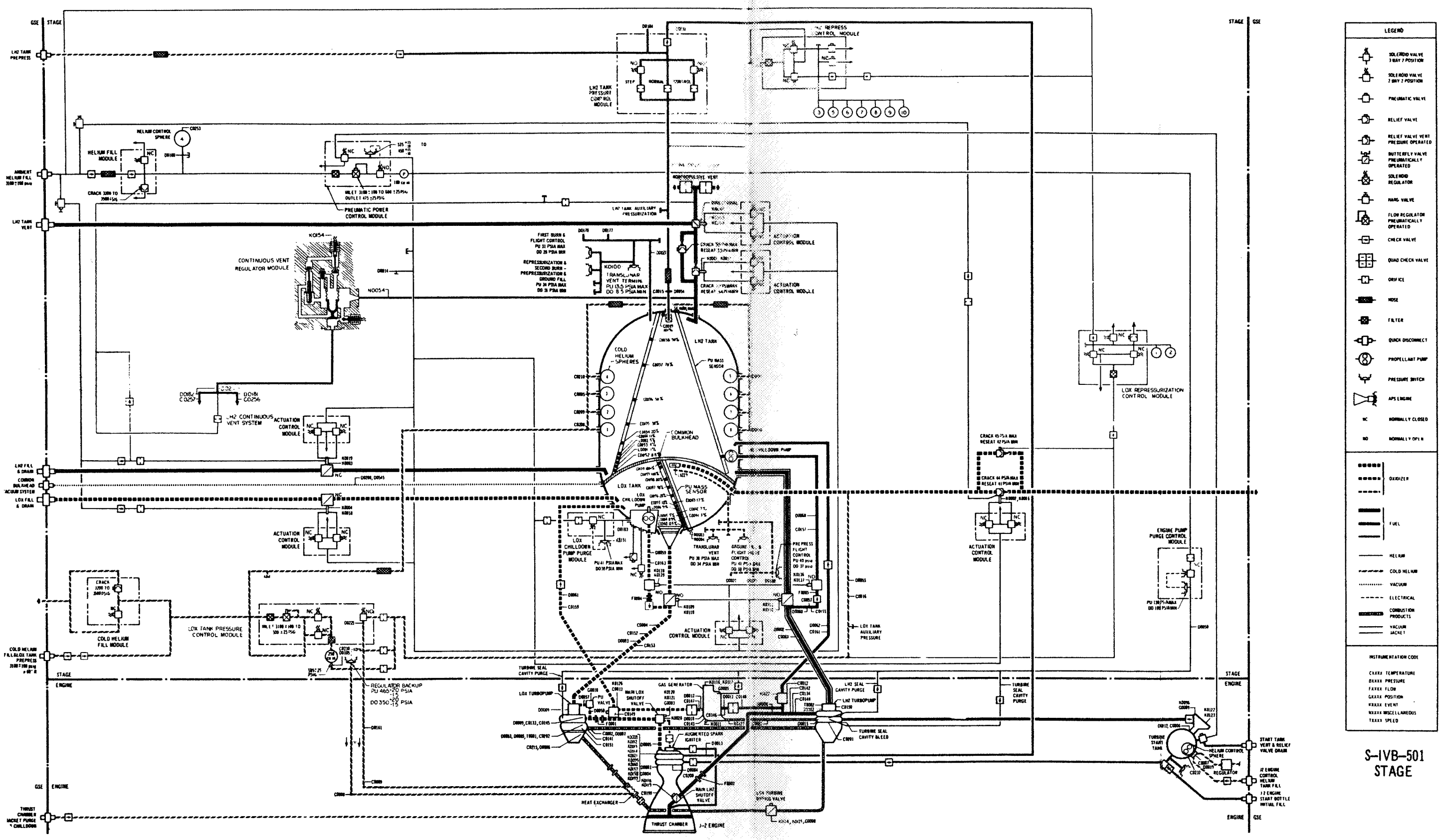


Figure D. Propulsion System Configuration & Instrumentation

SECTION I

FAILURE EFFECT ANALYSIS DATA (FEA DATA)

1.1 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of Ullage Positioning: Due to loss of electrical power or signal to thrust ullage rocket motors or 70 lb. ullage engines.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Prior to J2 engine start.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure of J2 engine to start.

6. TIME DEPENDENCY OF FAILURE: Minimum Failure Reaction Time (MFRT) = 1 second (battery failure).

7. OVERALL FAILURE MODE CRITICALITY: 520

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) Vehicle acceleration.
(2) Ullage rocket ignition.
(3) LH_2 and LOX pressures at pump inlets.

11. SENSOR LOCATION:
(1) A0005-411
(2) K0143-404
K0144-404
(3) XD0002-403
XD0003-403

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL:
(1) As shown in figure 1.
(2) As shown in figure 2.
(3) As shown in figures 3 and 4.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: Not available.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Turbopump cavitation would occur because of vapor entrainment caused by improper setting of propellants.

17. FLIGHT HISTORY: (1) As shown in figures 1 and 2.

18. DISCUSSION: Operation of either of the two ullage rocket motors will provide sufficient thrust to settle the propellants. Ullage rocket motor ignition occurs 0.1 second before separation and continues for 4.5 seconds.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, 14, & 15.

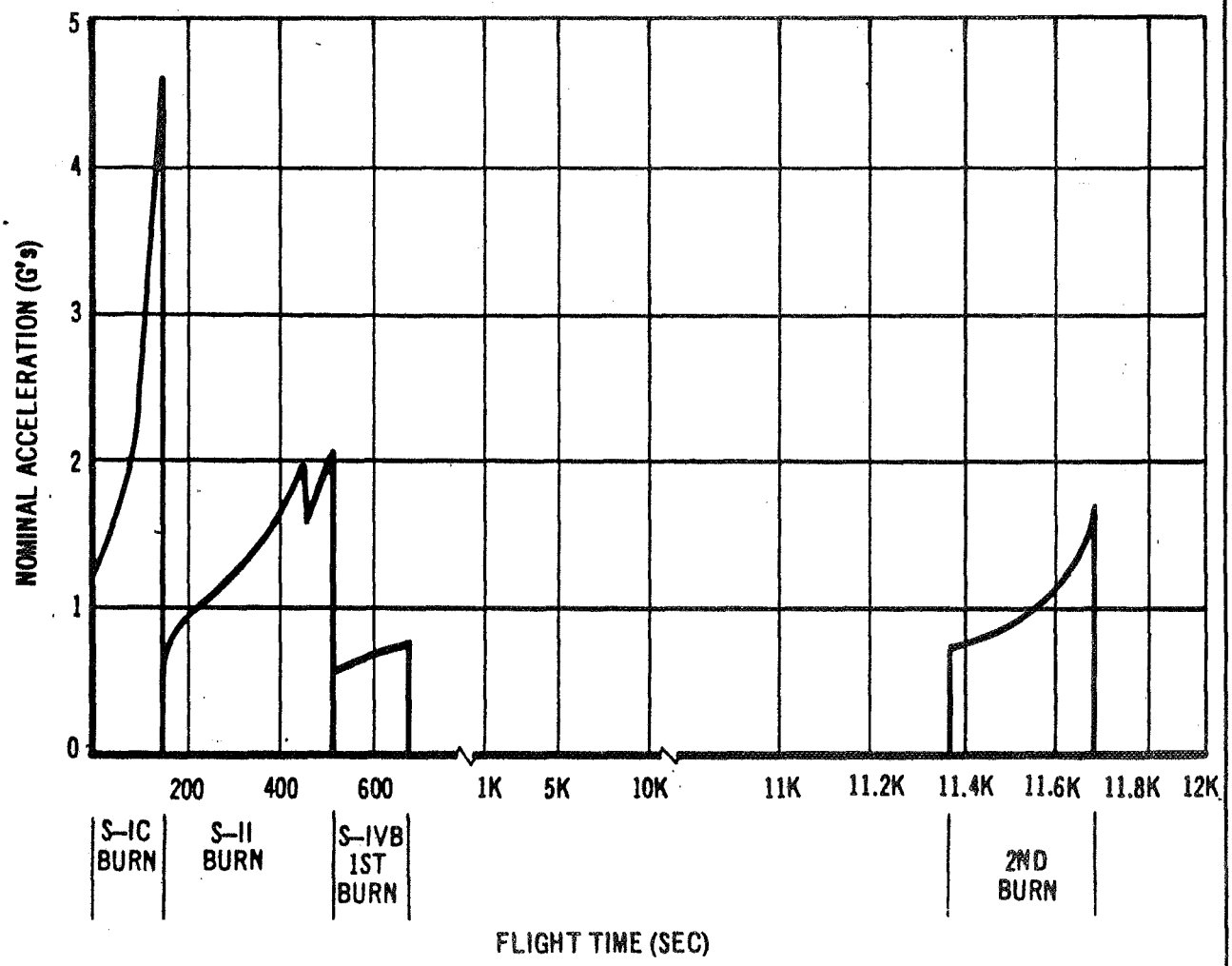


Figure 1. Expected Vehicle Axial Acceleration History

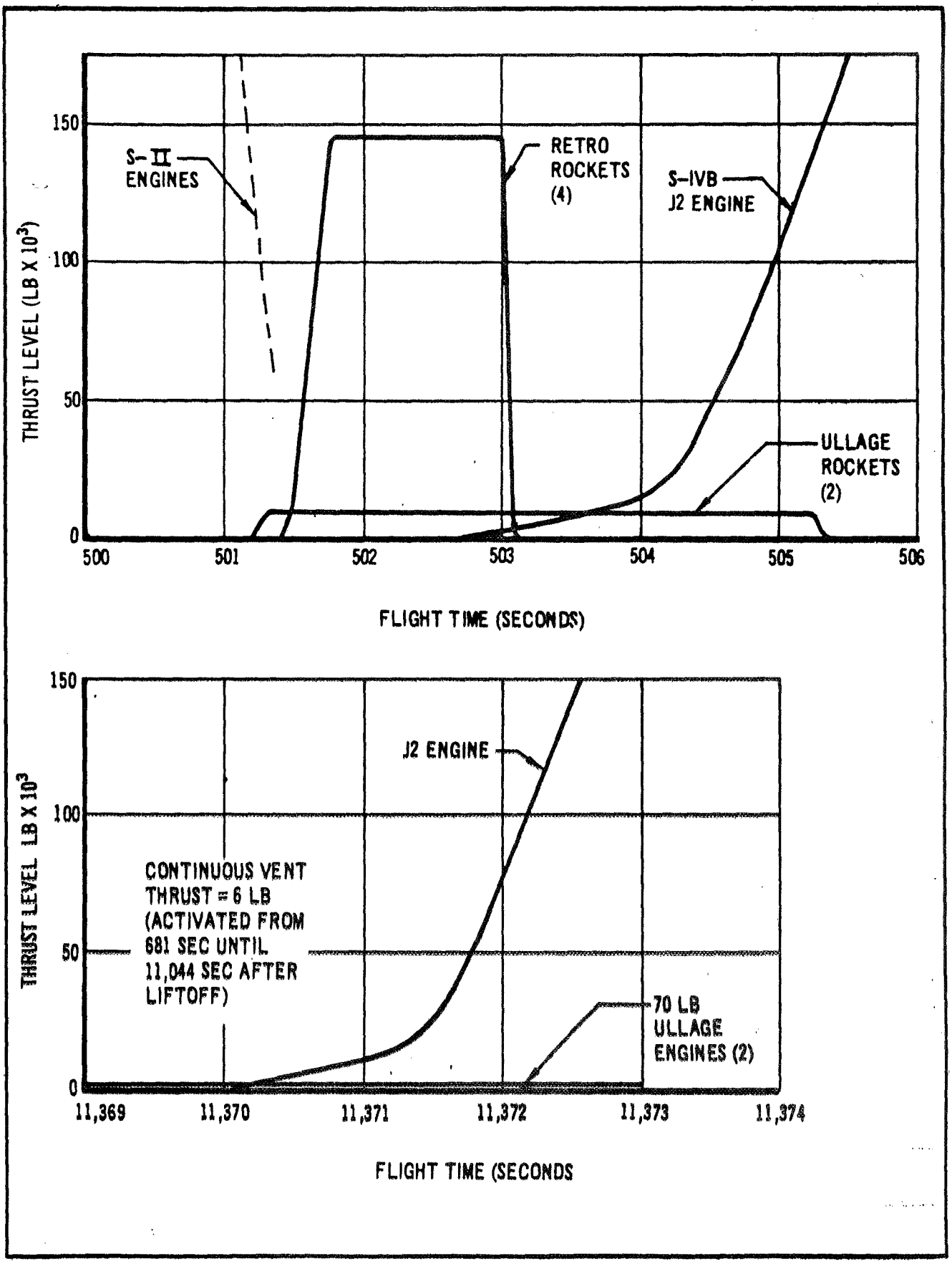


Figure 2. Timing and Thrust Levels During Start and Restart Operations

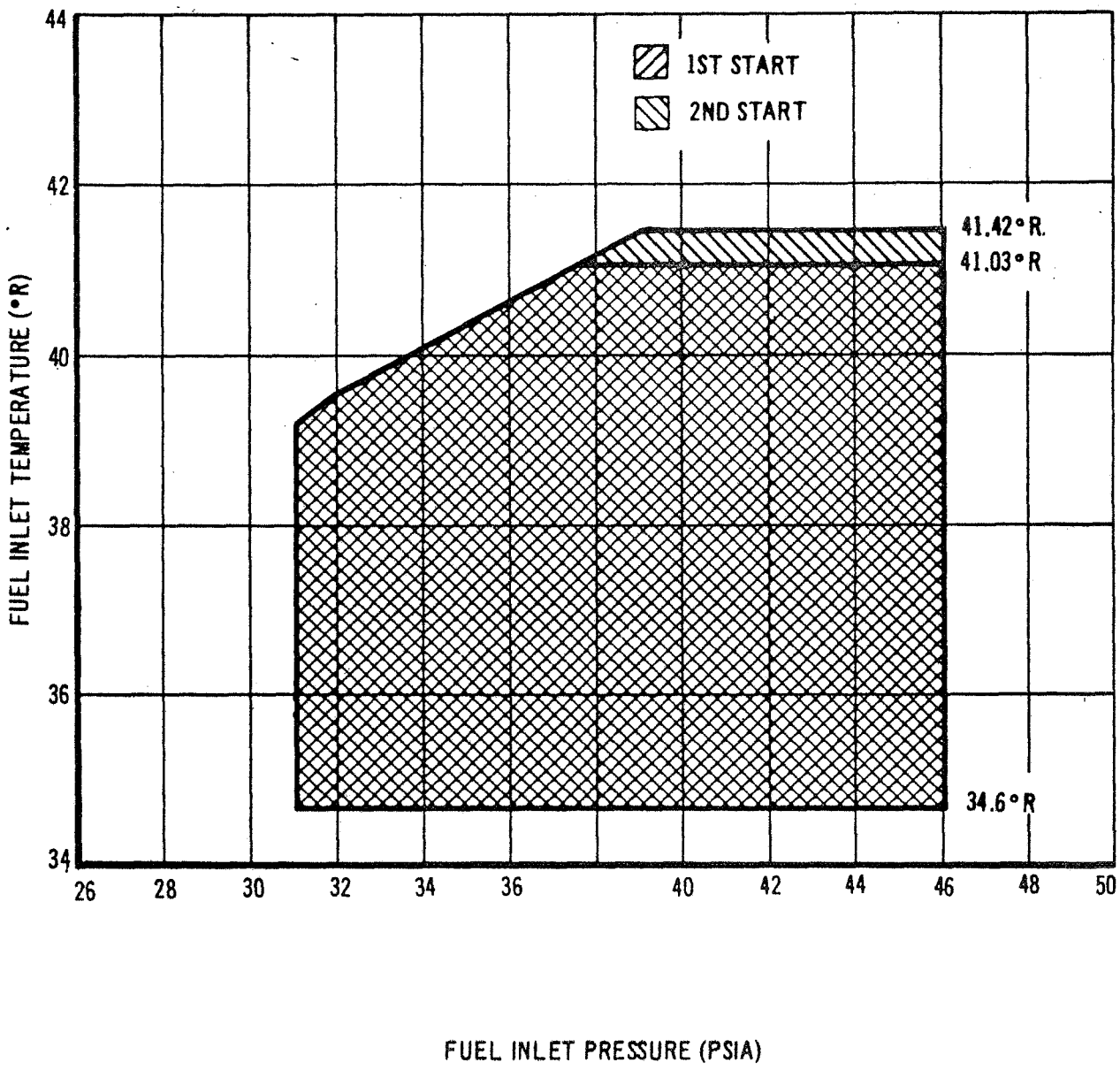


Figure 3. LH_2 Prestart Envelope

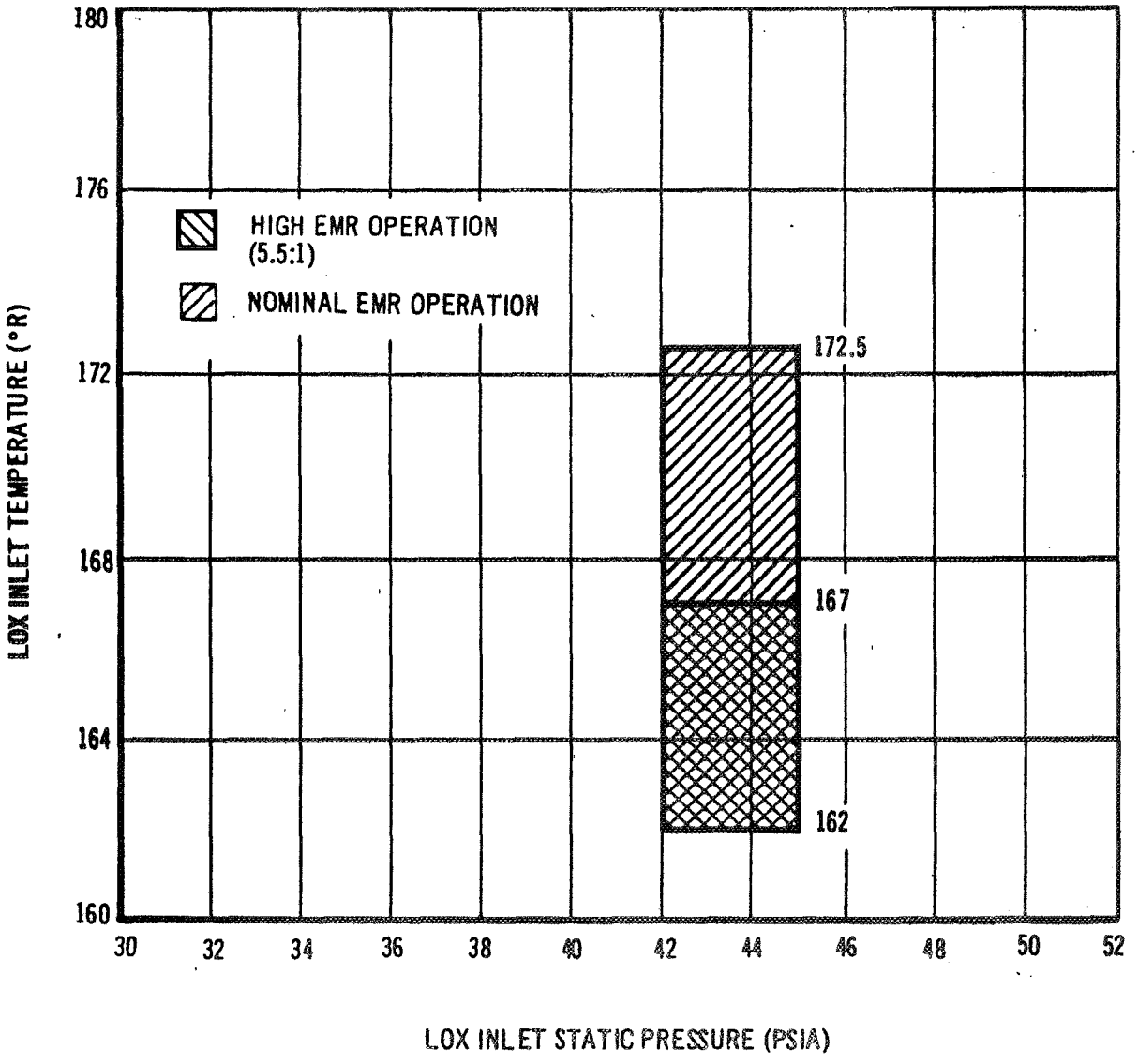


Figure 4. LOX Prestart Envelope

1.2 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of LH_2 Chilldown: Due to loss of chilldown pumping, valve failure along chilldown lines, loss of valve pneumatic power, loss of electrical power or command, leakage of J2 engine components.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 23.01 LH_2 Feed and Chilldown; 24 Pneumatic Control; 26 Thrust; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Prior to J2 engine first or second burn.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure of J2 engine to start.

6. TIME DEPENDENCY OF FAILURE: MFRT = 50 second (feed & chill shutoff valves).

7. OVERALL FAILURE MODE CRITICALITY: 3100

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) LH_2 turbopump inlet temperature.
(2) LH_2 chilldown flow rate.
(3) Pneumatic He quantity and pressure.
(4) Aft battery 2 load.

11. SENSOR LOCATION:
(1) XC0003-403
(2) VXF0005-404
(3) VXD0014-403
(4) M0022-404

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL:
(1) As shown in figure 5.
(3) As shown in figure 6.
(4) As shown in figure 7.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (2) 1.34 lb/sec. minimum at a head of 6.1 psig.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Loss of chilldown flow would result in vapor in the LH_2 lines and subsequent turbopump cavitation.

17. FLIGHT HISTORY: As shown in figures 5 thru 7.

18. DISCUSSION: Chilldown begins approximately 5 minutes before liftoff and continues until 0.6 second before J2 engine start. Second chilldown begins 5 minutes before engine restart.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, and 15.

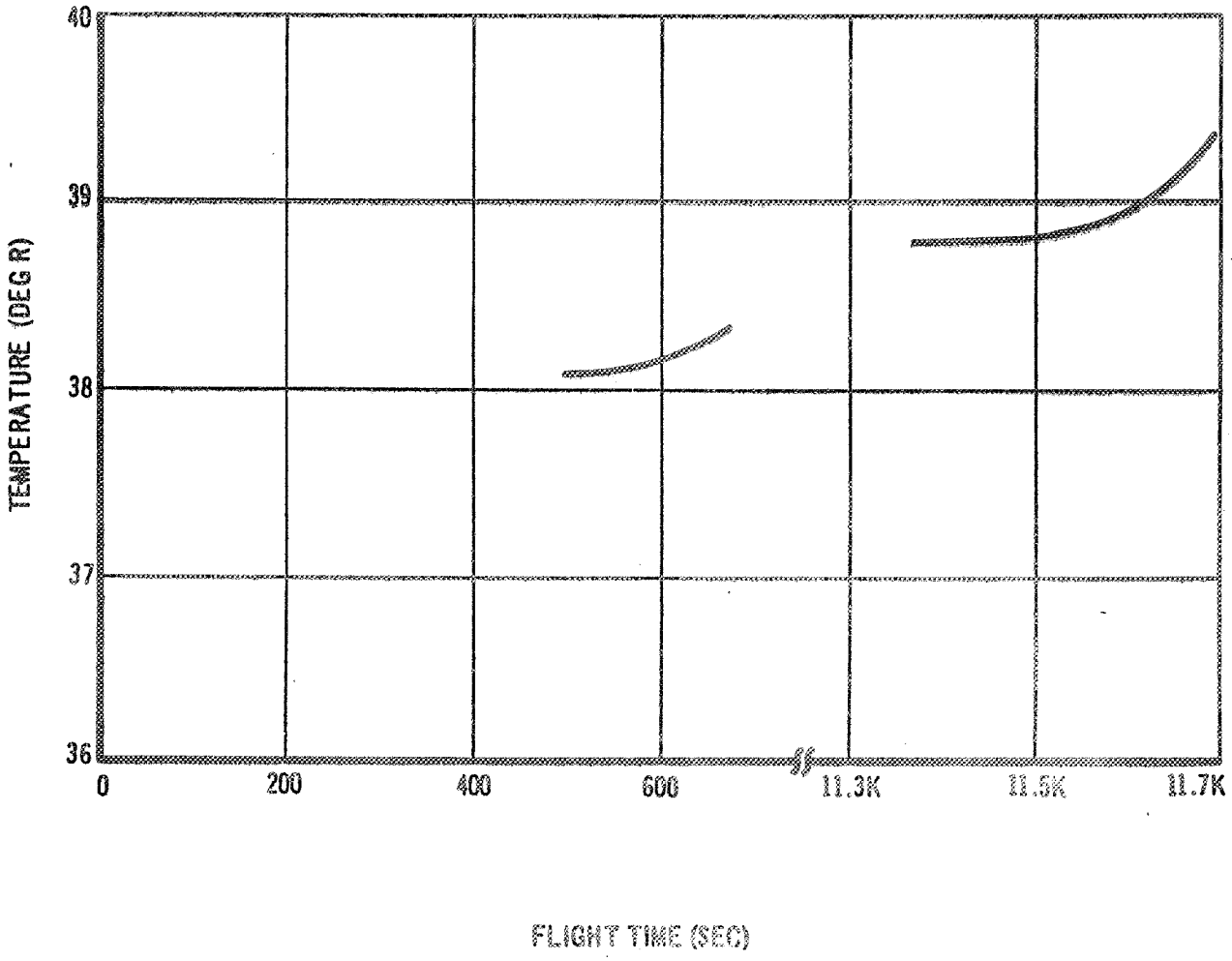


Figure 5. Expected LH_2 Turbopump Inlet Temperature History

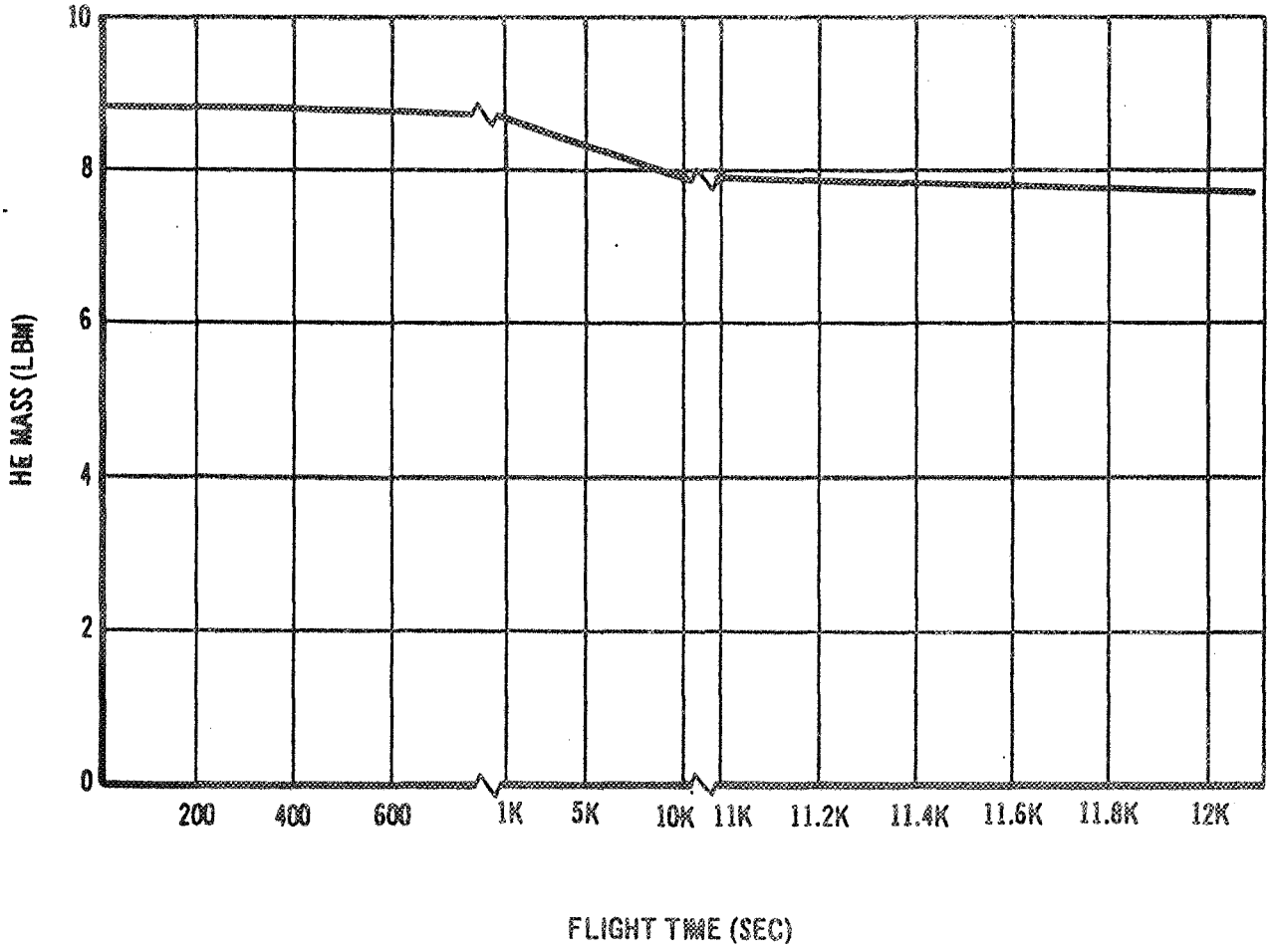


Figure 6. Pneumatic Helium Quantity History

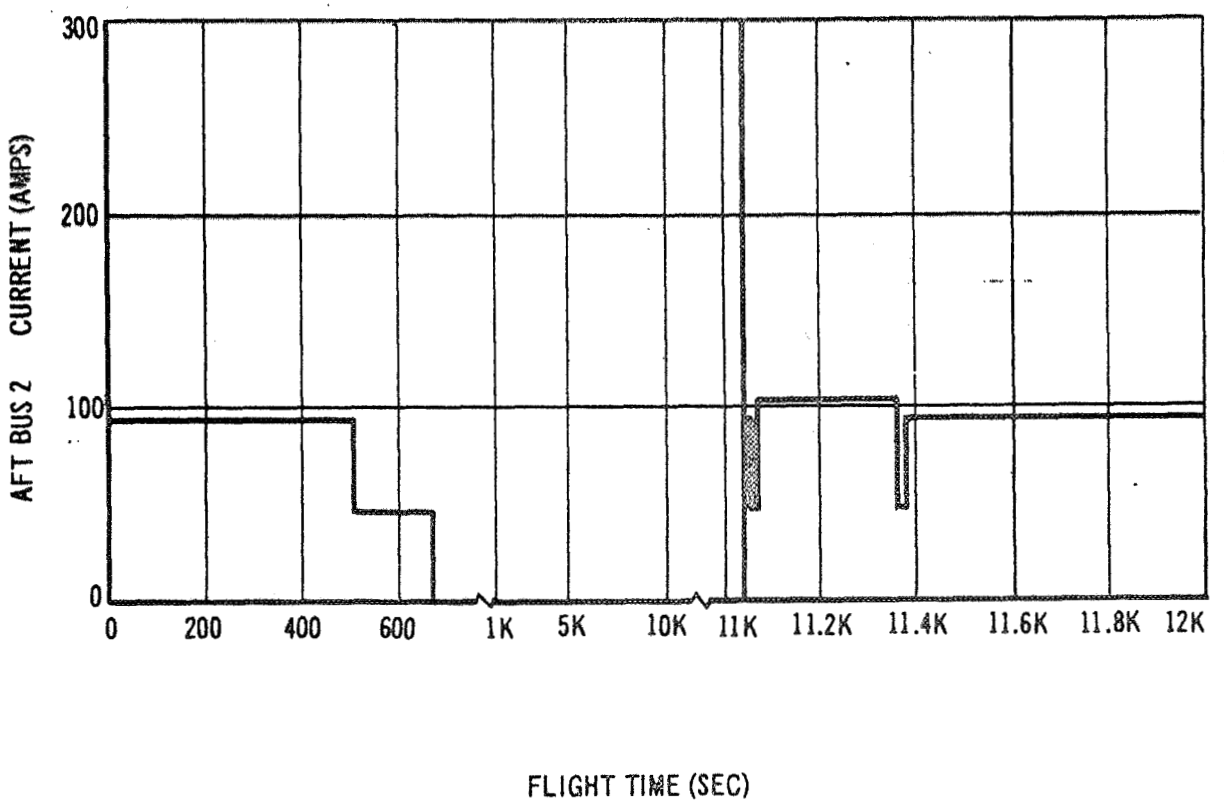


Figure 7. Aft Battery No. 2 Expected Current Profile

1.3 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of LOX Chilldown: Due to loss of chilldown pumping, valve failure along chilldown lines, loss of valve pneumatic power, loss of electrical power or command, leakage of J2 engine components.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 23.02 LOX Feed and Chilldown; 24 Pneumatic Control; 26 Thrust; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Prior to J2 engine first or second burn.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure of J2 engine to start.

6. TIME DEPENDENCY OF FAILURE: MFRT = 100 seconds (feed & chill shutoff valves).

7. OVERALL FAILURE MODE CRITICALITY: 2900

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) LOX turbopump inlet temperature.
(2) LOX chilldown flow rate.
(3) Pneumatic He quantity and pressure.
(4) Aft battery 2 load.

11. SENSOR LOCATION:
(1) XC0004-403
(2) VXF0004-424
(3) VXD0014-403
(4) M0022-404

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL:
(1) As shown in figure 8.
(3) As shown in figure 6.
(4) As shown in figure 7.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (2) 5 lb/sec. minimum at a head of 15 psig.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Loss of chilldown flow would result in vapor in the LOX feed lines and subsequent turbopump cavitation.

17. FLIGHT HISTORY: As shown in figures 6 thru 8.

18. DISCUSSION: Chilldown pumping begins approximately 5 minutes before liftoff and continues until 0.6 seconds before J2 engine start. Second chilldown begins 5 minutes before engine restart.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, and 15.

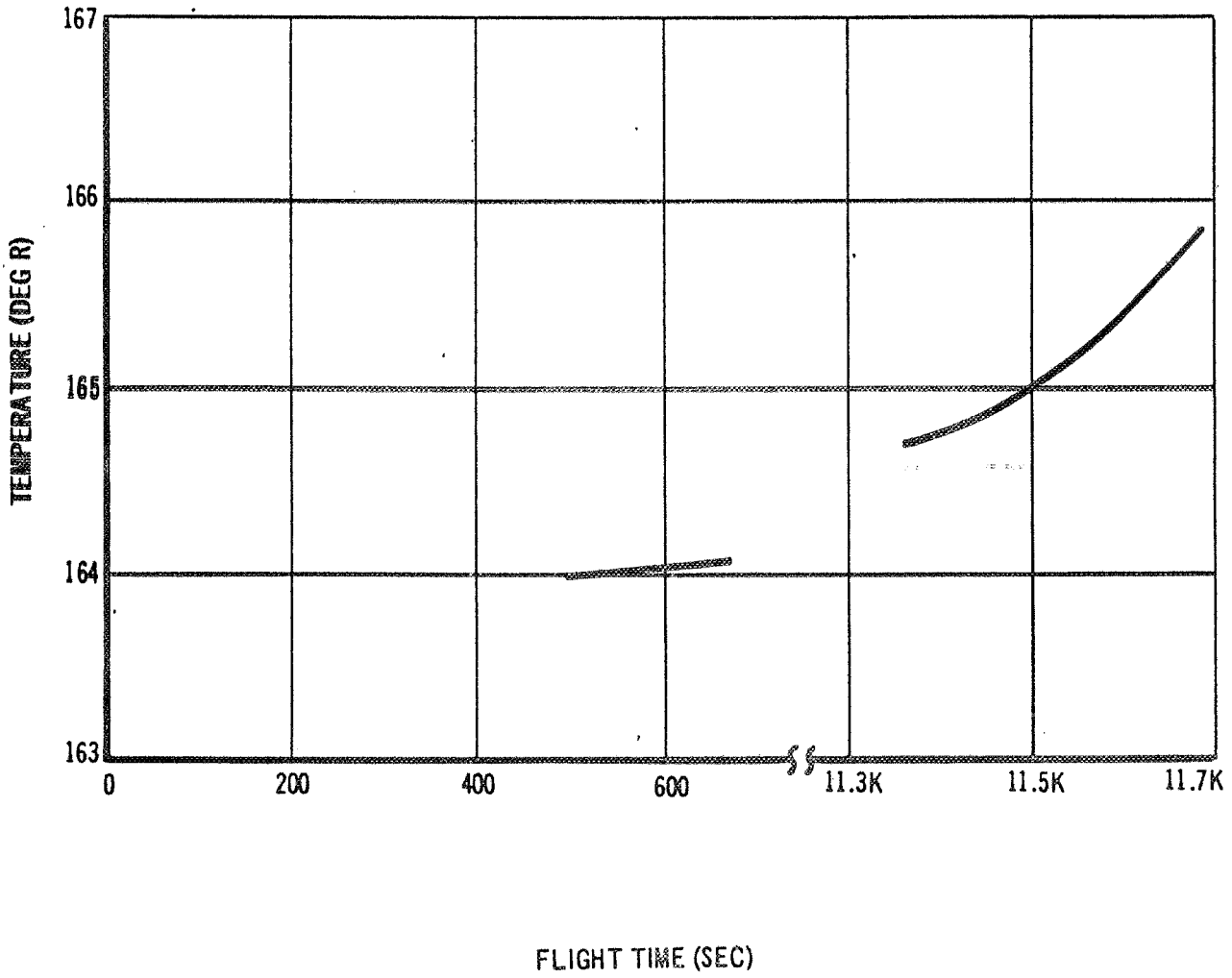


Figure 8. Expected LOX Turbopump Inlet Temperature History

1.4 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of Engine Start Capability: Due to loss of pneumatic power, loss of electrical power or start command, closed prevalve, loss of PU electronics output, closed main fuel valve, closed engine start tank valve.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 24 Pneumatic Control; 26 Thrust; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution; 45 Propellant Utilization.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Prior to J2 engine programmed ignition.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure of J2 engine to start.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (battery failure).

7. OVERALL FAILURE MODE CRITICALITY: 5000

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) Start tank pressure.
(2) PU valve position.
(3) Engine bus voltage.
(4) Prestart valve position.
(5) PU inverter-converter outputs.
(6) Pneumatic He quantity.
(7) Main fuel valve position.
(8) Start tank valve position.

11. SENSOR LOCATION:
(1) VXD0017-401
(2) VG0010-401
(3) M0006-401
M0007-401
(4) K0111-404
(5) VM0001-411
(6) VXD0014-403
(7) VK0018-401
(8) G0009-404

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL:
(1) Start tank pressure as shown in figure 9.
Start tank masses as shown in figure 10.
(5) 115 ± 3.45 V at 400 ± 6 cps
5.0 ± 0.5 VDC
21.0 (+ 1.5 VDC, − 1.0 VDC)
(6) As shown in figure 6.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (5) As shown in item 13.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Gas generator burnout may occur if PU (propellant utilization) valve drives to closed position, preventing engine start.

17. FLIGHT HISTORY: As shown in figures 6 and 10.

18. DISCUSSION: Information on J2 engine components contributing to this overall failure mode is presented in J2 Engine Failure Effect Analysis, Rocketdyne Report R-2600-17.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, and 15.

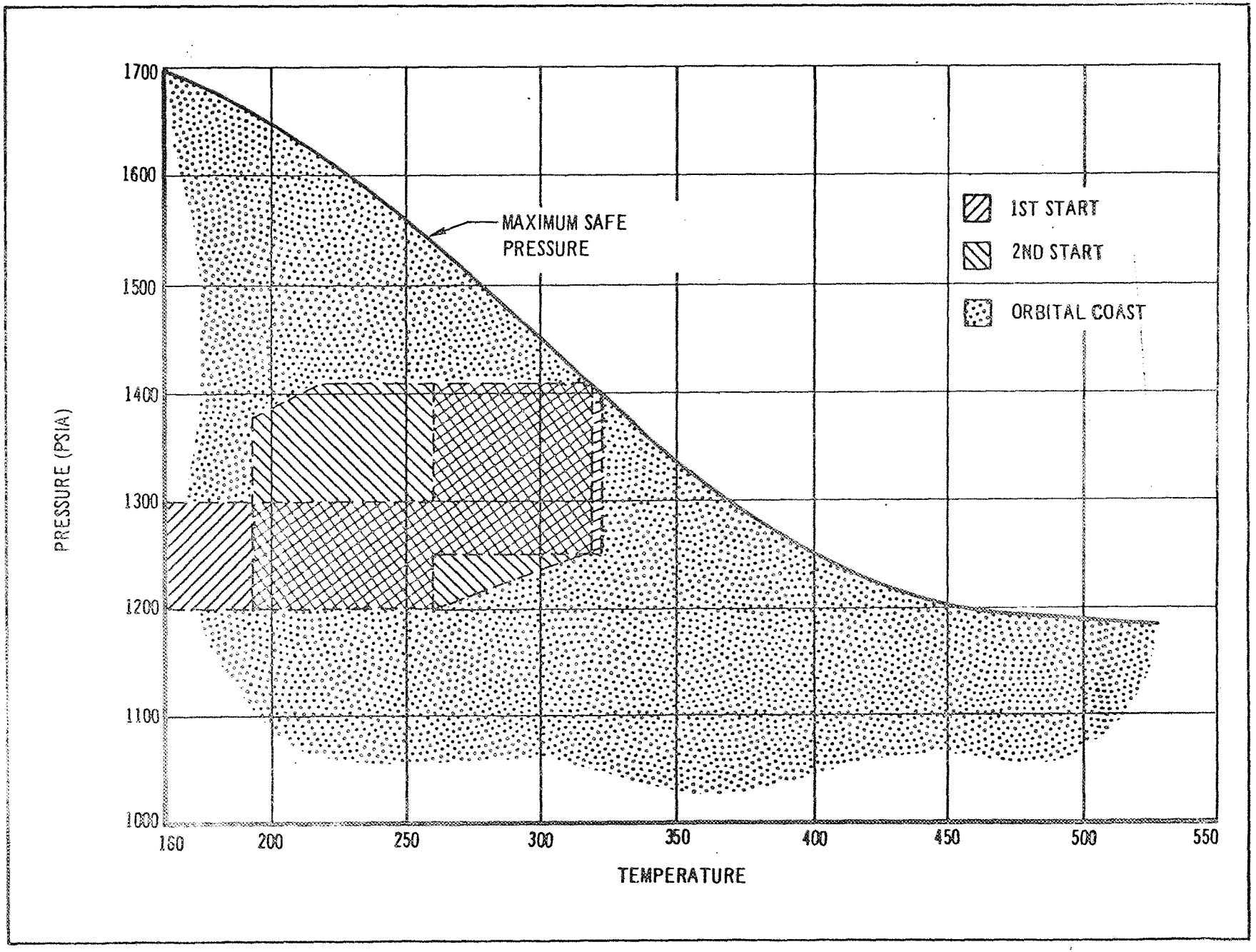


Figure 9. J2 Engine H_2 Bottle Start Envelope

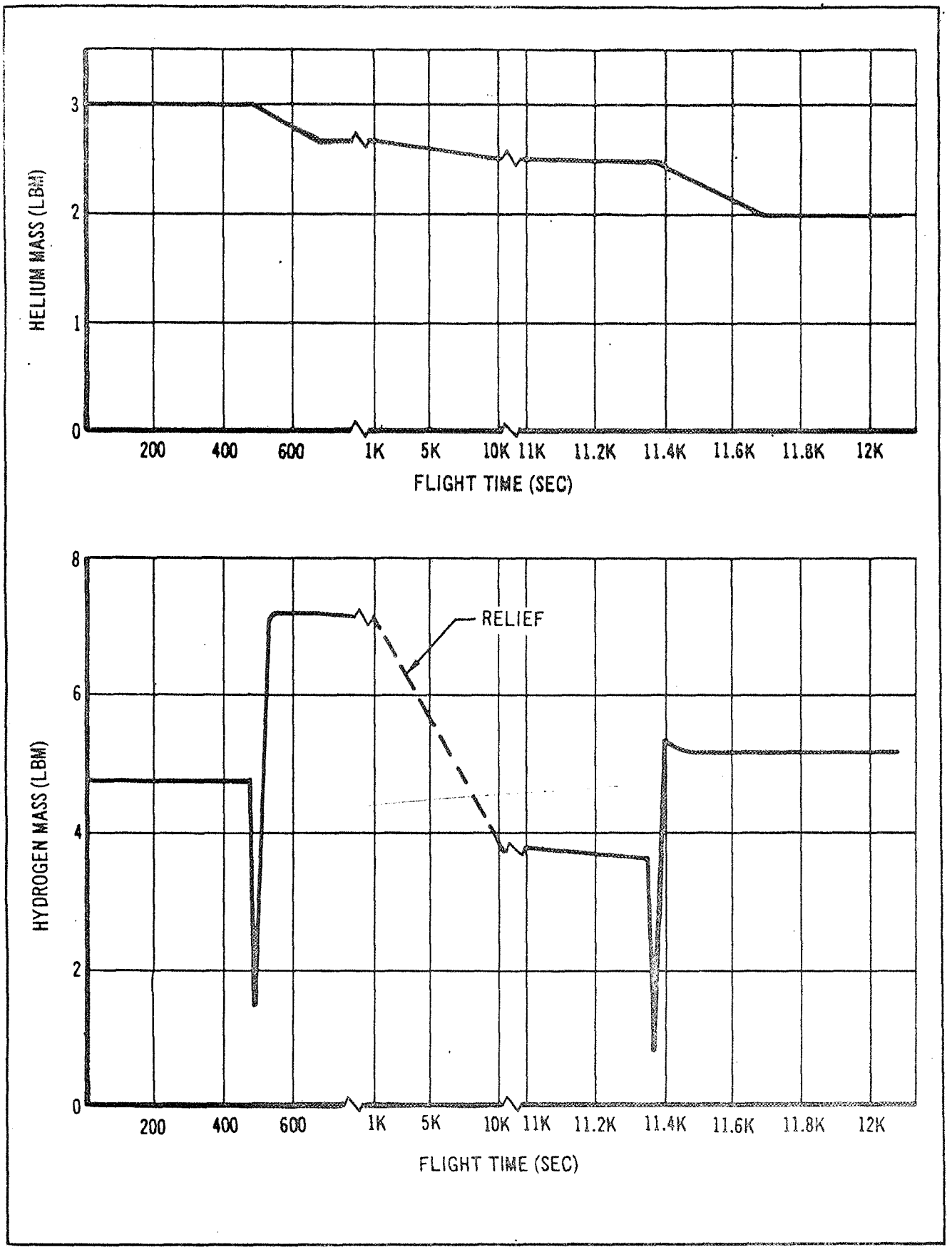


Figure 10. Expected Helium and Hydrogen Masses for Engine Start Tank

1.5 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of LH_2 Tank Pressurization: Due to open fill and drain valve, open ullage pressure system valves, feed or engine ducting leakage, loss of electrical power of command, loss of pneumatic power.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 21.01 LH_2 Fill and Drain; 22.01 LH_2 Tank Ullage Pressure; 23.01 LH_2 Feed and Chilldown; 24 Pneumatic Control; 26 Thrust; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Up to J2 engine programmed second cutoff.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure of J2 engine to start or premature cutoff.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (fill & drain or chill ducting).
2 seconds (ullage pressure system).

7. OVERALL FAILURE MODE CRITICALITY: 820

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: (1) LH_2 tank ullage pressure.
(2) Cold He mass.

11. SENSOR LOCATION: (1) XD0177-410
D0178-410
(2) None.

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: (1) As shown in figure 11.
(2) As shown in figure 16.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (1) 28 to 31 psia.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Loss of LH_2 tank ullage pressure results in turbopump cavitation. See figure 12.

17. FLIGHT HISTORY: See figures 11 thru 16.

18. DISCUSSION: During engine burn, LH_2 tank pressurization is maintained by means of gaseous hydrogen bled from the engine injector manifold.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

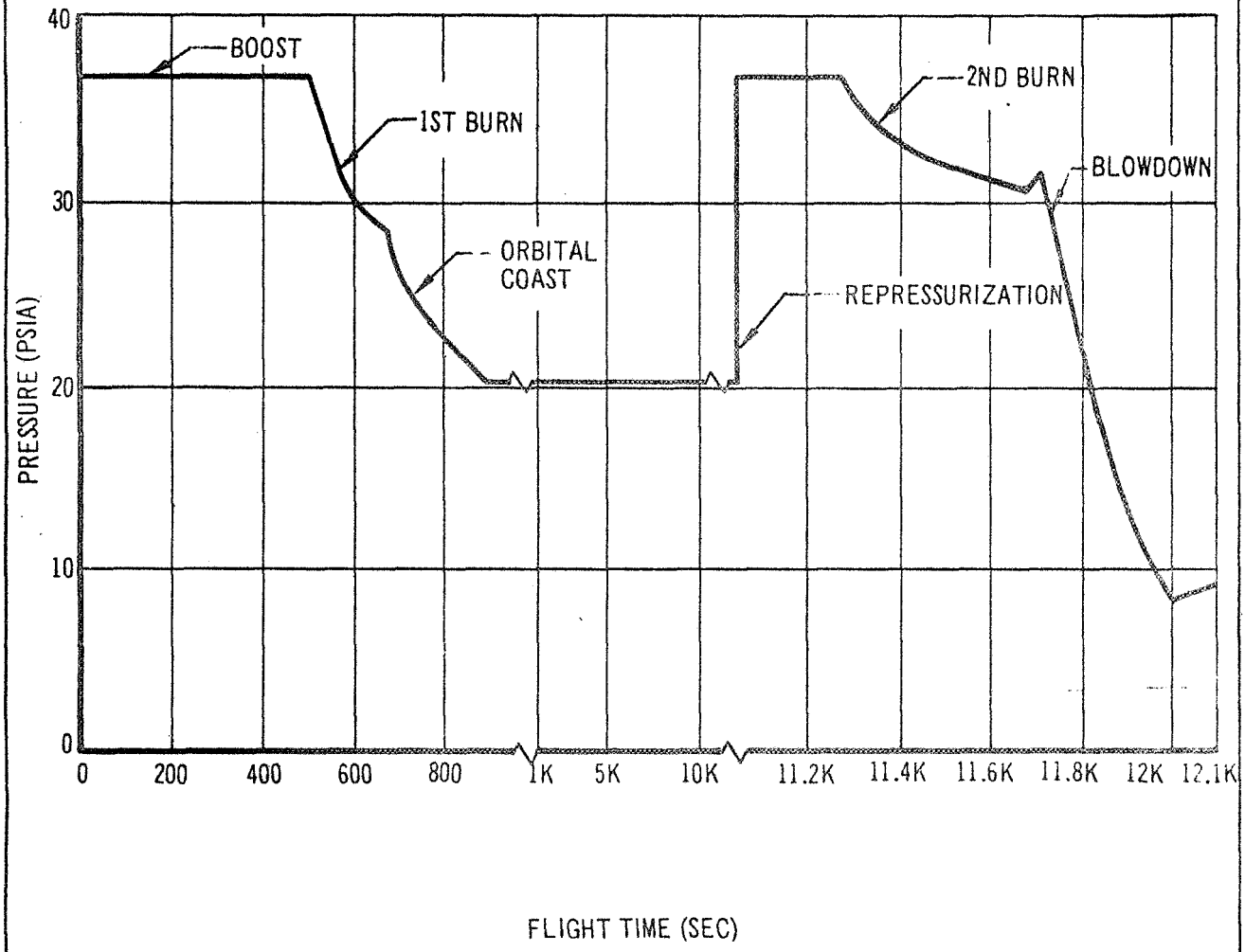


Figure 11. LH_2 Tank Expected Ullage Pressure History

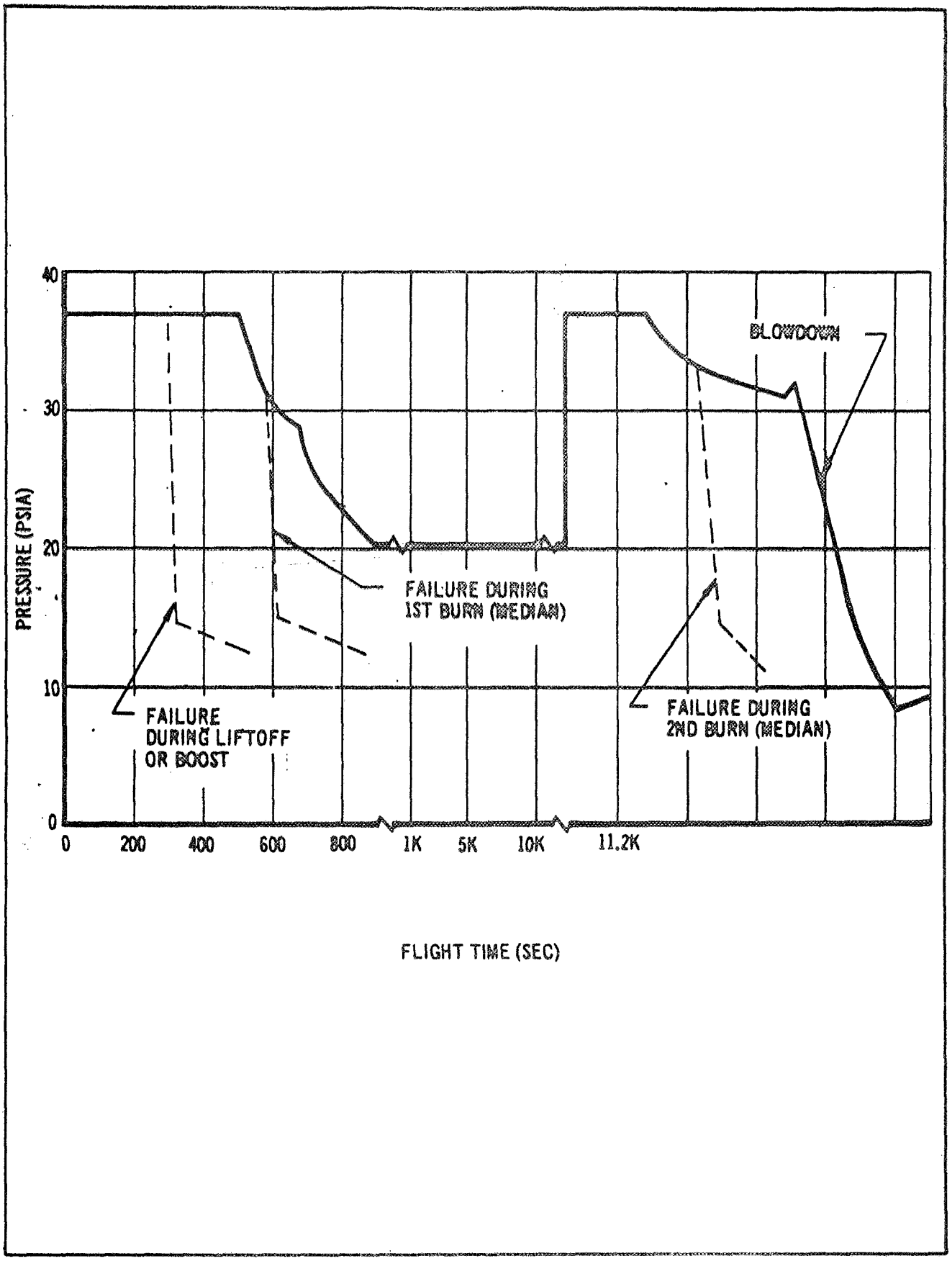


Figure 12. LH_2 Tank Ullage Pressure Decay for Vent Valve Failure

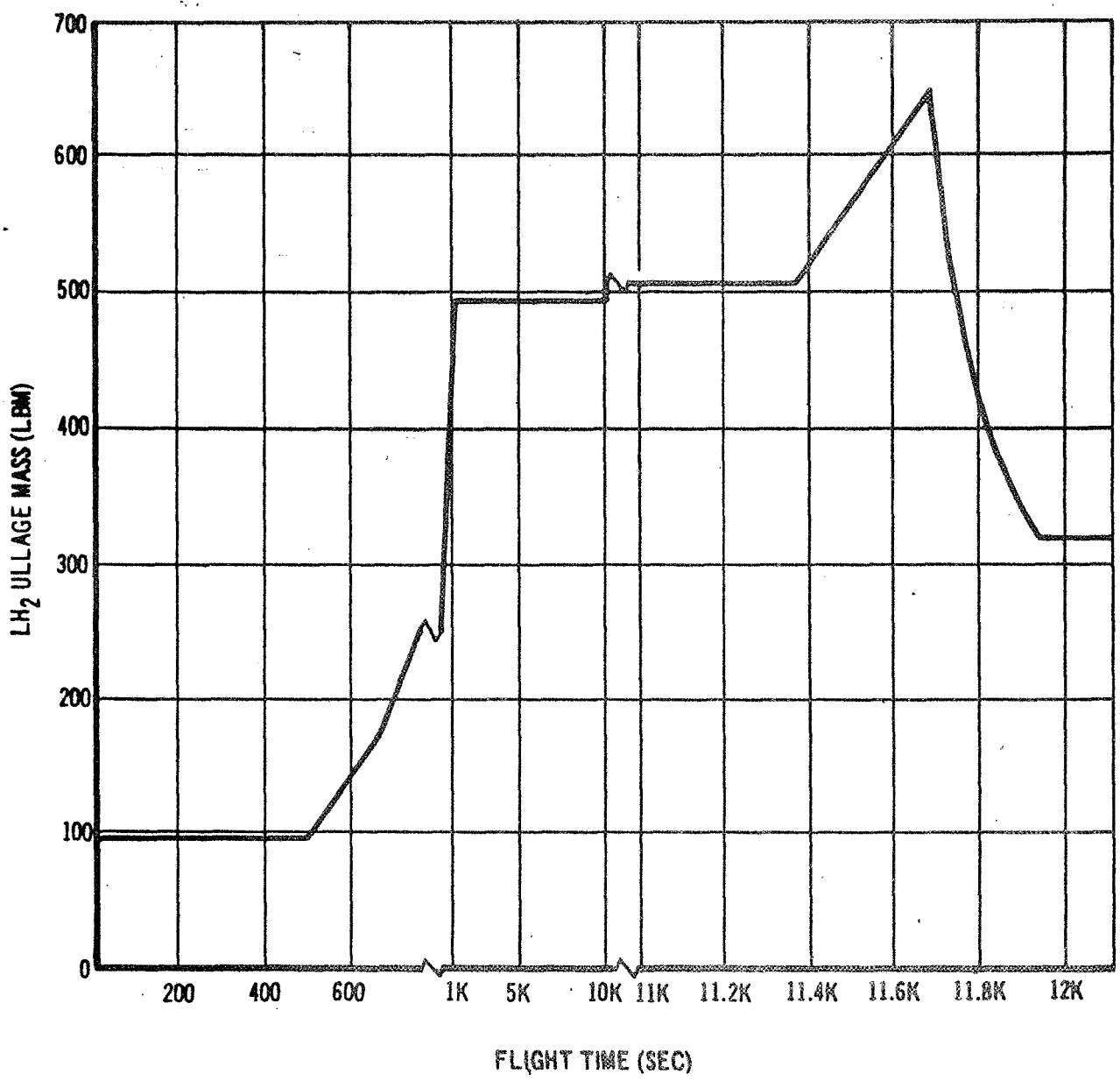


Figure 13. Expected LH_2 Tank Ullage Mass History

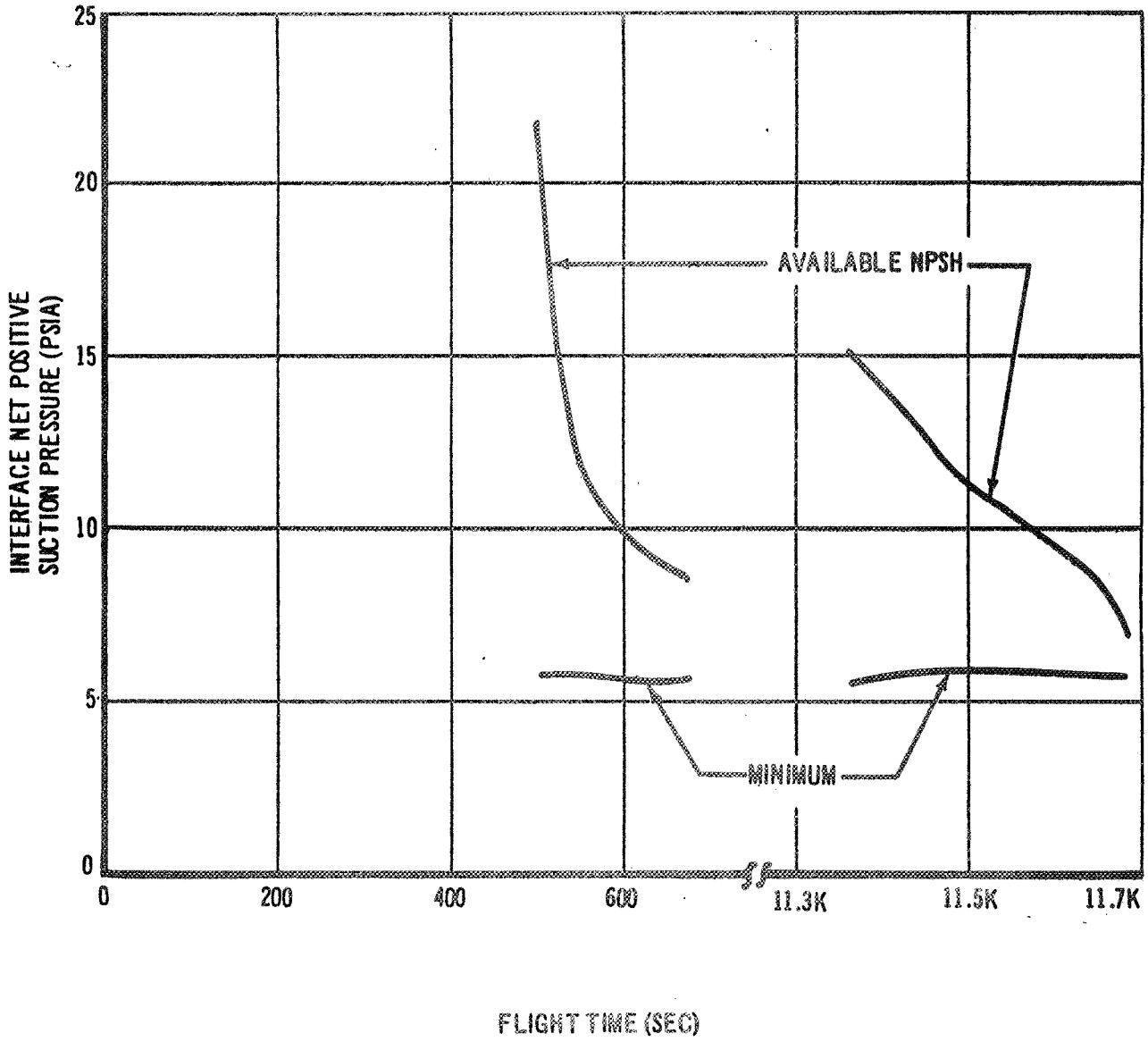


Figure 14. Expected LH_2 Interface NPSH History

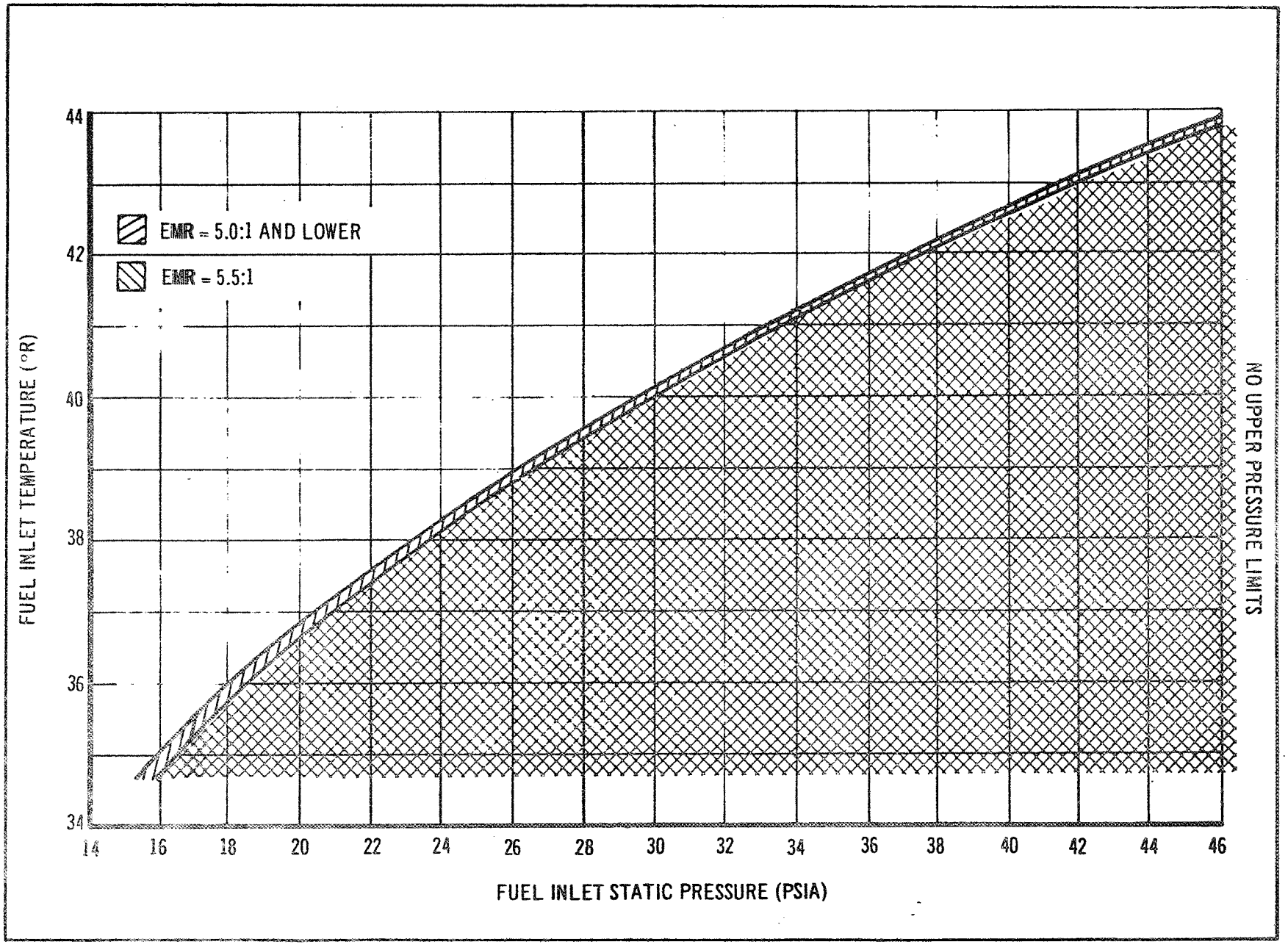


Figure 15. LH_2 Operating Limits

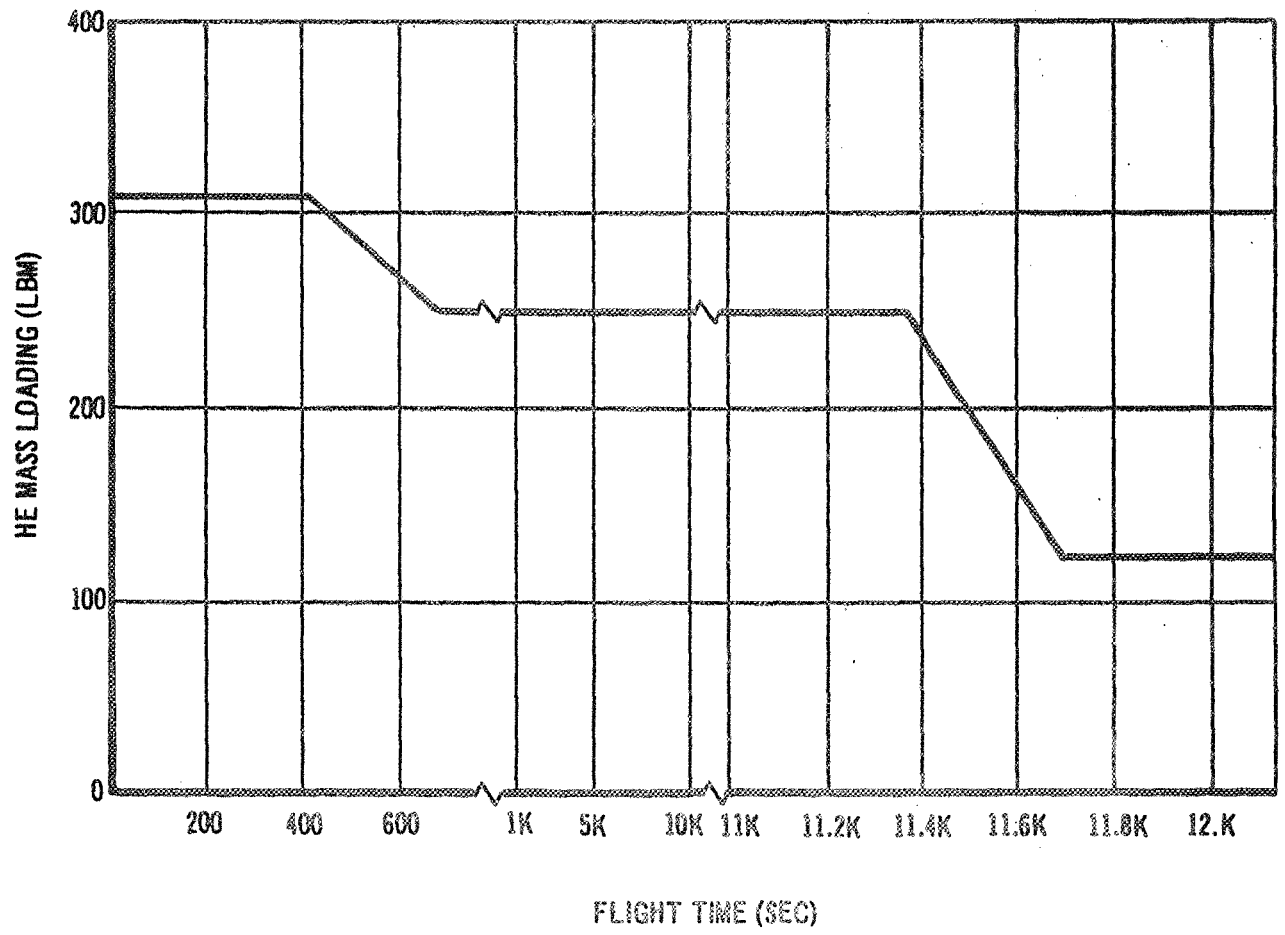


Figure 16. Expected Cold Helium Mass History

1.6 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of LH_2 Repressurization Capability; Due to open pressurization system valves, leakage or loss of flow of pressurizing He, loss of electrical power or command.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 22.01 LH_2 Tank Ullage Pressure; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Prior to J2 engine programmed second start.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure of J2 engine to start.

6. TIME DEPENDENCY OF FAILURE: MFRT = 10 seconds (ullage pressure system).

7. OVERALL FAILURE MODE CRITICALITY: 680

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: (1) Repressurization He quantity (ambient supply).
(2) LH_2 tank ullage pressure.

11. SENSOR LOCATION: (1) None.
(2) XD0177-410
D0178-410

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: (1) As shown in figure 17.
(2) 31 to 34 psia (repressurization and 2nd burn).
19 to 21 psia (orbital coast).

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (2) As shown in item 13.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Inability to repressurize the LH_2 tank results in cavitation of the LH_2 turbopump.

17. FLIGHT HISTORY: As shown in figure 17.

18. DISCUSSION: During coast phase before engine second burn, switch 22.01-06 controls repressurization cycle by maintaining LH_2 tank pressure to between 31 and 34 psia.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

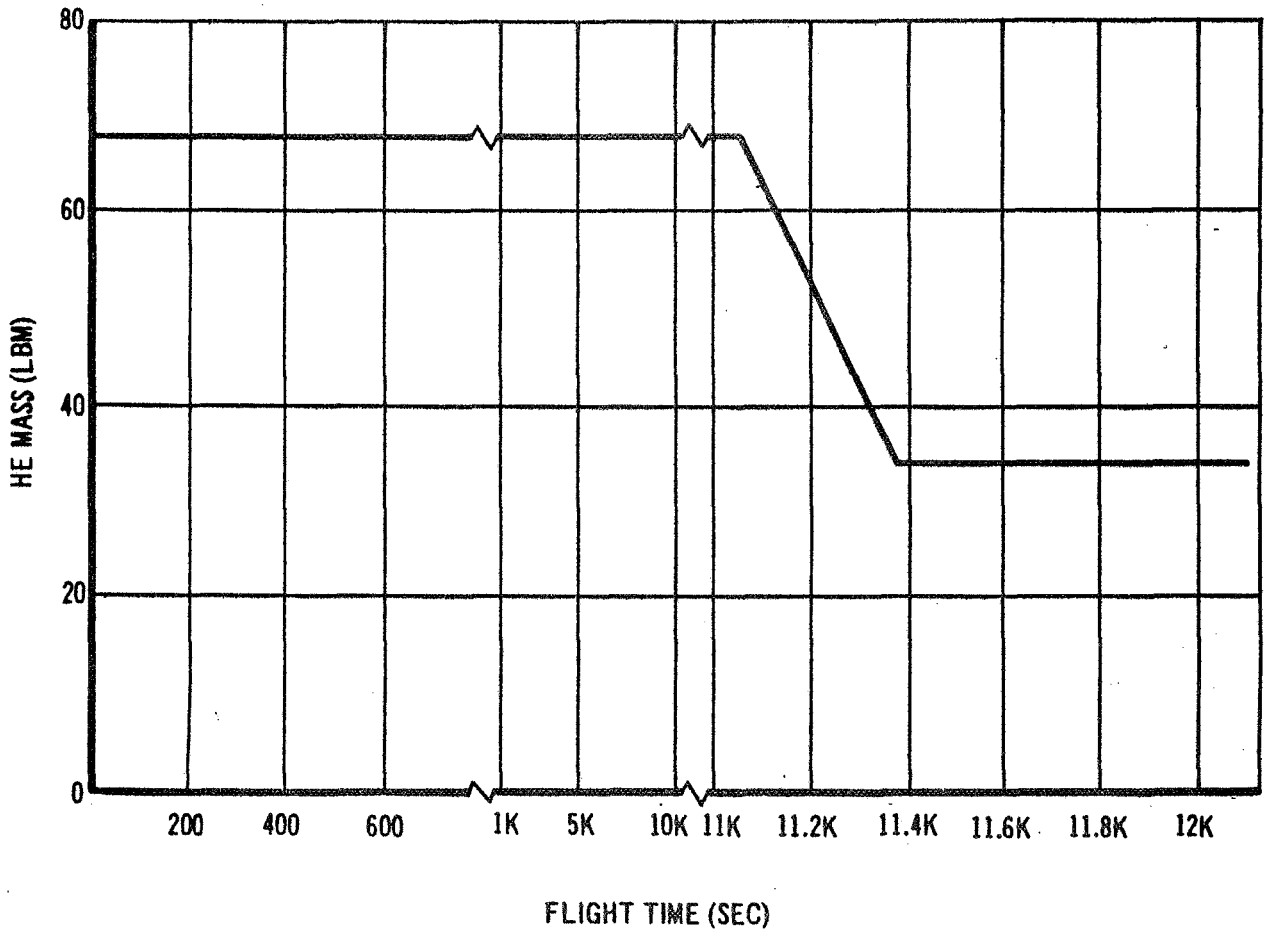


Figure 17. LH_2 Tank Repressurization Helium Mass

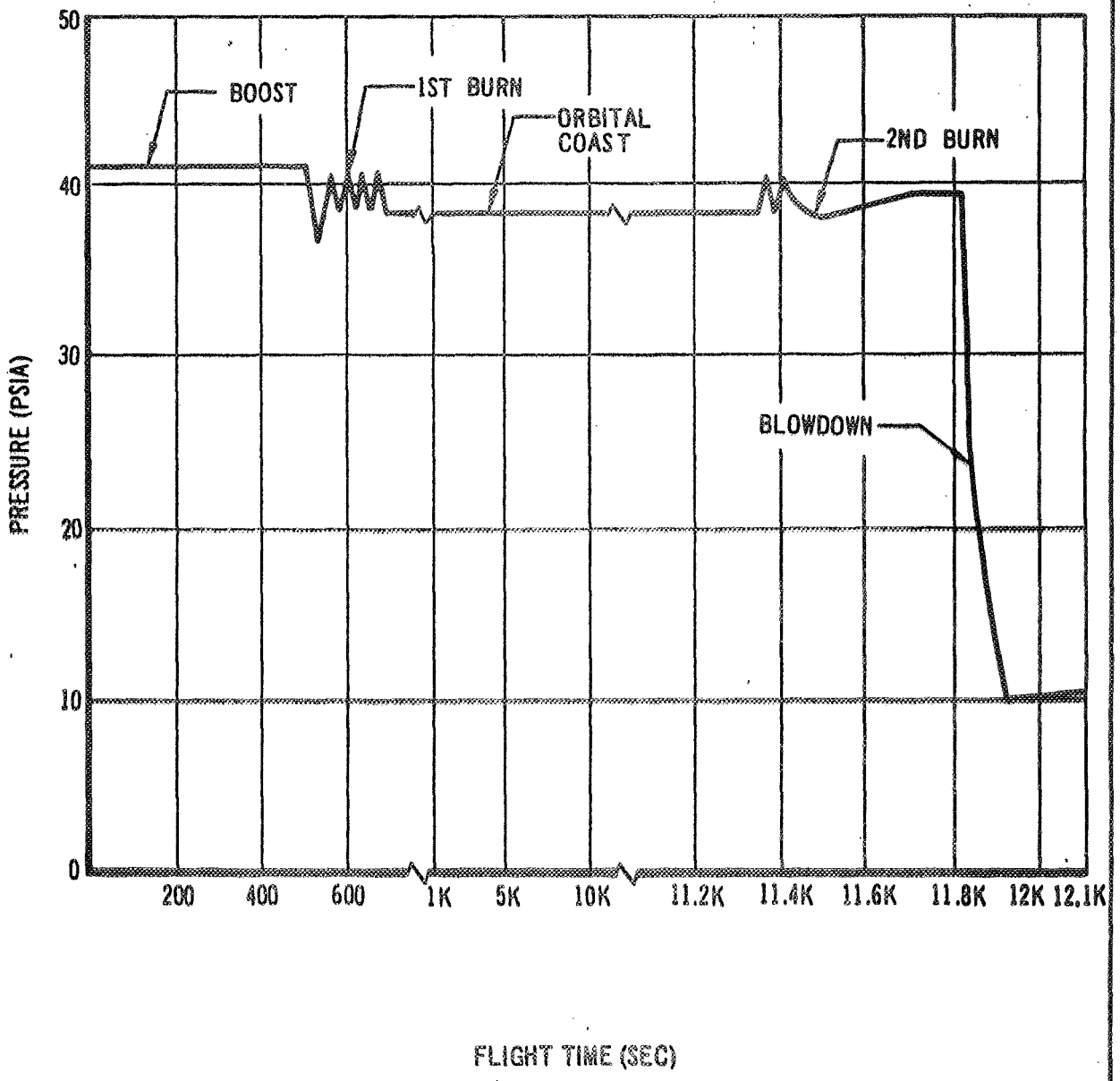


Figure 18. LOX Tank Expected Ullage Pressure History

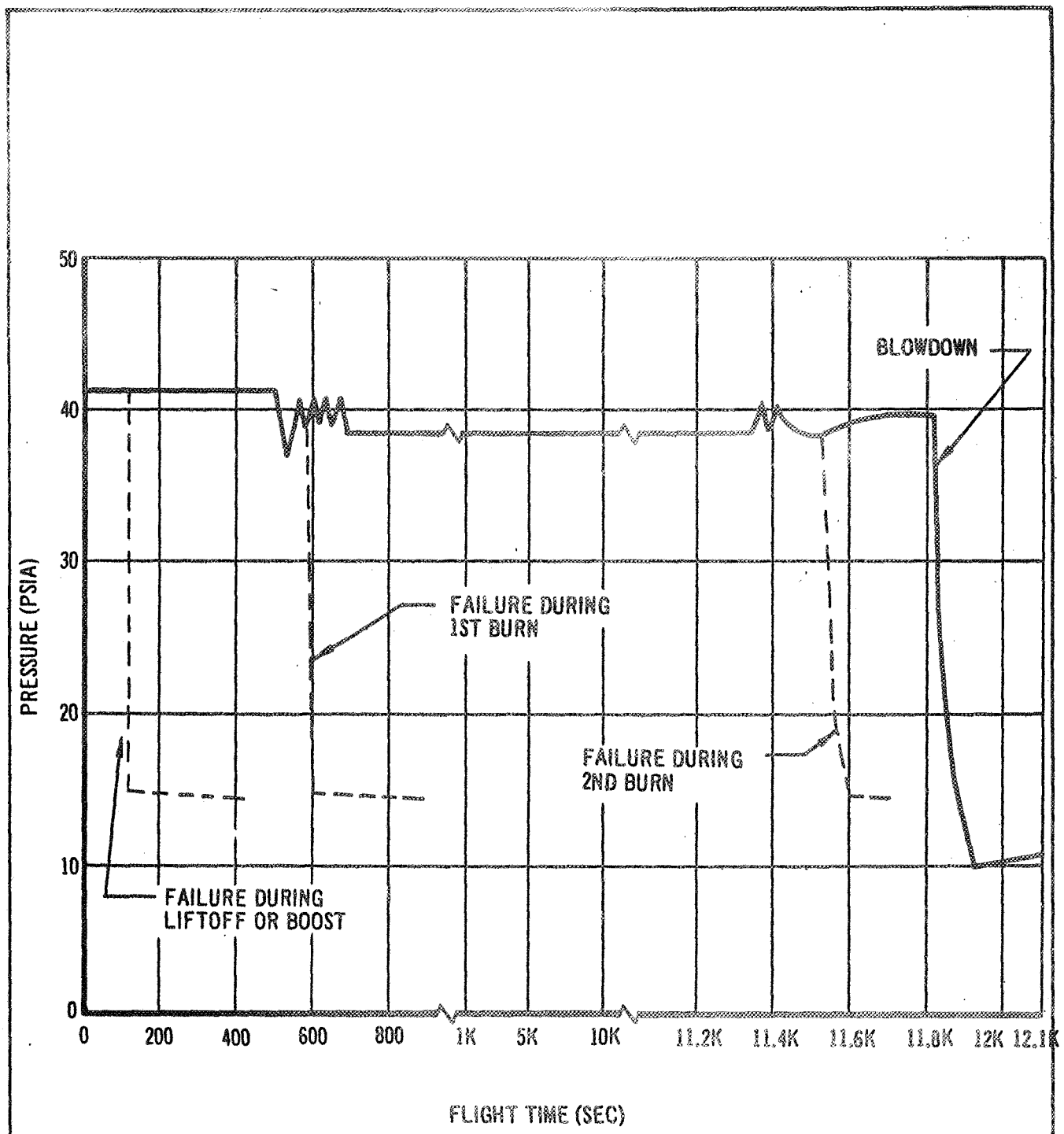


Figure 19. LOX Tank Ullage Pressure Decay for Vent Valve Failure

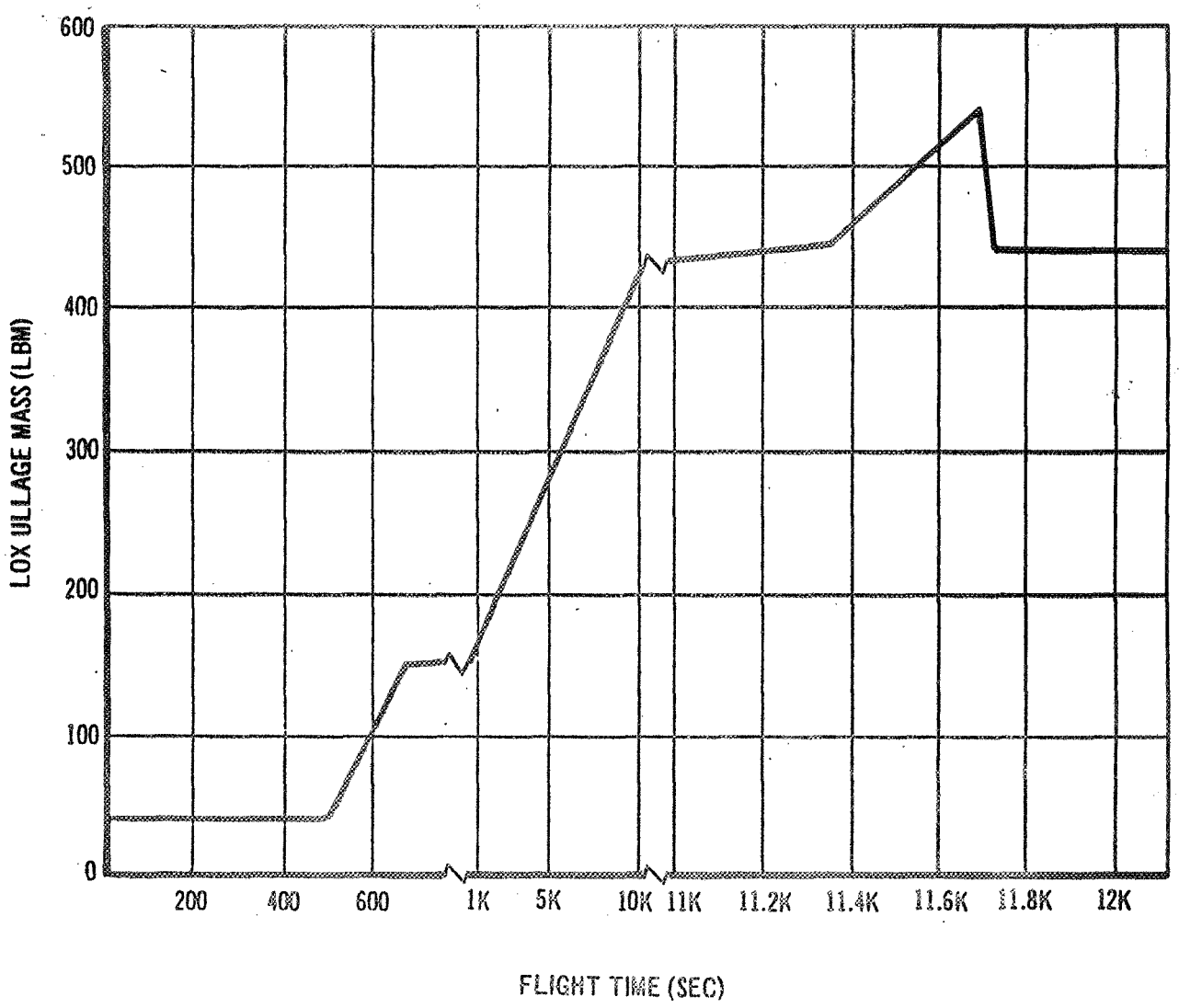


Figure 20. Expected Lox Tank Ullage Mass History

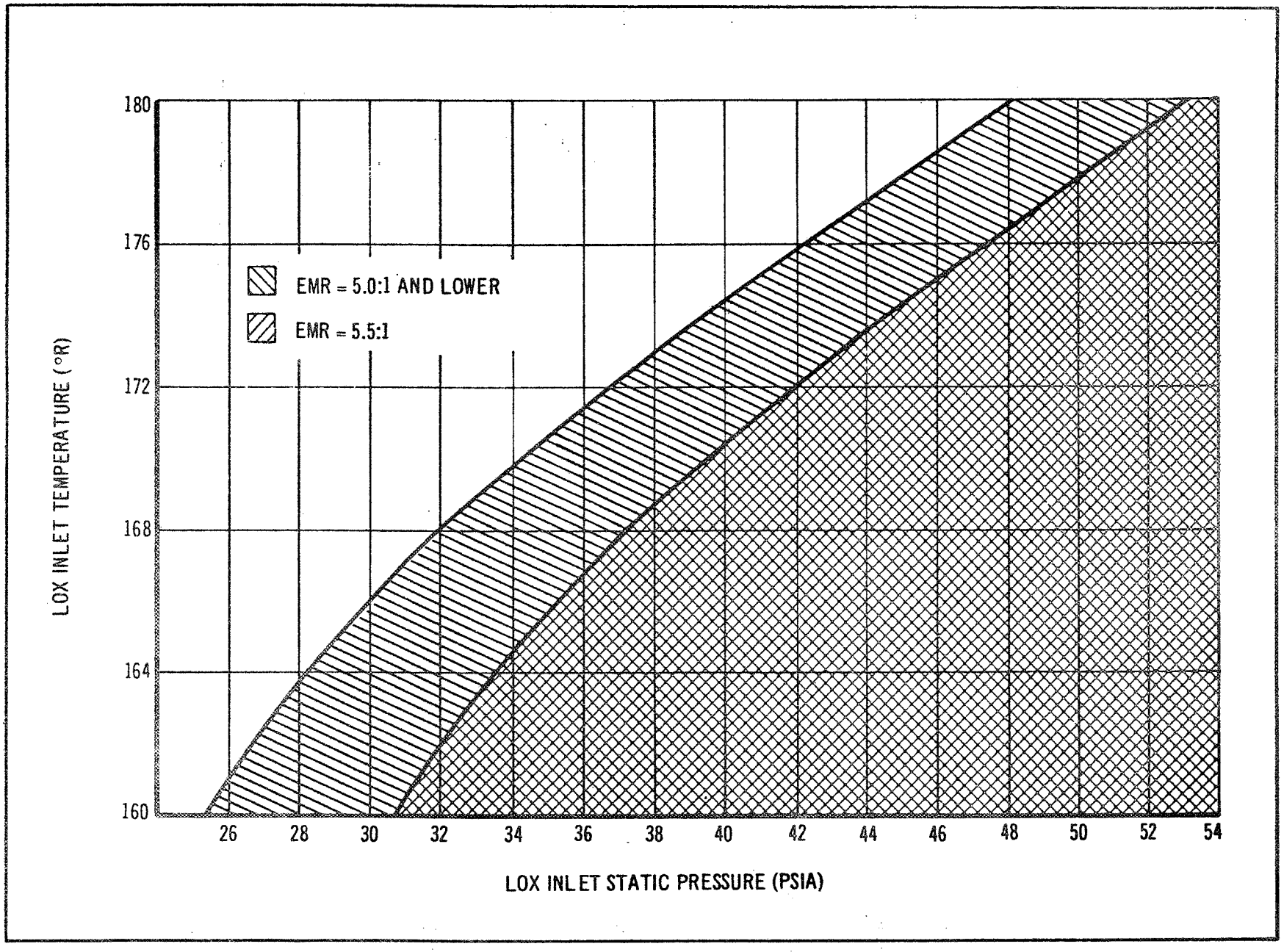


Figure 21. LOX Operating Limits

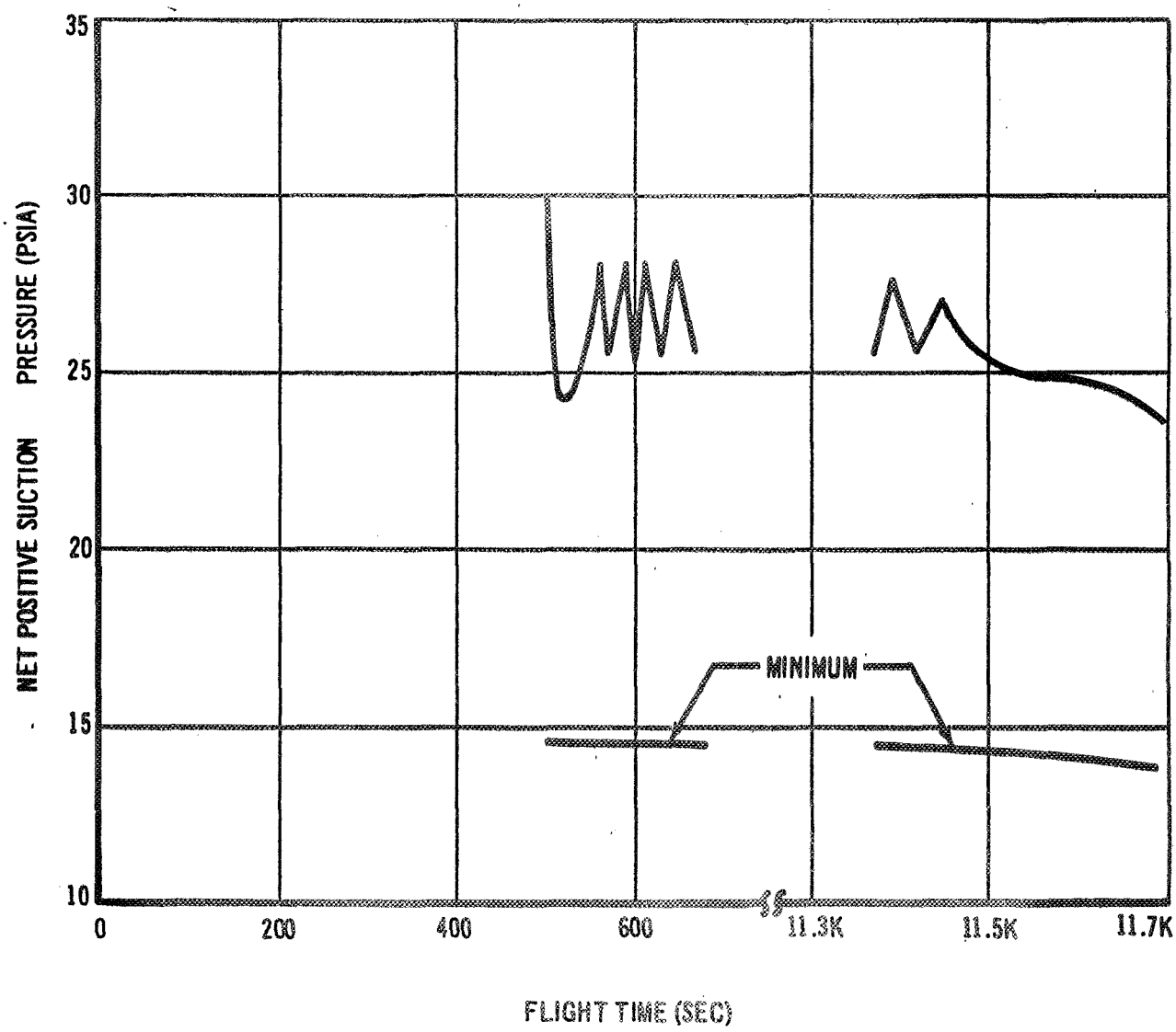


Figure 22. Expected LOX Interface NPSH History

1.8 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of LOX Repressurization Capability: Due to open pressurization system valves, leakage or flow stoppage of pressurizing He, loss of electrical power or command.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 22.02 LOX Tank Ullage Pressure; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Prior to J2 engine programmed second start.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure of J2 engine to start.

6. TIME DEPENDENCY OF FAILURE: MFRT = 20 seconds (ullage pressure).

7. OVERALL FAILURE MODE CRITICALITY: 620

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: (1) Repressurization He quantity (ambient supply).
(2) LOX tank ullage pressure.

11. SENSOR LOCATION: (1) None.
(2) XD0179-424
D0180-424

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: (1) As shown in figure 23.
(2) 38 to 41 psia (repressurization and 2nd burn).

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (2) As shown in item 13.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Inability to repressurize the LOX tank results in turbopump cavitation.

17. FLIGHT HISTORY: As shown in figure 23.

18. DISCUSSION: During phase E (coast phase before engine second burn), switch 22.02-06 starts repressurization cycle when LOX tank pressure drops below 38 psia.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

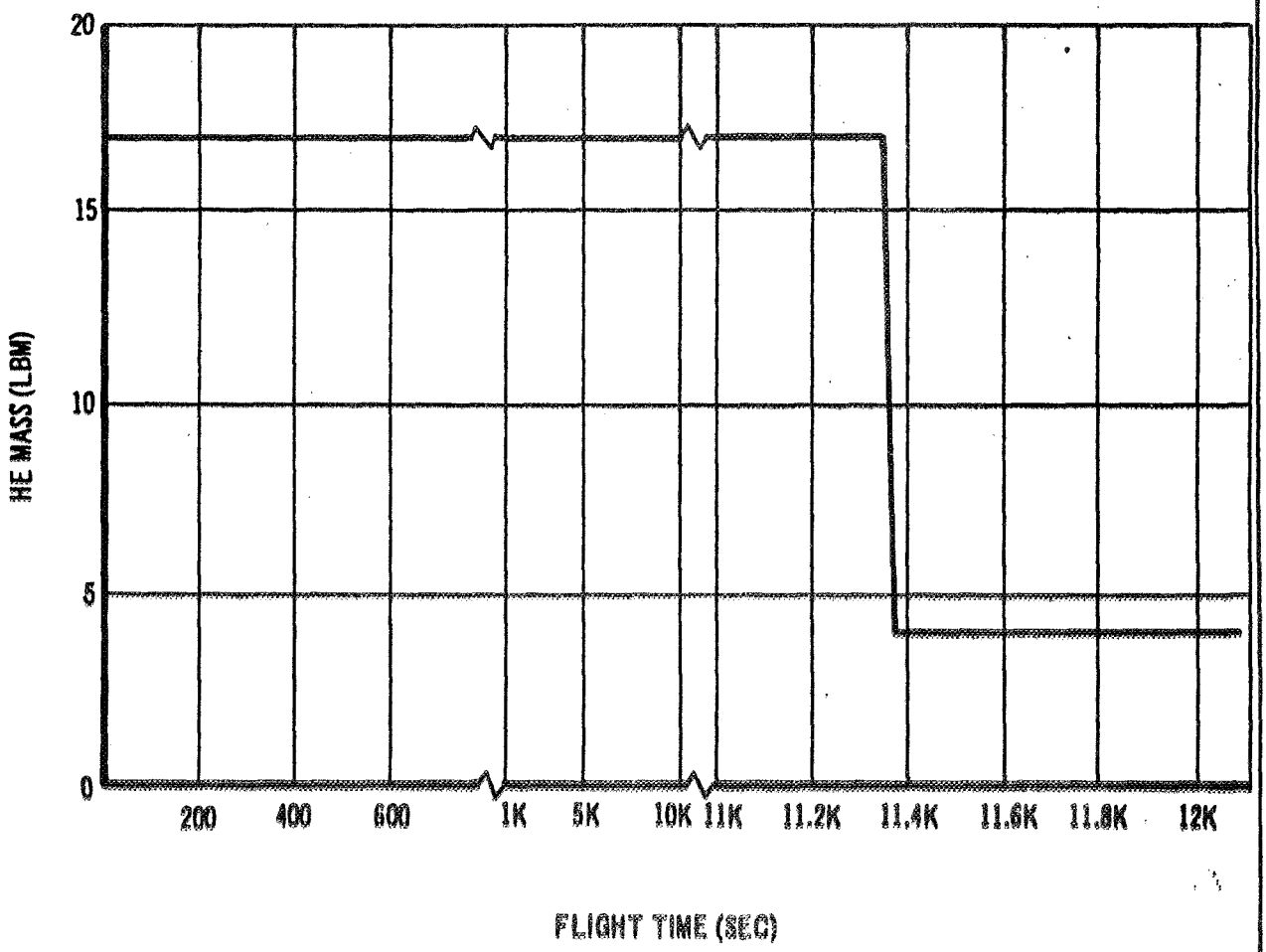


Figure 23. Lox Tank Repressurization Helium Mass

1.9 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of LH_2 Feed: Due to closed LH_2 shutoff valves, loss of pneumatic power, loss of electrical power or command.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 23.01 LH_2 Feed and Chilldown; 24 Pneumatic Control; 26 Thrust; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: During J2 engine burn.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure of J2 engine to start or premature cutoff.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (LH_2 shutoff valves).

7. OVERALL FAILURE MODE CRITICALITY: 720

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) LH_2 flow rate.
(2) LH_2 pre-valve open/closed.
(3) LH_2 main shutoff valve open/closed.
(4) Pneumatic He quantity.

11. SENSOR LOCATION:
(1) F0002-401
(2) K0111-404
K0112-404
(3) VK0018-401
K0019-401
(4) VKD0014-403

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL:
(2) 5.0: 1 EMR LH_2 flow rate = 78.5 lb/sec.
4.43: 1 EMR LH_2 flow rate = 76.1 lb/sec.
(4) As shown in figure 6.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: Not available.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Loss of thrust due to fuel starvation.

17. FLIGHT HISTORY: First burn EMR = 5.0: 1
Second burn 1st 5.5 seconds and last 147.4 seconds EMR = 5.0: 1.
Second burn middle 163.2 seconds EMR = 4.5: 1.

18. DISCUSSION: Shutoff valve 23.01-05 provides emergency shutoff capability. Shutoff valve opens prior to engine start and closes about one half second after shutoff. It opens 60 seconds later and closes one half second after second shutoff of the engine. Shutoff valve opens 60 seconds later and remains open.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, 14, & 15.

1.10 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of LOX Feed: Due to closed LOX shutoff valves, loss of pneumatic power, loss of electrical power or command.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 23.02 LOX Feed and Chilldown; 24 Pneumatic Control; 26 Thrust; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Prior to and during J2 engine burn.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure of J2 engine to start or premature cutoff.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (LOX shutoff valve).

7. OVERALL FAILURE MODE CRITICALITY: 930

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) LOX flow rate.
(2) LOX pre-valve open/closed.
(3) LOX main shutoff valve open/closed.
(4) Pneumatic He quantity.

11. SENSOR LOCATION:
(1) F0001-401
(2) K0109-403
K0110-403
(3) VK0120-401
K0121-401
(4) VXD0014-403

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL:
(2) 5.0: 1 EMR LOX flow rate = 404.5 lb/sec.
4.43:1 EMR LOX flow rate = 337 lb/sec.
(4) As shown in figure 6.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: Not available.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Loss of thrust due to engine LOX starvation.

17. FLIGHT HISTORY: First burn, EMR = 5.0:1.
Second burn, 1st 5.5 seconds and last 147.4 seconds, EMR = 5.0:1.
Second burn, middle 163.2 seconds, EMR = 4.5:1.

18. DISCUSSION: Shutoff valve 23.02-05 provides emergency shutoff capability to the main LOX valve. Shutoff valve opens prior to first engine start and closes about one half second after shutoff. It opens 60 seconds later and closes one half second after second engine shutoff. Valve opens 60 seconds later and remains open.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, 14, & 15.

1.11 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: High LH_2 Temperature: Loss of bypass regulator, loss of electrical power or command to open bypass regulator, loss of electrical power or signal.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 22.01 LH_2 Tank Ullage Pressure; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: During J2 engine burn.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure of J2 engine to start or premature cutoff.

6. TIME DEPENDENCY OF FAILURE: MFRT = 330 seconds (bypass regulator).

7. OVERALL FAILURE MODE CRITICALITY: 340

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) LH_2 tank temperature.
(2) LH_2 tank ullage temperature.

11. SENSOR LOCATION:
(1) C0051-408 thru C0053-408
C0062-408 thru C0068-408
(2) C0034-408 thru C0039-408

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: LH_2 temp. = -423°F at 1 atm.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: -425° to -413°F

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Stratification of the LH_2 into layers would occur which would cavitate the LH_2 turbopump.

17. FLIGHT HISTORY: Within limits stated in item 13 throughout flight.

18. DISCUSSION: Bypass regulator 22.01-17.03 maintains LH_2 tank pressure at 20 to 20.5 psia during phase E (coast phase before engine second burn) by bleeding excess gaseous hydrogen overboard through the continuous vent system. Valve 22.01-17.01 bleeds gaseous hydrogen through the continuous vent system at approximately the rate of boiloff thereby allowing 22.01-17.03 to remain closed most of the time.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

1.12 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Propellant Sloshing: Due to loss of continuous venting system, loss of electrical power or command.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 22.01 LH_2 Tank Ullage Pressure; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: During J2 engine burn.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to failure to start or premature engine cutoff.

6. TIME DEPENDENCY OF FAILURE: MFRT = 330 seconds (continuous vent shutoff valve).

7. OVERALL FAILURE MODE CRITICALITY: 460

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: (1) Continuous venting pressure (LH_2 tank pressure).
(2) Continuous vent shutoff valve open/closed.

11. SENSOR LOCATION: (1) D0181-409, D0182-409 (2) K0154-410, K0155-410

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: (1) 20.5 psia.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (1) 20 to 20.5 psia.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Propellant sloshing may introduce vapor into propellant feed lines and cause pump cavitation.

17. FLIGHT HISTORY: Pressure constant during orbital coast phase.

18. DISCUSSION: Shutoff valve 22.01-17.01 controls the flow of ullage gases to the continuous vent nozzles. Failure would result in irregular accelerations being produced by the opening and closing of bypass regulator 22.01-17.03 as it attempts to maintain correct pressure. Unsettling of propellants may result.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

1.13 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: LH_2 Depletion: Due to open or leaking LH_2 fill and drain valve, leaking LH_2 ducts, loss of pneumatic power, open main LH_2 valve, or open gas generator valve.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 21.01 LH_2 Fill and Drain; 23.01 LH_2 Feed and Chilldown; 24 Pneumatic Control; 26 Thrust.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Up to J2 engine second cutoff.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to premature J2 engine cutoff.

6. TIME DEPENDENCY OF FAILURE: Not available.

7. OVERALL FAILURE MODE CRITICALITY: 33

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: LH_2 quantity.

11. SENSOR LOCATION: L0001-408
L0002-408

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: As shown in figure 24.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: 1.3% RSS (3 σ value)

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Engine operation would terminate before programmed cutoff due to fuel starvation.

17. FLIGHT HISTORY: As shown in figure 24.

18. DISCUSSION: Depletion cutoff occurs with an LH_2 mass of 490 lb.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

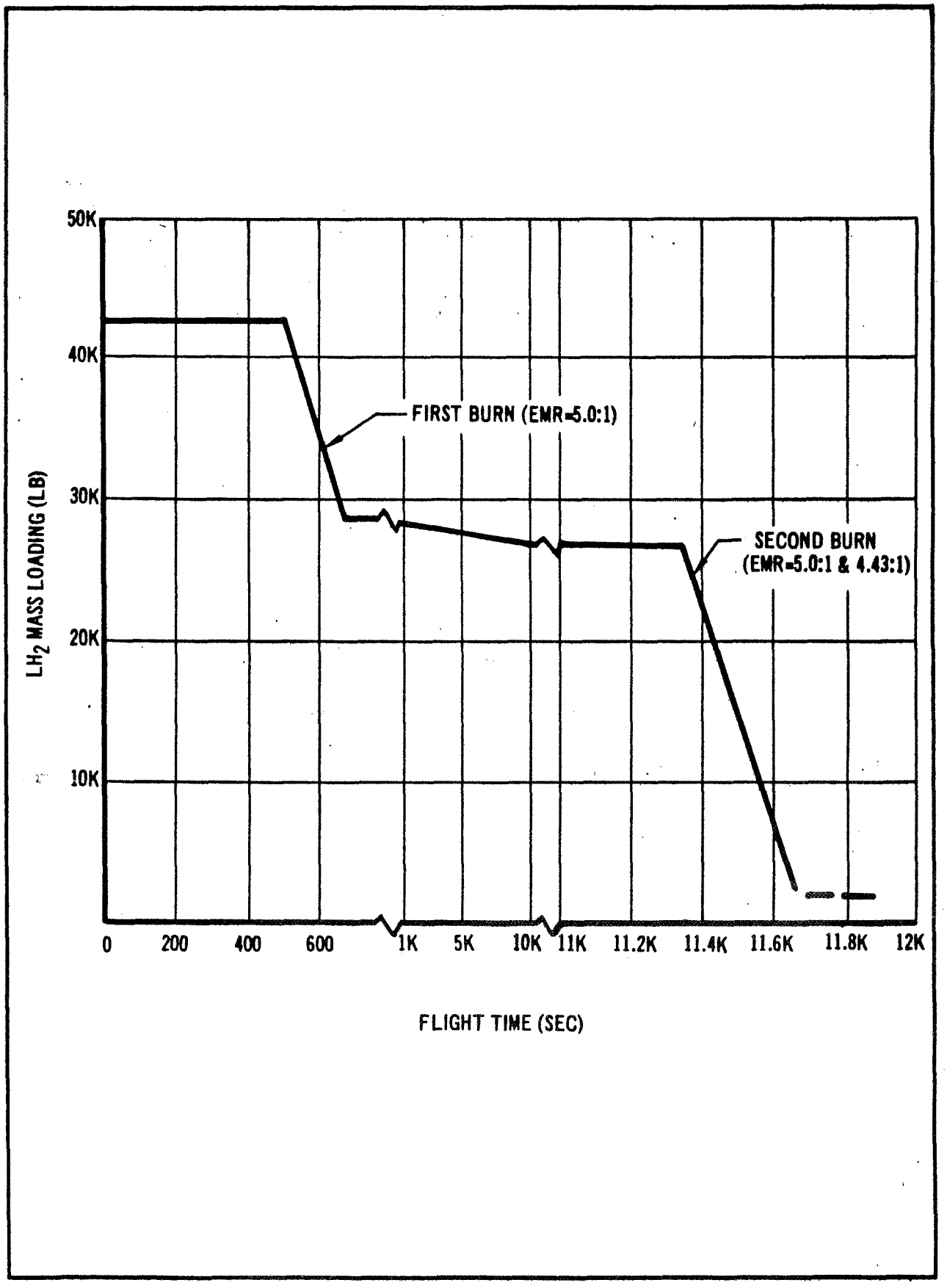


Figure 24. Expected LH_2 Mass History

1.14 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: LOX Depletion: Due to open or leaking LOX fill and drain valve, leaking LOX ducting, loss of pneumatic control, open main LOX valve, or propellant utilization (PU) valve driven to hard closed position.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 21.02 LOX Fill and Drain; 23.02 LOX Feed and Chilldown; 24 Pneumatic Control; 26 Thrust; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution; 46 Propellant Utilization.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Until J2 engine second cutoff.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to premature cutoff.

6. TIME DEPENDENCY OF FAILURE: Not available.

7. OVERALL FAILURE MODE CRITICALITY: 830

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: LOX quantity.

11. SENSOR LOCATION:

L0004-406	L0008-406	L0011-406
L0005-406	L0009-406	L0012-406
L0006-406	L0010-406	L0013-406

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: As shown in figure 25.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: 1.3% RSS (3σ value).

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Engine operation would terminate before programmed cutoff due to oxidizer starvation.

17. FLIGHT HISTORY: As shown in figure 25.

18. DISCUSSION: Failure in the PU electronics which would give a spurious output to drive the PU valve to hard close (EMR = 5.62:1) would deplete the LOX and would lower the total impulse. Depletion cutoff occurs with a LOX mass of 1880 lb.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

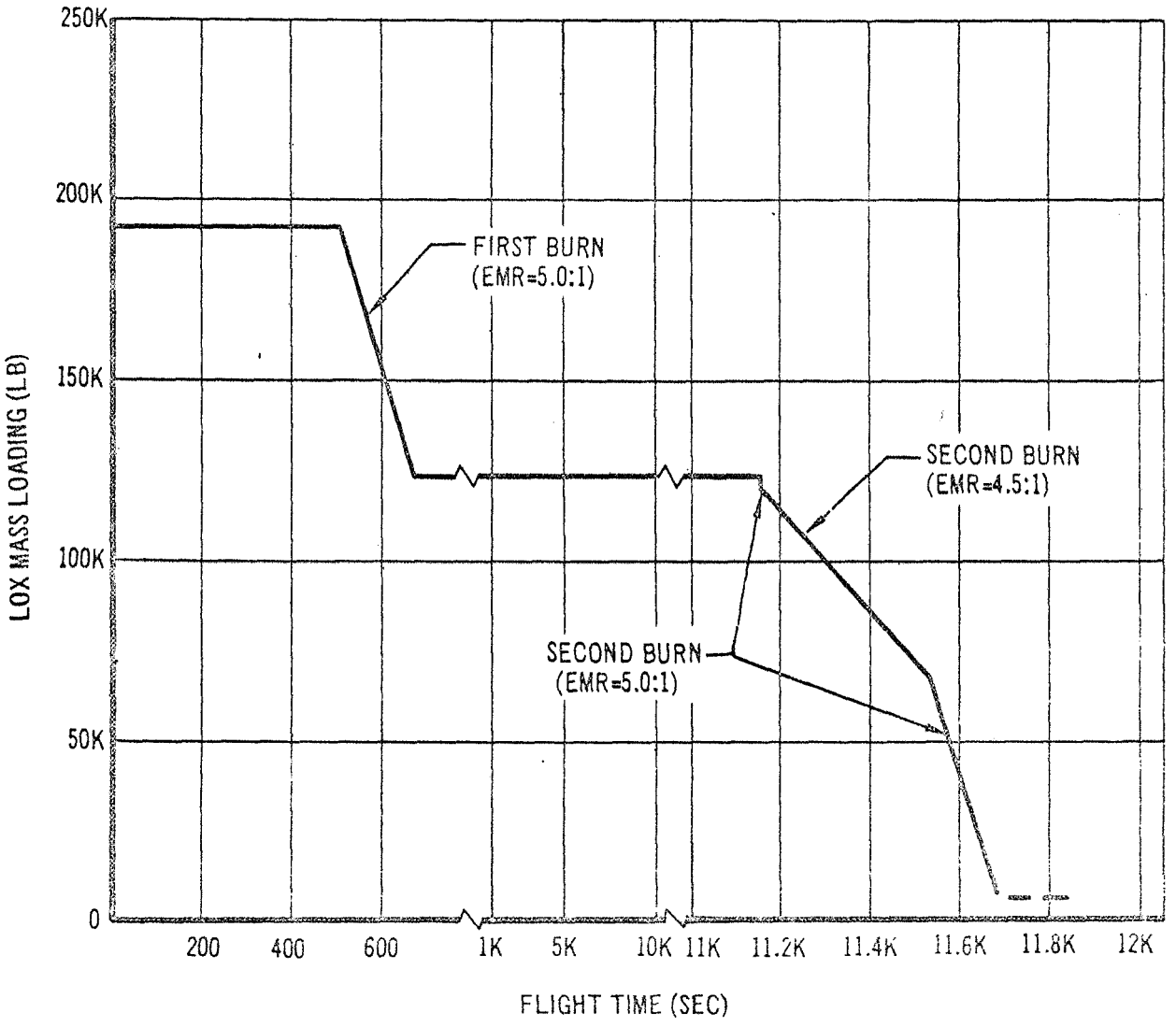


Figure 25. Expected Lox Mass History

1.15 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Vapor in LOX Feed Lines: Due to open chilldown shutoff valve, loss of pneumatic power, loss of electrical power, or loss of pneumatic system operating signals.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 23.02 LOX Feed and Chilldown; 24 Pneumatic Control; 26 Thrust; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: During J2 engine second burn.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to premature cutoff.

6. TIME DEPENDENCY OF FAILURE: MFRT = 2 seconds (LOX chilldown shutoff valve).

7. OVERALL FAILURE MODE CRITICALITY: 740

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) Chilldown shutoff valve open/closed.
(2) Cold He pressure.
(3) Engine control He supply.
(4) Pneumatic He supply.

11. SENSOR LOCATION:
(1) K0138-424, K0139-424
(2) VXD0016-425
(3) VXD0019-401
(4) VXD0014-403

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: (4) As shown in figure 6.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: Not available.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Premature J2 engine cutoff would occur due to the oxidizer being supplied to the engine partially in the vapor phase.

17. FLIGHT HISTORY: As shown in figure 6.

18. DISCUSSION: Oxygen vapor may flow into the LOX feed line only when the liquid level is not sufficient in the chilldown feed line as during the last few seconds of J2 engine second burn or if ullage thrust is insufficient before start.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, 14, & 15.

1.16 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Premature Engine Shutdown Initiation: Due to closed propellant shutoff valves, loss of pneumatics, faulty J2 engine operation, premature range safety charging, loss of electrical power, or spurious cutoff signal.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 23.01 LH_2 Feed and Chilldown; 23.02 LOX Feed and Chilldown; 24 Pneumatic Control; 26 Thrust; 41 Electrical Power; 42 Electrical Control; 81 Range Safety.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Up to programmed J2 engine second burnout.

5. FAILURE MODE CONSEQUENCE: Loss of thrust due to premature cutoff.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (propellant shutoff valves).

7. OVERALL FAILURE MODE CRITICALITY: 2600

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) Cutoff signal.
(2) Range safety arm/cutoff signal.
(3) Propellant shutoff valves open/closed.
(4) Forward 1 and Aft 1 bus voltage and load.

11. SENSOR LOCATION:

(1) K0013-401	(3) K0136-409	(4) M0014-404
(2) K0098-411	K0137-409	M0015-411
K0099-411	K0138-424	M0019-411
	K0139-424	M0021-404

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: (4) As shown in figures 26 and 27.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (4) Fwd bus 1: 30 to 35 VDC (prestart).
Aft bus 1: 30 to 35 VDC (prestart).
(4) See figures 24 and 25.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Engine operation would terminate prematurely because of propellant starvation or an erroneous cutoff signal.

17. FLIGHT HISTORY: (4) As shown in figures 26 and 27.

18. DISCUSSION: Engine cutoff is normally a velocity cutoff [illegible] programmed signal from the Instrument Unit via switch selector. Cutoff may also be accomplished by signal from range safety or the emergency detection system or by the propellant tank depletion sensors. Uncovering [illegible] the 3 depletion sensors in each tank will initiate engine cutoff after a fixed time delay; [illegible] seconds for LH_2 and [illegible] seconds for LOX.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

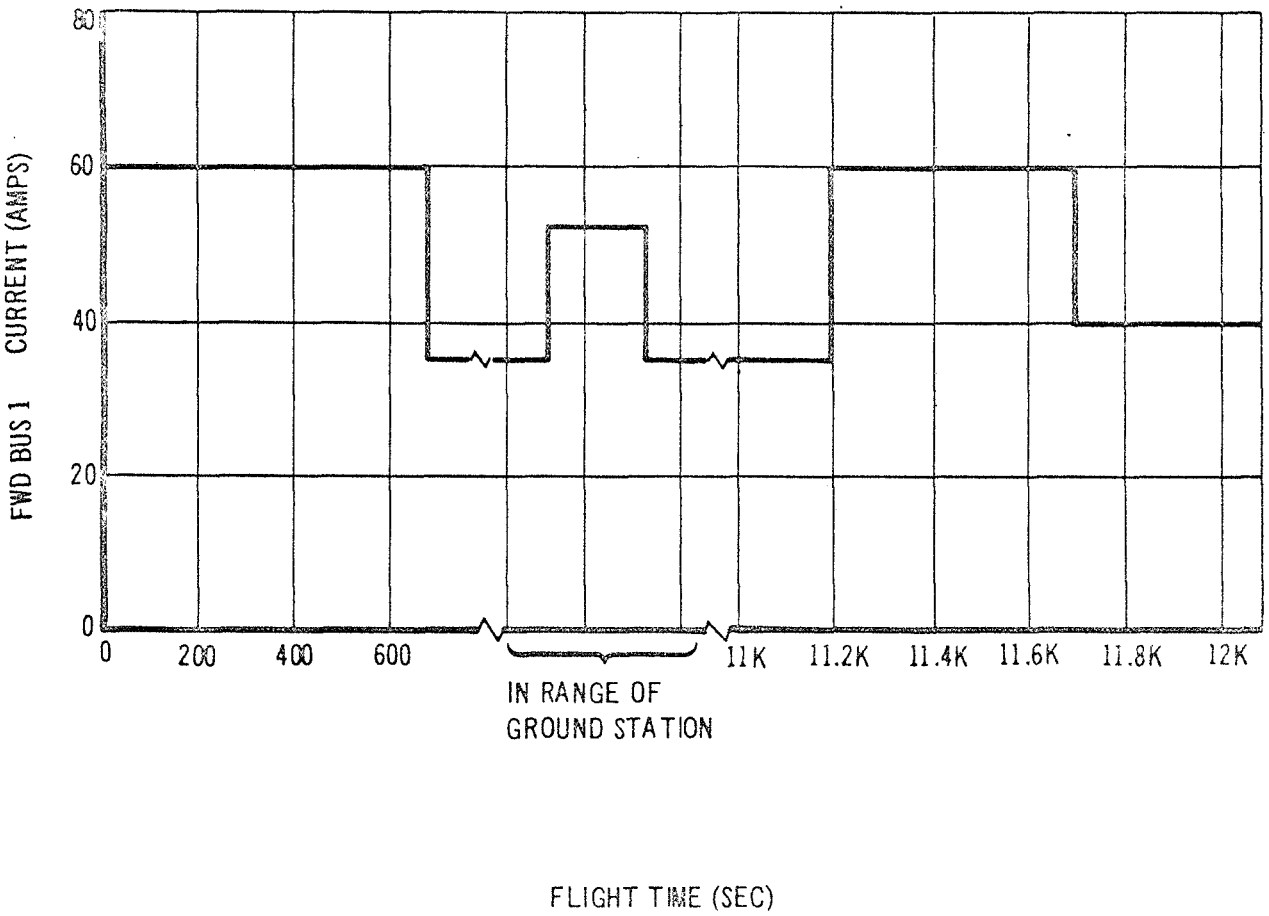


Figure 26. Forward Battery No. 1 Expected Current Profile

FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of Hydraulic Pressure: Due to failure of hydraulic pumps, air or fluid leakage, failure of accumulator, loss of fluid temperature control, loss of electrical power or control.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 31 Hydraulic: 41 Electrical Power: 42 Electrical Control.

4 PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Up to J2 engine second burnout.

5. FAILURE MODE CONSEQUENCE: Loss of flight control due to loss of steering ability.

6. TIME DEPENDENCY OF FAILURE: MFRT = 2 seconds (hydraulic system).

7. OVERALL FAILURE MODE CRITICALITY: 2400

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) Hydraulic pressure.
(2) Hydraulic fluid quantity.
(3) Hydraulic fluid temperature.
(4) Fwd 1 and Aft 2 load.

11. SENSOR LOCATION:

(1) VD0042-403	(3) VC0051-403	(4) M0015-404
(2) VXL0007-403	C0218-401	M0016-411
(3) VC0050-401		M0019-411
		M0022-404

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL:
(1) GN_2 limits shown in figure 29.
(3) Main hydraulic pump inlet temp during J2 engine burn: 0° to 260°F.
(4) As shown in figures 7 and 26.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT:
(1) As shown in figure 26.
(2) As shown in figure 28.
(4) Fwd bus 1 and Aft bus 2: 30 to 35.5 VDC (prestart).

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Loss of steering ability would occur because of inability to position the engine gimbal actuators.

17. FLIGHT HISTORY: Not available.

18. DISCUSSION: Auxiliary pump delivers 1.5 gpm at 3550 to 3650 psig as sole source. Auxiliary pump provides temperature control, maintains system readiness and serves as redundant source. Main hydraulic pump is driven by J2 engine and delivers 7.0 gpm at 3550 to 3650 psig.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, 15, & 17.

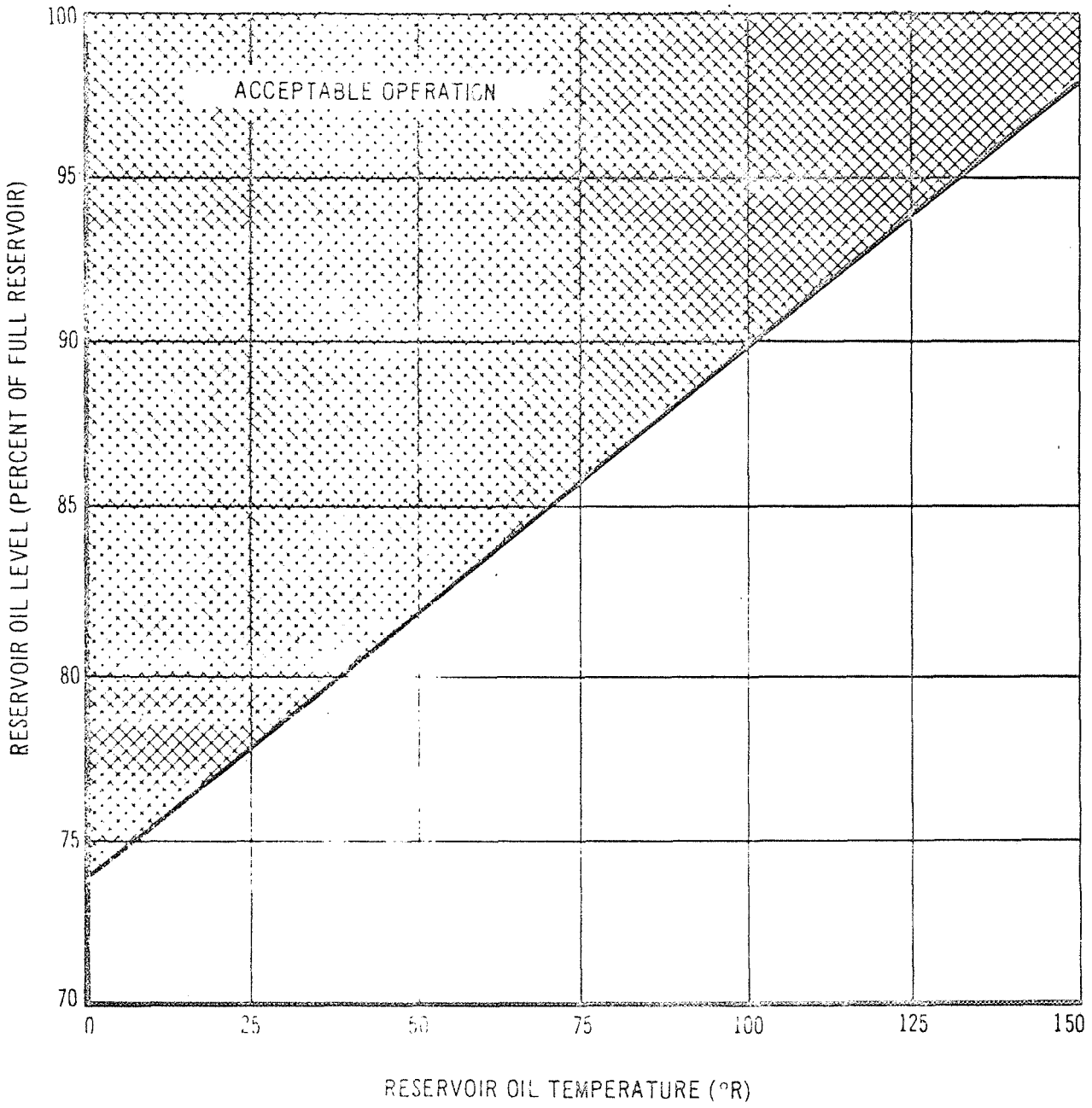


Figure 28. Hydraulic Reservoir Oil Limits

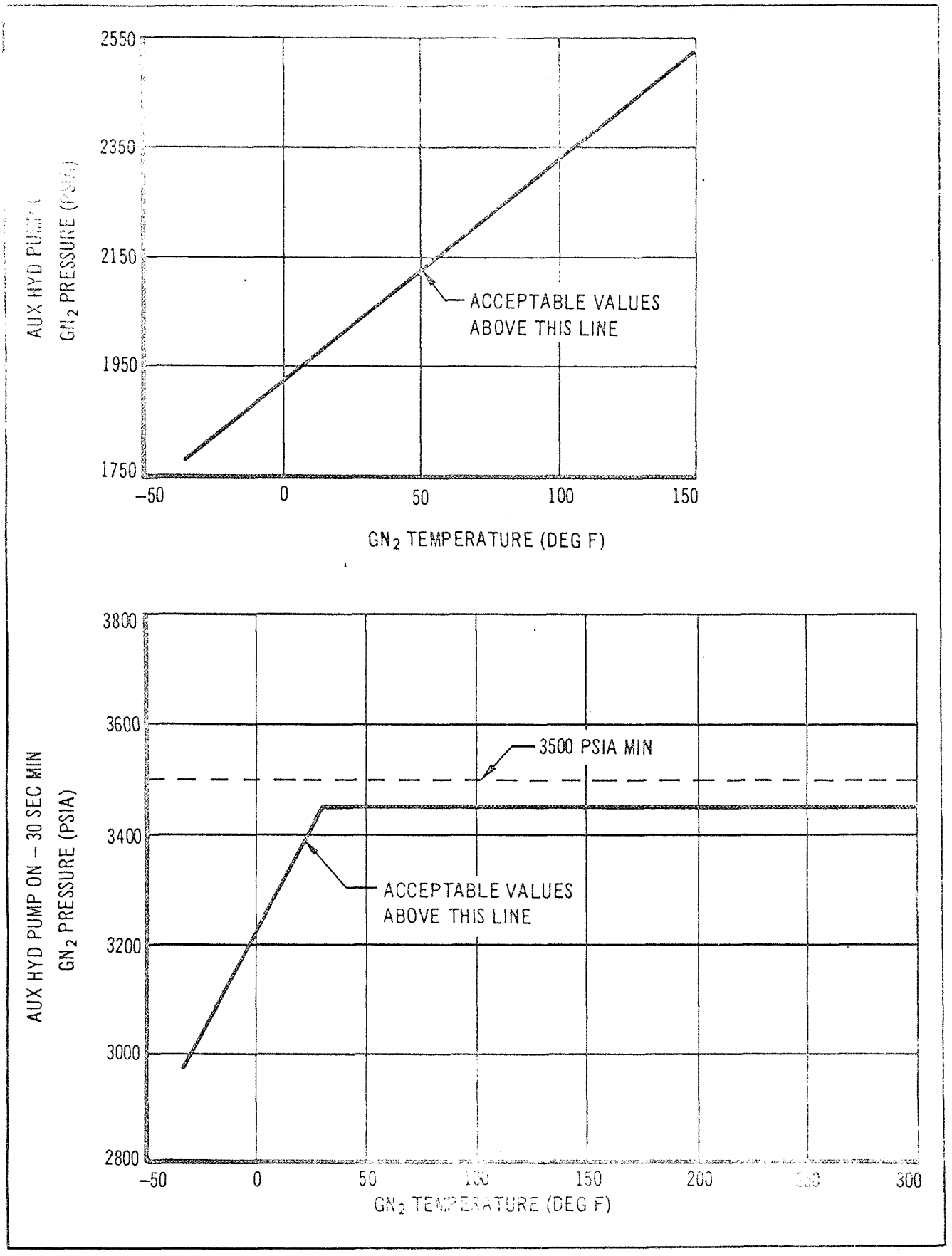


Figure 29. Hydraulic System GN_2 Mass Limits

[illegible] EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of Steering Control: Failure of hydraulic actuators to operate, loss of electrical power or control.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 31 Hydraulic; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Until J2 engine second burnout.

5. FAILURE MODE CONSEQUENCE: Loss of flight control due to loss of steering ability.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (hydraulic actuators).

7. OVERALL FAILURE MODE CRITICALITY: 1300

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: Actuator positions.

11. SENSOR LOCATION: G0001-403
G0002-403

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: As shown in figure 30.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: As shown in figure 30.

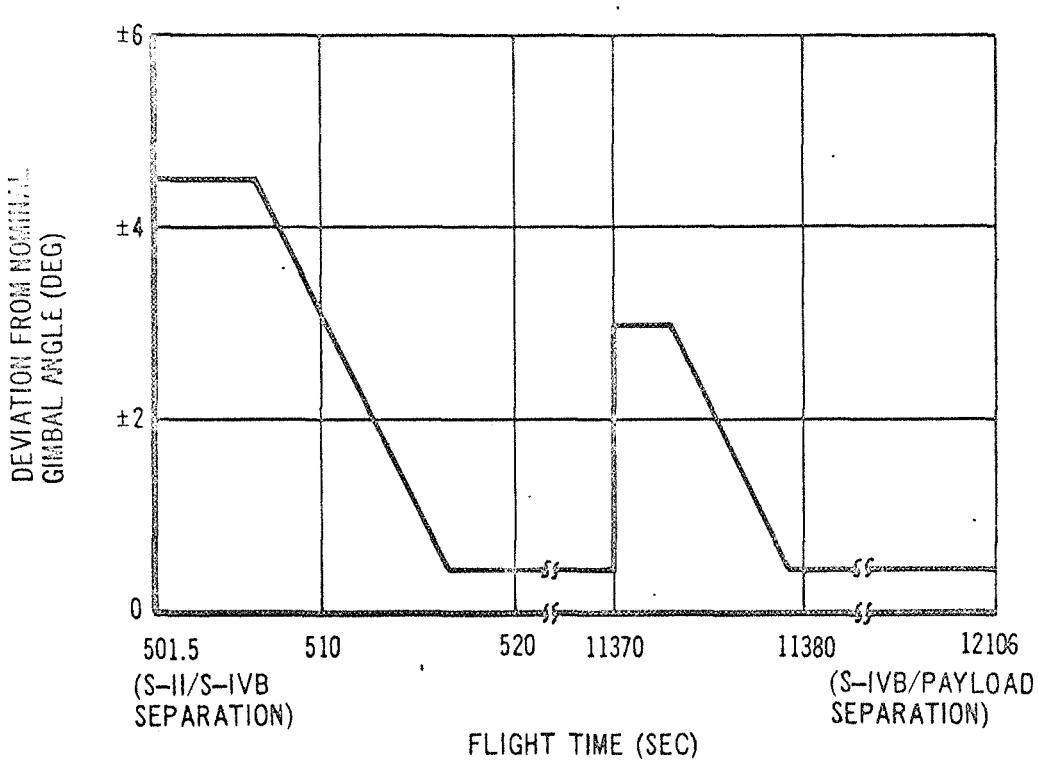
15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Loss of ability to steer during thrust phases would occur due to loss of the pitch and yaw gimbaling capability of the hydraulic actuators.

17. FLIGHT HISTORY: As shown in figure 30.

18. DISCUSSION: Suggested additional parameters: guidance signals.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, 14, & 15.



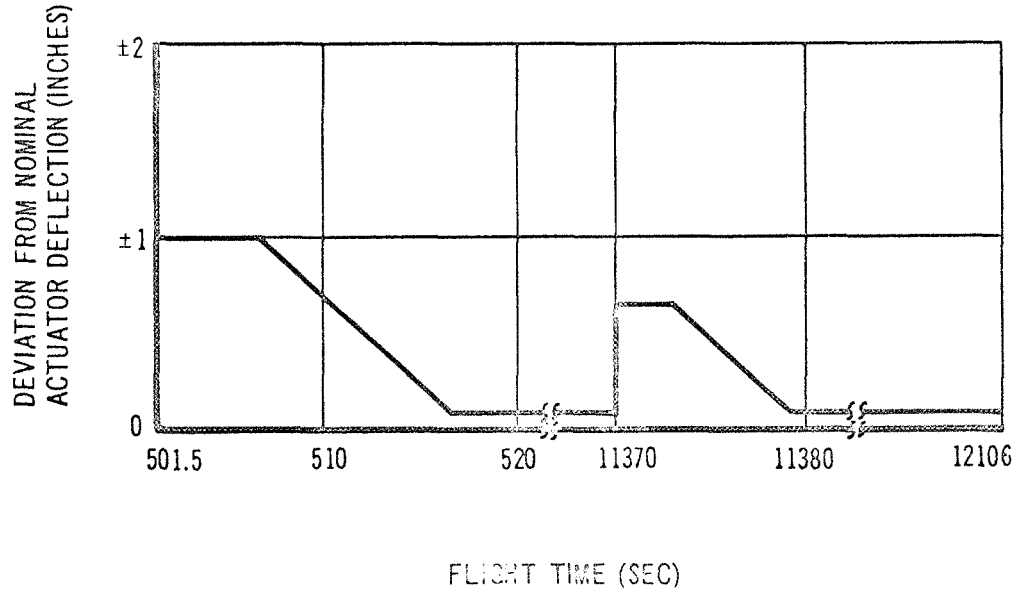


Figure 30. J2 Engine Actuator and Gimbal Angle History

1.19 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of Attitude Control; Due to failure of auxiliary propulsion system (APS) to thrust, APS engine burnthrough, loss of electrical power or control signals.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 32.01 Auxiliary Propulsion 1; 32.02 Auxiliary Propulsion 2; 41.01 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Until stage separation from payload while in transfer orbit.

5. FAILURE MODE CONSEQUENCE: Loss of flight control due to loss of vehicle attitude control capability.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (APS).

7. OVERALL FAILURE MODE CRITICALITY: 2800

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) Pitch, yaw, and roll attitude and rate.
(2) Fwd. 1 and Aft 1 load.
(3) APS engine pressures.

11. SENSOR LOCATION:

(2)	M0014-404	(3) D0027-414	D0031-415
	M0016-411	D0028-414	D0032-415
	M0019-411	D0029-414	D0220-414
	M0021-404	D0030-415	D0221-415

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: As shown in figure 31 for parameters (1). As shown in figures 32 thru 36 for parameters (2).

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (1) As shown in figures 32 thru 36 for parameters (1). Max roll accel deviation = $\pm$ 1.5 deg/sec^2. (2) 30 to 35.5 VDC (prestart). (3) 75 to 125 psia (redline).

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Failure of the APS system will prevent the vehicle from maintaining a fixed attitude in any coordinate during coast and certain failures will cause loss of roll control during thrust phases.

17. FLIGHT HISTORY: As shown in figures 31 thru 36.

18. DISCUSSION: APS is disabled until 1.3 seconds before J2 engine start, at which time roll control engines 32.01-22 and -23 and 32.02-22 and -23 are enabled. During coast phases all engines are enabled.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

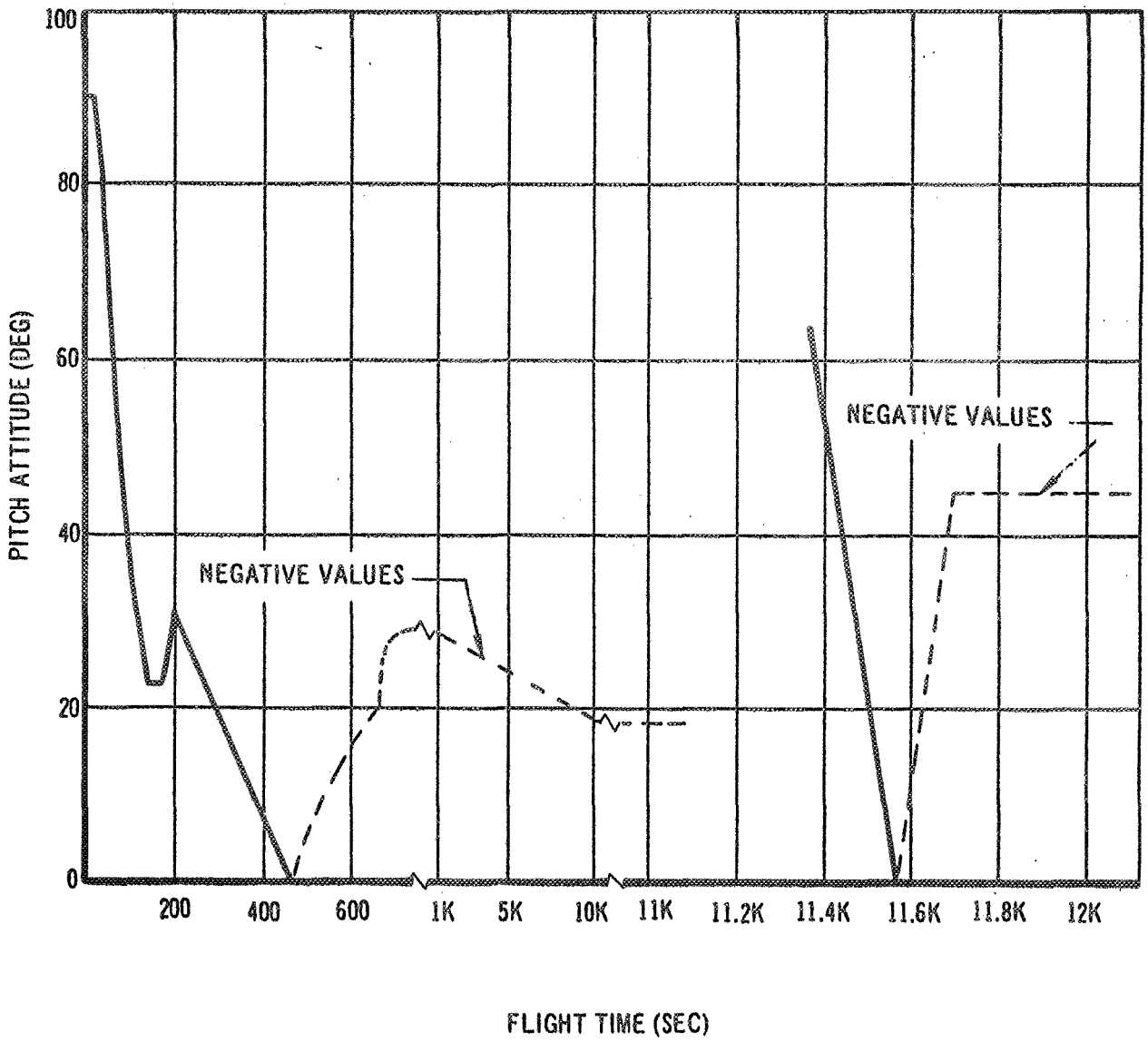


Figure 31. Nominal Expected Pitch Attitude History

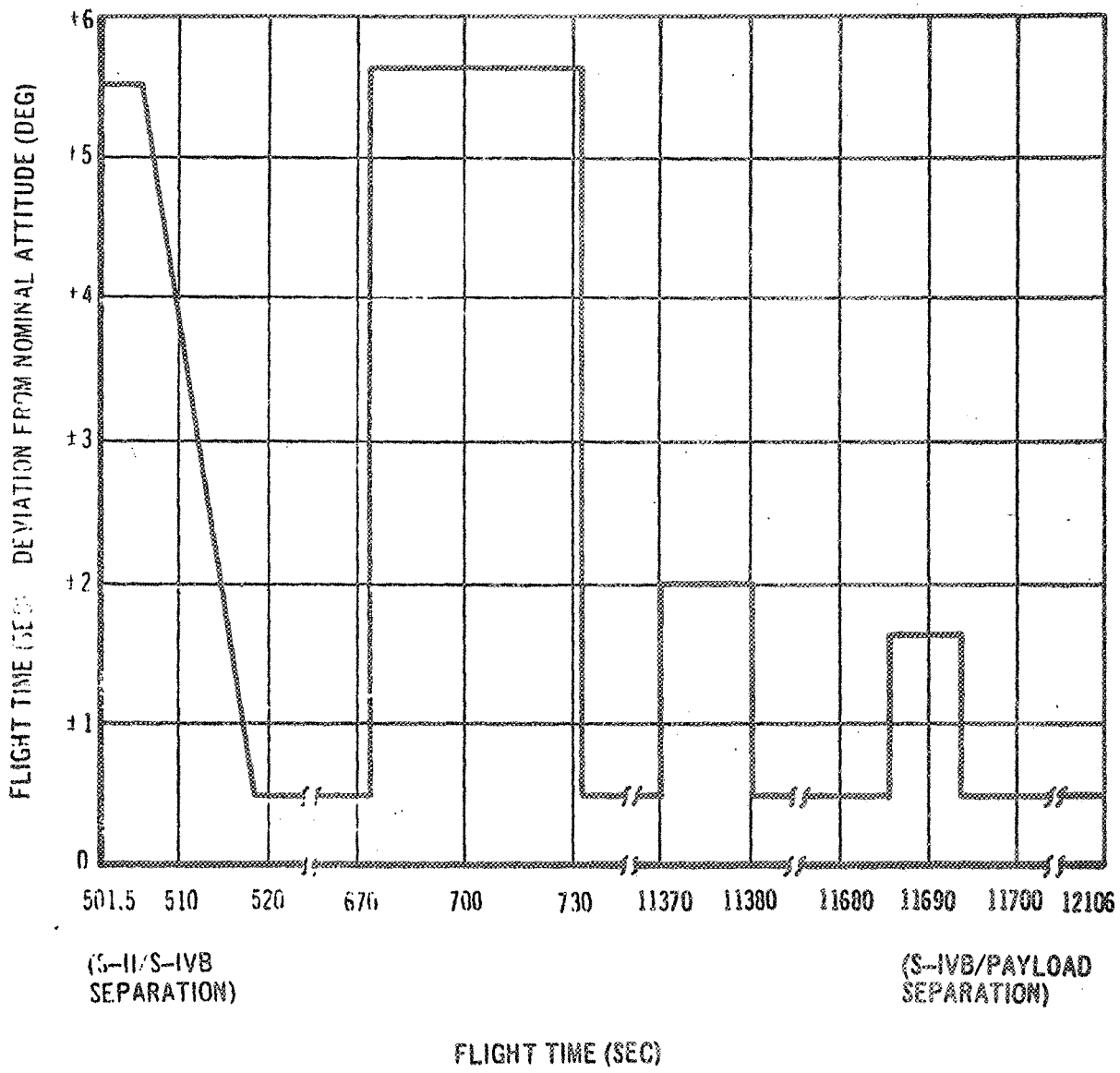


Figure 32. Maximum Expected Pitch & Yaw Attitude Deviation History

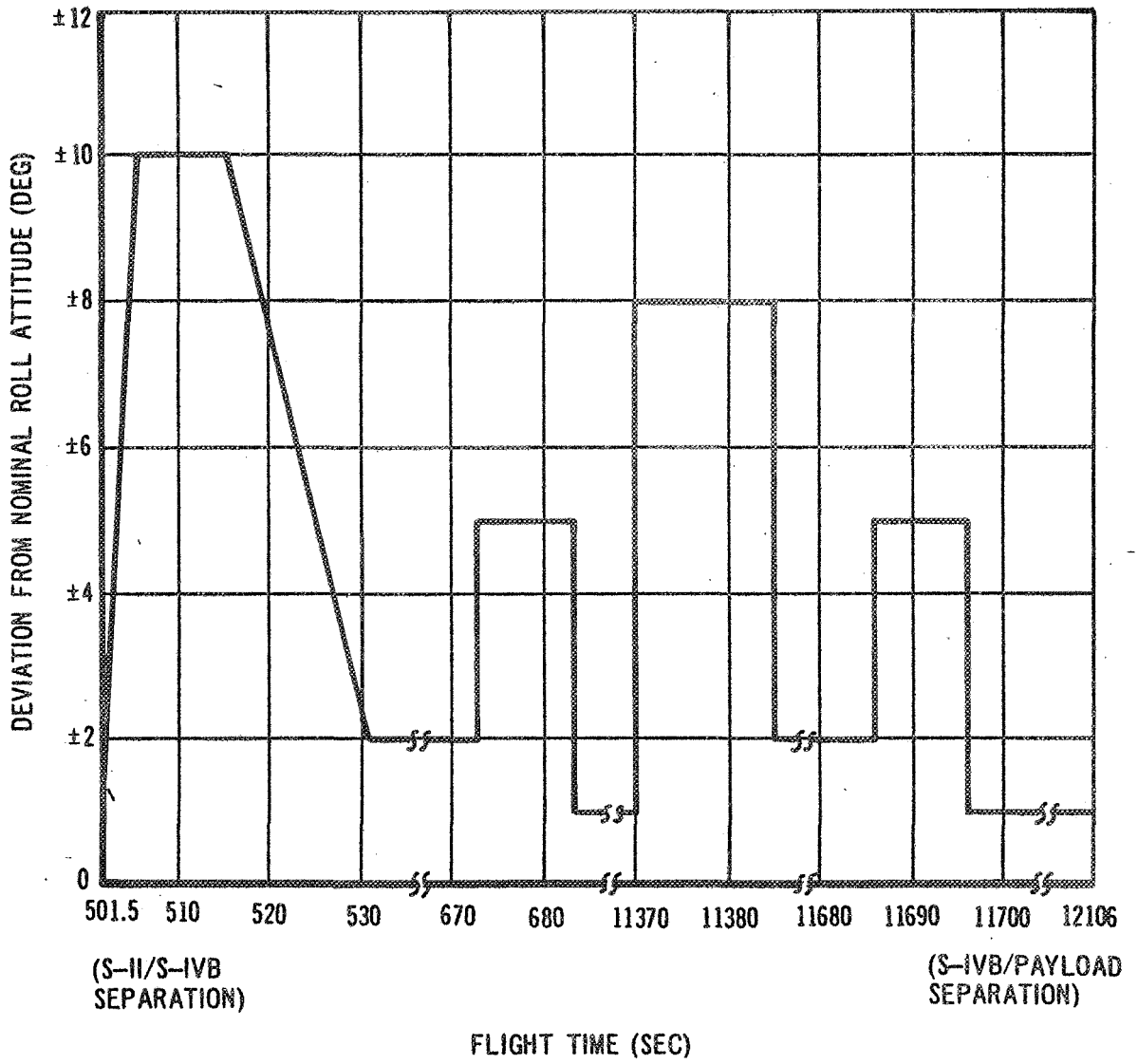


Figure 33. Maximum Expected Roll Attitude Deviation History

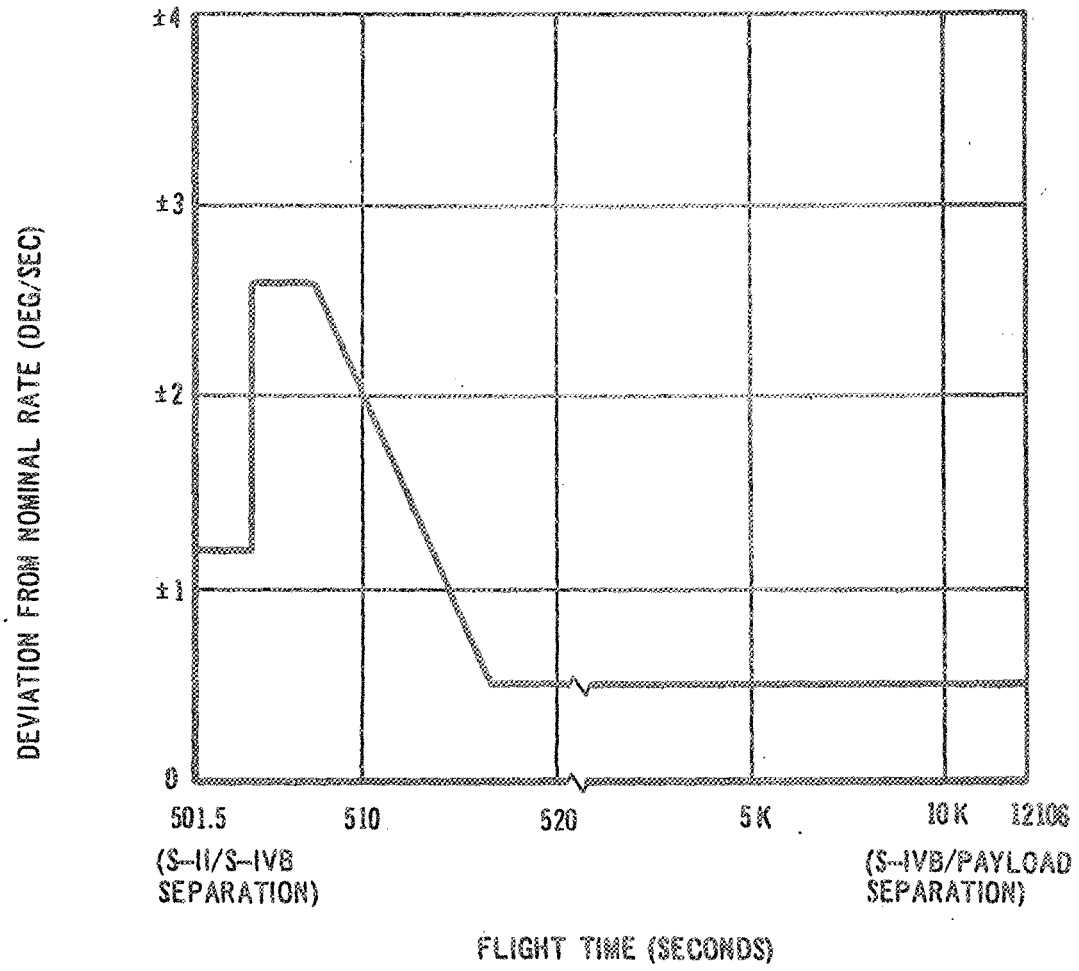


Figure 34. Maximum Expected Pitch & Yaw Rate Deviation History

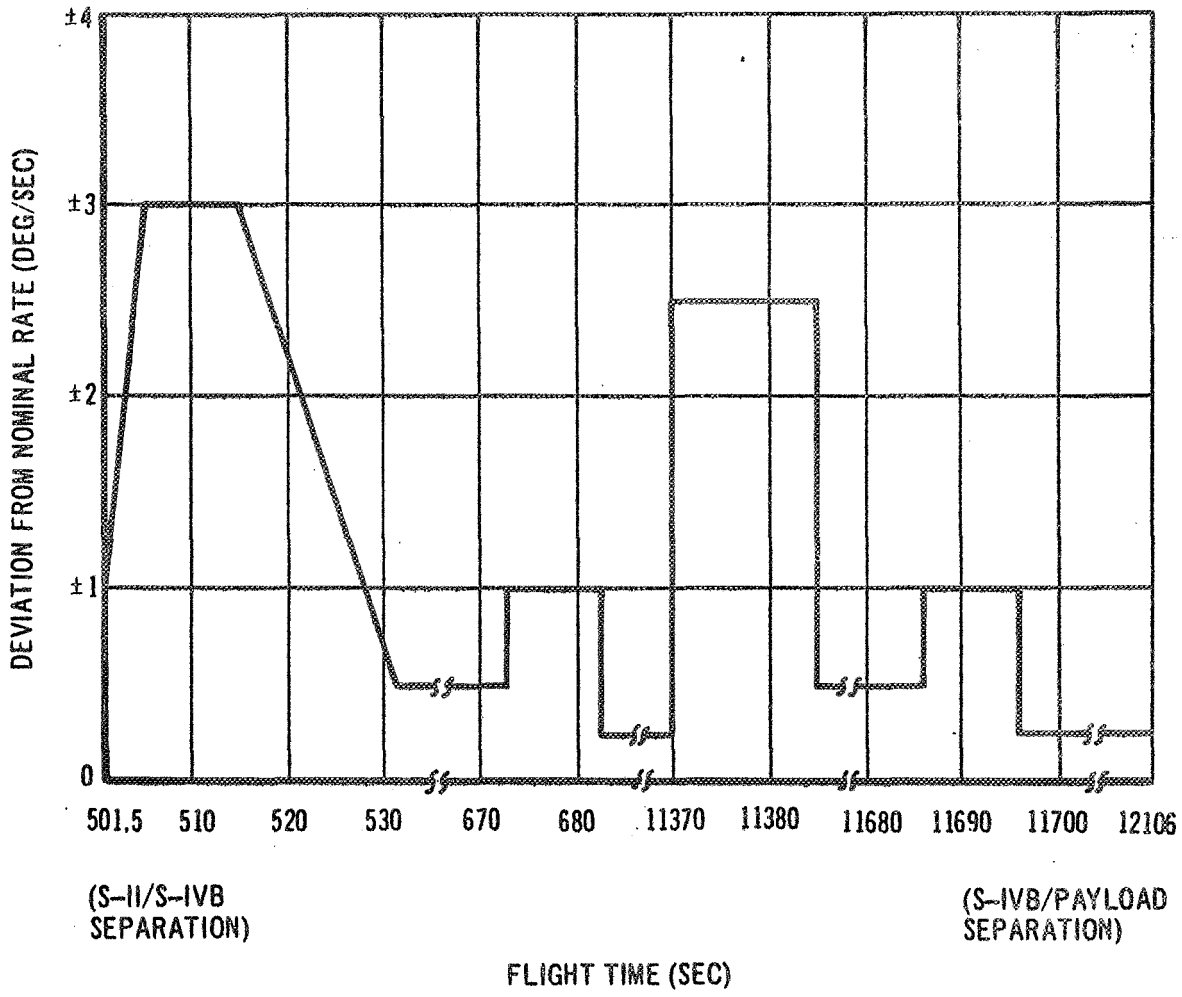


Figure 35. Maximum Expected Roll Rate Deviation

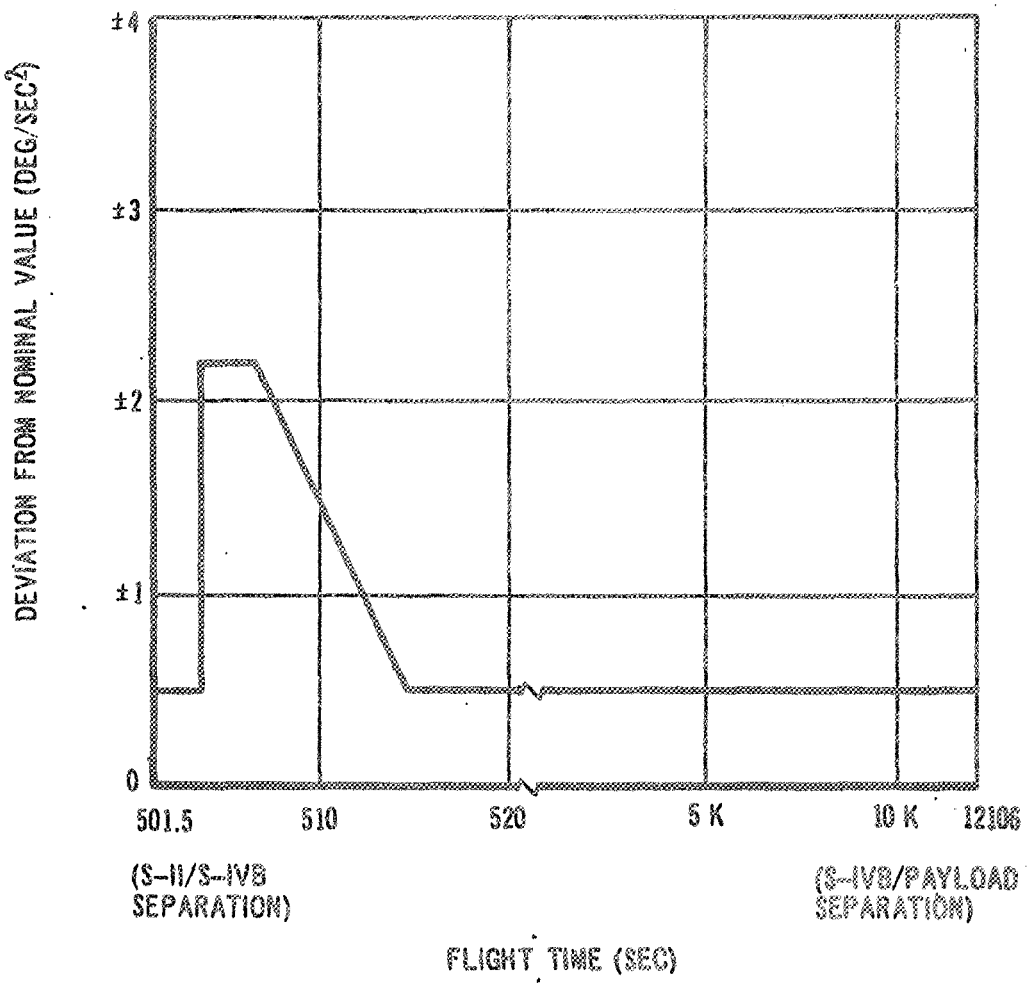


Figure 36. Maximum Expected Pitch & Yaw Acceleration Deviation History

1.20

FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: APS Propellant Depletion: Due to hypergolic propellant leakage, spurious electrical signals to APS, failure to shutoff propellant flow, excessive control requirement imposed by J2 engine and venting perturbations.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 26 Thrust; 32.01 Auxiliary Propulsion 1; 32.02 Auxiliary Propulsion 2; 42 Electrical Control.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: From J2 ignition to stage separation from payload.

5. FAILURE MODE CONSEQUENCE: Loss of flight control due to loss of vehicle attitude control capability.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (APS).

7. OVERALL FAILURE MODE CRITICALITY: 280

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) Hypergolic fuel quantity.
(2) Hypergolic oxidizer quantity.
(3) APS helium quantity.

11. SENSOR LOCATION: None.

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: (1) and (2) as shown in figure 37.
(3) as shown in figure 38.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: Not available.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Depletion of propellants and subsequent APS shutdown will prevent the vehicle from maintaining a programmed attitude in any of the three vehicle coordinates.

17. FLIGHT HISTORY: As shown in figures 37 and 38.

18. DISCUSSION: Excessive roll control requirements imposed on the APS during J2 engine operation may cause depletion of propellants before the end of the mission.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, 14, & 15.

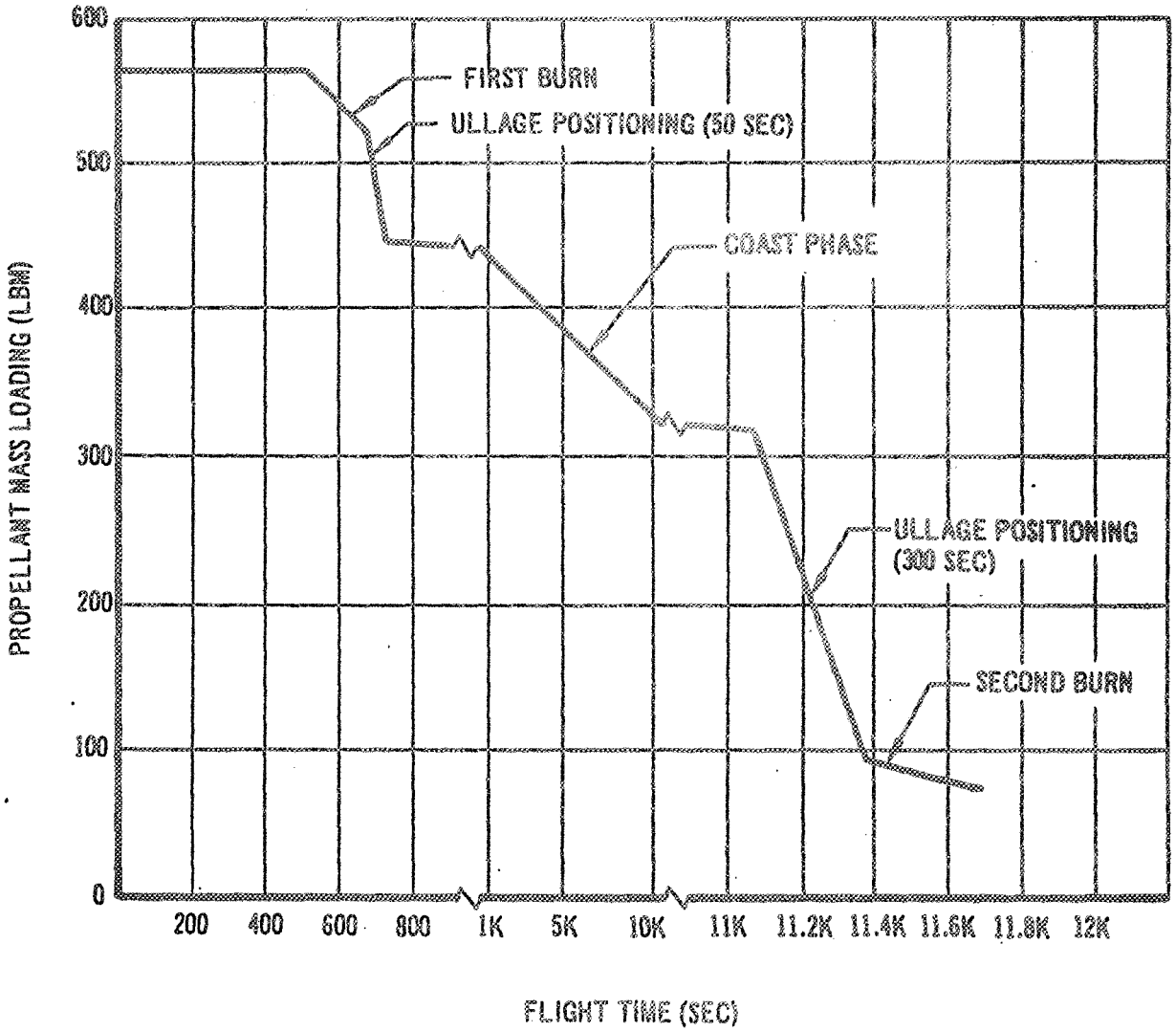


Figure 37. Expected APS Propellant Mass History

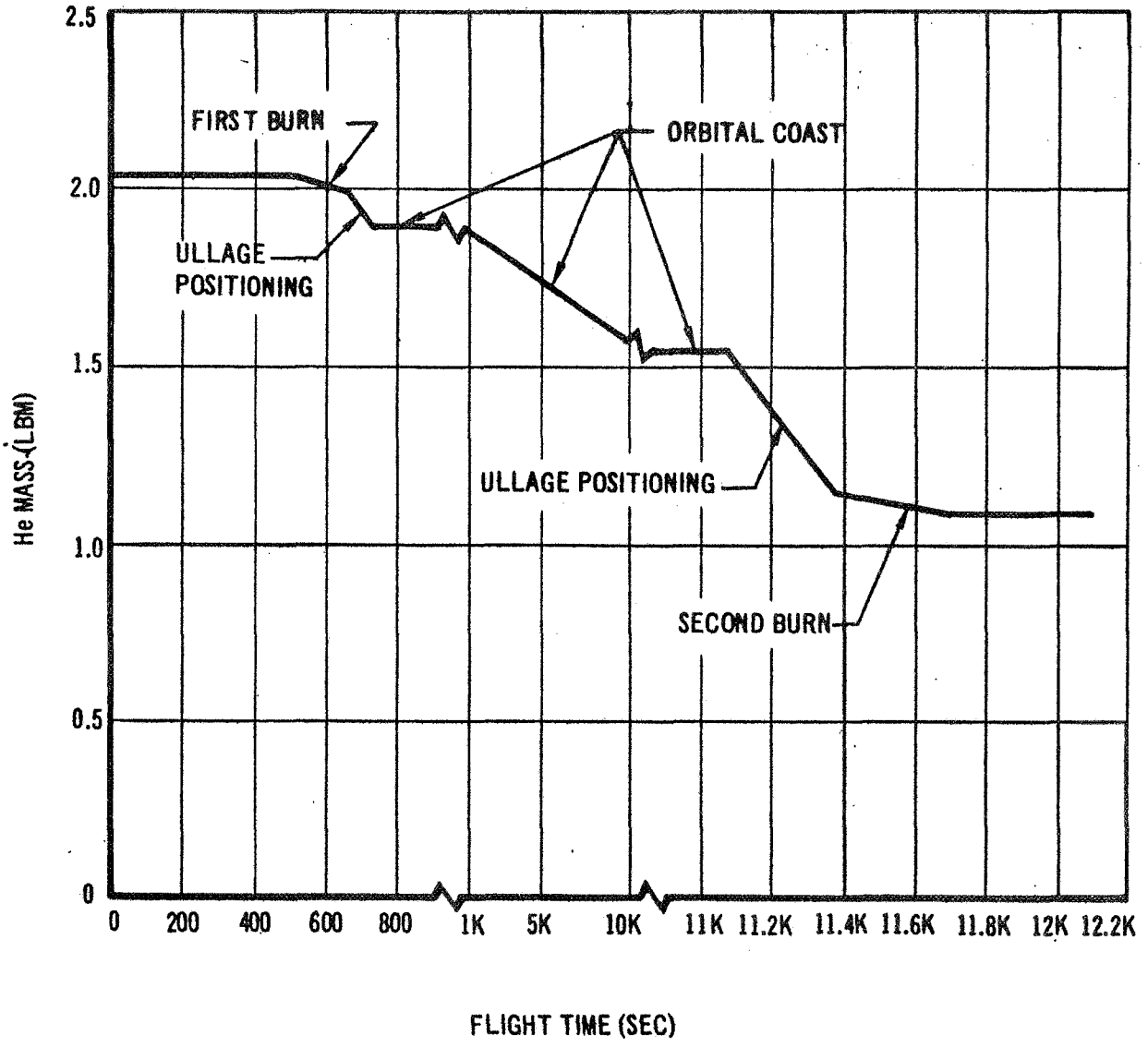


Figure 38. Expected APS Helium Quantity History

1.21

FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of Lower Stage Flight Control: Erroneous gyro or accelerometer outputs to lower stage, loss of control by Instrument Unit, loss of electrical power or control signals.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 41.01 Electrical Power; 42 Electrical Control; 43 Electrical Distribution; 44 Lower Stage Flight Control.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Prior to the end of S-II stage burn.

5. FAILURE MODE CONSEQUENCE: Loss of flight control due to improper trajectory.

6. TIME DEPENDENCY OF FAILURE: Not available.

7. OVERALL FAILURE MODE CRITICALITY: 260

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: As determined by analyses of lower stages.

11. SENSOR LOCATION: None.

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: Not available.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: Rate and acceleration deviations as shown in figures 34 thru 36.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Degree of loss of flight control will depend on extent of loss of lower stage control, however erroneous rate or acceleration could result in incorrect damping of thrust or attitude excursions.

17. FLIGHT HISTORY: As shown in figure 31.

18. DISCUSSION: Erroneous rate or acceleration signals will cause insufficient damping of the flight control system and will result in possible loss of the stage (approximately 10% probability). Pitch & yaw rate and pitch & yaw acceleration signals are supplied during S-IC and S-II burn phases.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, 13, & 15.

1.22 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Premature Separation: Due to premature operation of severance EBW firing units.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 61 Severance.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: From charging of the severance EBW firing units to programmed firing of them.

5. FAILURE MODE CONSEQUENCE: Loss of flight control due to improper trajectory.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (severance EBW units).

7. OVERALL FAILURE MODE CRITICALITY: 2

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: (1) Angle of attack.
(2) EBW firing units operation.

11. SENSOR LOCATION: None.

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: (1) As shown in figure 39. (2) Programmed severance occurs at about 501.3 seconds after liftoff.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: Not available.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Severance prior to S-II burnout would leave the vehicle incapable of witnstanding any bending moments at the S-II/S-IVB separation plane.

17. FLIGHT HISTORY: (1) As shown in figure 39.

18. DISCUSSION: This failure can occur only during the 33 seconds between charging of the firing units and programmed firing of them. A spurious signal from the S-II stage during this time will cause severance of the tension tie between the stages.

19. INFORMATION DEFICIENCY: Information not available for items 4, 9, 12, 14, & 15.

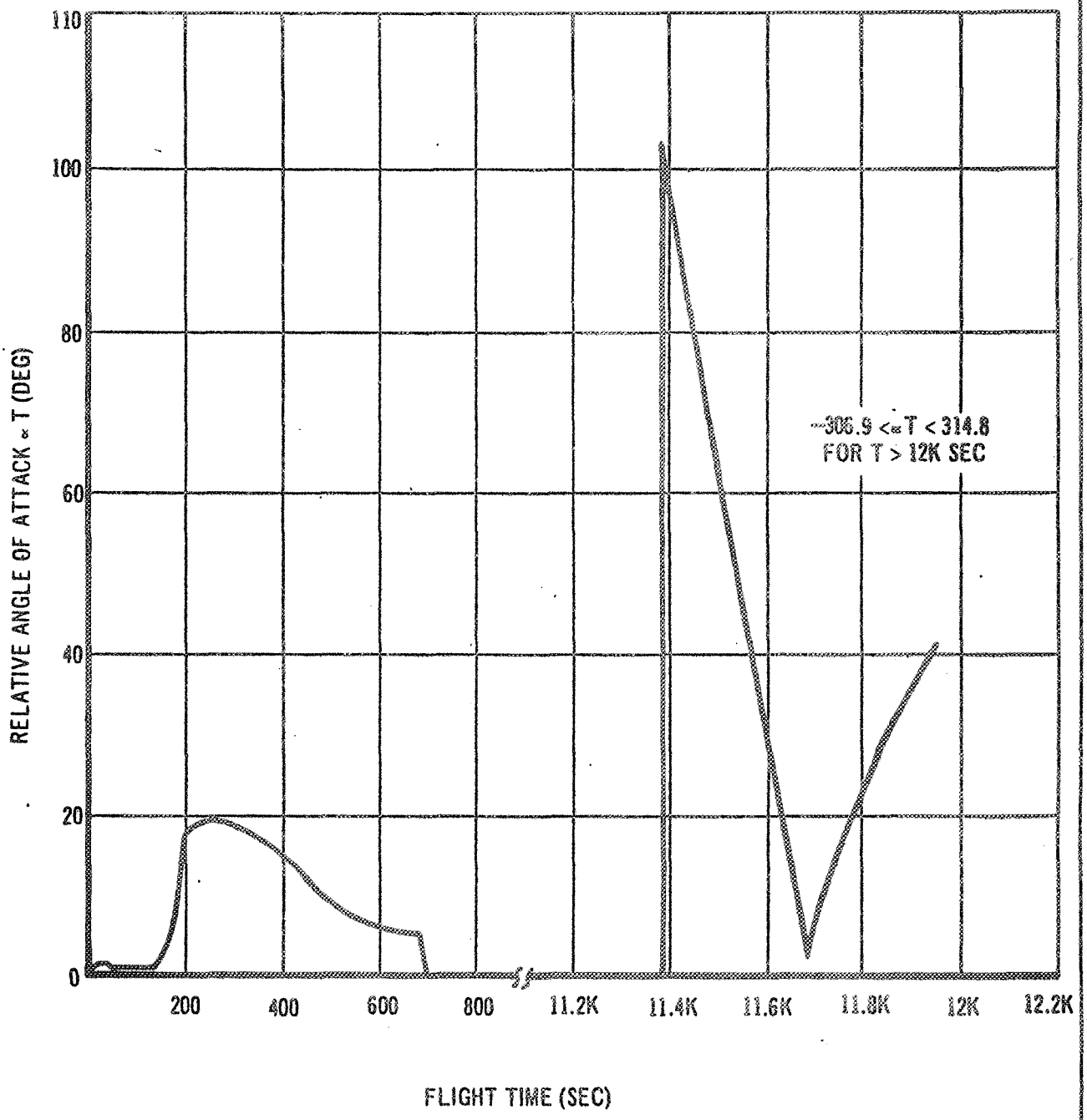


Figure 39. Vehicle Relative Angle of Attack History

1.23 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Failure to Separate: Due to premature operation of retro rockets.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 42 Electrical Control; 62 Lower Stage Reverse Thrust.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: From charging of the retro rocket EBW firing units to programmed firing of them.

5. FAILURE MODE CONSEQUENCE: Loss of flight control due to improper trajectory.

6. TIME DEPENDENCY OF FAILURE: MFRT = 3 seconds (retro rocket EBW firing units).

7. OVERALL FAILURE MODE CRITICALITY: 1R

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: (1) Extensiometer measurement.
(2) EBW firing units operation.

11. SENSOR LOCATION: (1) N0009-404
N0010-404
N0045-404
N0046-404

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: (1) 0 to 12 inches and 0 to 340 inches. (2) Programmed reverse thrust occurs at about 501.3 seconds after liftoff.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: Not available.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Premature thrusting of the retro rockets would leave the stages incapable of separating to a safe distance before J2 engine ignition. Engine start would be catastrophic.

17. FLIGHT HISTORY: Programmed separation occurs at 501.3 seconds after liftoff.

18. DISCUSSION: This failure can occur only during the 12 seconds after charging and before programmed firing of the EBW firing units. A spurious signal during this time will cause firing of the retro rockets. Retro rocket firing, when initiated, continues for 1.5 seconds.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, 14, & 15.

1.24 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Loss of Engine Cutoff Sequencing: Due to loss of electrical power, loss of engine cutoff control.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 26 Thrust; 41 Electrical Power; 42 Electrical Control; 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: At either programmed cutoff of J2 engine.

5. FAILURE MODE CONSEQUENCE: Loss of flight control due to improper trajectory.

6. TIME DEPENDENCY OF FAILURE: MTBF = 1 second (battery).

7. OVERALL FAILURE MODE CRITICALITY: 640

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: Forward battery 1 load.

11. SENSOR LOCATION: M0019-411

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: As shown in figure 26.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: 30 to 35.5 vdc (prestart).

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Inability to shut the J2 engine off would result in the vehicle being placed in an orbit other than programmed.

17. FLIGHT HISTORY: As shown in figure 26.

18. DISCUSSION: Engine first cutoff occurs at 673.8 seconds after liftoff. Second cutoff occurs at 11686.1 seconds after liftoff.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 13.

1.25 FAILURE EFFECT ANALYSIS DATA

1 GENERAL FAILURE MODE: Degraded Engine Performance: Loss of engine electrical bus power, failure of propellant utilization (PU) probes, loss of PU power, spurious control signal.

2 STAGE: Saturn V S-IVB-501

3 SYSTEM: 20 Thrust: 41.01 Primary Electrical Power; 41.02 Secondary Electrical Power; 42 Electrical Control; 43 Electrical Distribution; 46 Propellant Utilization.

4 PERIOD DURING WHICH FAILURE MODE MAY OCCUR: During S-IVB J2 engine burn.

5 FAILURE MODE CONSEQUENCE: Improper trajectory.

6 TIME DEPENDENCY OF FAILURE: Not available.

7 OVERALL FAILURE MODE CRITICALITY: 5000

8 MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9 MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10 MEASURING PARAMETER:
(1) Engine control bus voltage.
(2) PU valve control voltage.
(3) PU inverter-converter voltage.
(4) PU valve position.
(5) Forward battery 2 load.

11 SENSOR LOCATION:
(1) M0006-401
(2) M0060-411
(3) VM0001-411
(4) VG0010-401

12 EDS TIME DELAY: Not available.

13 NORMAL PARAMETER OPERATING LEVEL:
(3) 115 ± 3.45 V at 400 ± [illegible] cps
5.0 ± 0.5 VDC
21.0 ($^{+1.5}_{-1.0}$) VDC
(5) See figure 40.

14 MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (3) See above.

15 EDS MONITOR SETTING: Not available.

16 FAILURE EFFECT ANALYSIS: The vehicle would fail to achieve the proper orbit because of decreased total impulse.

17 FLIGHT HISTORY: During J2 engine first burn, LOX/LH_2 engine mixture ratio EMR = [illegible]:1. During second burn: EMR = 5.0:1 for first 5.5 seconds; 4.5:1 for next 1[illegible].2 seconds; and [illegible].0:1 for last [illegible] seconds. See figure 40.

18 DISCUSSION: PU electronics controls setting of engine mixture ratio valve to vary from 4.[illegible]:1 to 5.0:1. At an EMR = 5.0:1, total thrust is 200K lb and I_s = 4[illegible]. At an EMR = 4.5:1, total thrust is 175K lb and I_s = 43[illegible].

19 INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

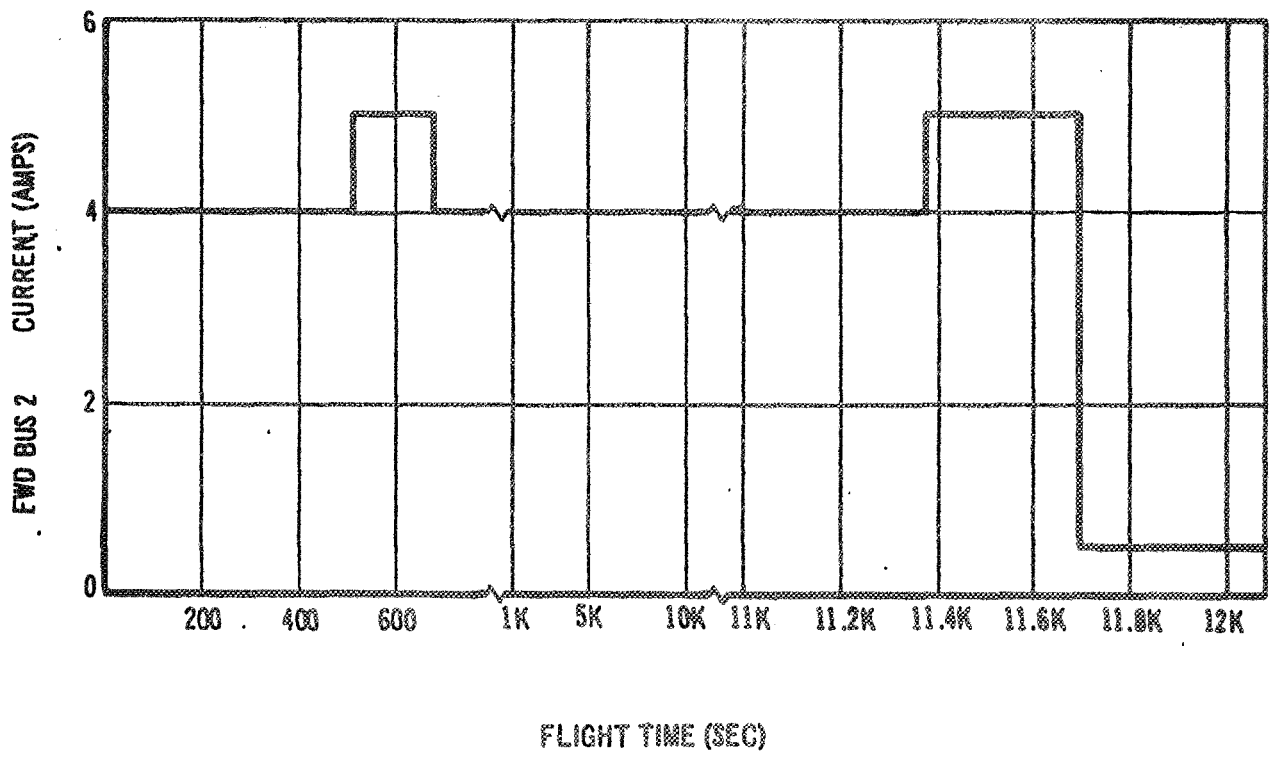


Figure 40. Forward Battery No. 2 Expected Current Profile

1.26 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Ignition Prior to Staging: Due to premature energizing of J2 engine start control.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 26 Thrust.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: Prior to programmed J2 engine first ignition.

5. FAILURE MODE CONSEQUENCE: Vehicle breakup due to structural damage.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (sequencer, aft cable).

7. OVERALL FAILURE MODE CRITICALITY: 13

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) Thrust chamber spark system on/off.
(2) Engine start on/off.
(3) Extensiometer measurement.

11. SENSOR LOCATION:
(1) VK0010-401
(2) VK0021-404
(3) N0009-404
N0010-404
N0045-404
N0046-404

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: (1) (2) Bi-level signals.
(3) 0 to 12 inches and 0 to 340 inches.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: Not available.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Ignition before staging would confine engine combustion products.

17. FLIGHT HISTORY: Programmed completed separation occurs at 501.4 seconds after liftoff. Programmed engine start occurs at 502.8 seconds.

18. DISCUSSION: Information on J2 engine components contributing to this overall failure mode is presented in J2 Engine Failure Effect Analysis, Rocketdyne Report R-2[illegible]0-17.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 14, & 15.

1.27 FAILURE EFFECT ANALYSIS DATA

1. **OVERALL FAILURE MODE:** Fire: Due to motor or engine bursting or burnthrough, hypergolic propellant leakage.

2. **STAGE:** Saturn V/S-IVB-501

3. **SYSTEM:** 25 Ullage Positioning; 26 Thrust; 32 Auxiliary Propulsion; 62 Lower Stage Reverse Thrust.

4. **PERIOD DURING WHICH FAILURE MODE MAY OCCUR:** All flight phases.

5. **FAILURE MODE CONSEQUENCE:** Vehicle breakup due to structural damage.

6. **TIME DEPENDENCY OF FAILURE:** MFRT = 1 second (APS engines, ullage rockets).
   3 seconds (retro rockets).

7. **OVERALL FAILURE MODE CRITICALITY:** 870

8. **MSFC RECOMMENDATION FOR EDS MONITOR:** Not available.

9. **MSC RECOMMENDATION FOR EDS MONITOR:** Not available.

10. **MEASURING PARAMETER:**
    (1) APS engine chamber pressure.
    (2) Ullage rocket chamber pressure.
    (3) Retro rocket chamber pressure.

11. **SENSOR LOCATION:**

(1)	D0027-414	(1)	D0031-415	(3)	D0153-423
	D0028-414		D0032-415		D0154-421
	D0029-414	(2)	D0216-428		D0155-420
	D0030-415		D0317-429		D0156-422

12. **EDS TIME DELAY:** Not available.

13. **NORMAL PARAMETER OPERATING LEVEL:** Not available.

14. **MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT:** Not available.

15. **EDS MONITOR SETTING:** Not available.

16. **FAILURE EFFECT ANALYSIS:** Fire damage due to escaping hot gases or ignition of leaking propellants.

17. **FLIGHT HISTORY:** Not available.

18. **DISCUSSION:** Fire due to propellant leakage is considered a problem primarily while the vehicle is still within the atmosphere.

19. **INFORMATION DEFICIENCY:** Information not available for items 8, 9, 12, 13, 14, 15, & 17.

1.28

FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Explosion: Due to bursting or burnthrough of rocket motors or engines, propellant leakage, open LH_2 fill and drain valve, loss of pneumatic control.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 21.01 LH_2 Fill and Drain; 23.01 LH_2 Feed and Chilldown; 24 Pneumatic Control; 25 Ullage Positioning; 26 Thrust; 32 Auxiliary Propulsion; 62 Lower Stage Reverse Thrust.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: All flight phases.

5. FAILURE MODE CONSEQUENCE: Vehicle breakup due to structural damage.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (APS engines, ullage motors).
3 seconds (retro rockets).

7. OVERALL FAILURE MODE CRITICALITY: 850

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER:
(1) LH_2 fill and drain valve open/closed.
(2) Chamber pressure.

11. SENSOR LOCATION:
(1) K0019-403
(2) Same as for OFM 28: Fire

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: Not available.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: Not available.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Explosion due to rupture of rocket motors or leakage of explosive propellants.

17. FLIGHT HISTORY: Not available.

18. DISCUSSION: Detection of imminent explosion might be accomplished by sensors to monitor engines for combustion instability.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, 13, 14, 15, & 17.

1.29 FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Launch Damage: Due to improper disconnection of umbilical connectors.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 43 Electrical Distribution.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: At liftoff.

5. FAILURE MODE CONSEQUENCE: Vehicle breakup due to structural damage.

6. TIME DEPENDENCY OF FAILURE: MFRT = 1 second (umbilical connectors).

7. OVERALL FAILURE MODE CRITICALITY: 6

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: None.

11. SENSOR LOCATION: None.

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: None.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: None.

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Improper disconnection of umbilicals may tear out portions of the stage internal cabling causing severe structural damage.

17. FLIGHT HISTORY: None.

18. DISCUSSION: Visual identification of improper disconnect may be possible.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 12, & 15.

1.30

FAILURE EFFECT ANALYSIS DATA

1. OVERALL FAILURE MODE: Engine Breakup: Due to closed LH_2 shutoff valve, engine turbopump disintegration, leakage or burnthrough of gas generators, spurious LH_2 shutoff signal, loss of pneumatic control.

2. STAGE: Saturn V/S-IVB-501

3. SYSTEM: 23.01 LH_2 Feed and Chilldown; 24 Pneumatic Control; 26 Thrust; 42 Electrical Control.

4. PERIOD DURING WHICH FAILURE MODE MAY OCCUR: During J2 engine burn.

5. FAILURE MODE CONSEQUENCE: Vehicle breakup due to structural damage.

6. TIME DEPENDENCY OF FAILURE: MTBF ≈ 1 second (LH_2 shutoff valves).

7. OVERALL FAILURE MODE CRITICALITY: 1/0

8. MSFC RECOMMENDATION FOR EDS MONITOR: Not available.

9. MSC RECOMMENDATION FOR EDS MONITOR: Not available.

10. MEASURING PARAMETER: Engine turbopump speed.

11. SENSOR LOCATION: (1) T0001-401, T0002-402 (2) T0502-401, T0503-401

12. EDS TIME DELAY: Not available.

13. NORMAL PARAMETER OPERATING LEVEL: Not available.

14. MAXIMUM DEVIATION EXPECTED DURING NORMAL FLIGHT: (2) LH_2 pump cutoff max: 28,400 rpm
LOX pump cutoff max: 9600 rpm

15. EDS MONITOR SETTING: Not available.

16. FAILURE EFFECT ANALYSIS: Cavitation of the LH_2 turbopump or escaping hot gases would cause the J2 engine to break up.

17. FLIGHT HISTORY: Not available.

18. DISCUSSION: Abnormal noise and vibration might precede the breakup due to pump cavitation. Engine thrust oscillations might also be present prior to breakup. Vibration and pressure sensors mounted in critical locations on the pump and thrust chamber may allow anticipation of this overall failure mode.

19. INFORMATION DEFICIENCY: Information not available for items 8, 9, 11, 13, 15, 17.

2.1 – 2.4

LOSS OF THRUST

MALFUNCTION DETECTION SYSTEM SUMMARY

FAILURE		CRITI-CALITY NUMBER	MEASURING PARAMETER	TIME DEPENDENCY OF FAILURE			ABORT MODE	SIGNAL	REMARKS
TYPE/MODE	EFFECT			L/V LIMIT	LES LIMIT	FLIGHT TIME			
1. Loss of Ullage Positioning: Loss of electrical power. Loss of signal to thrust ullage motors or 70 lb ullage engines.	Loss of thrust due to inability to start engine.	520	1. Vehicle acceleration. 2. LH_2/LOX press at pump inlet.			Prior to engine start/restart.		1. Accelerometer PAM/FM/FM PCM/FM. 2. Press transducer PAM/FM/FM. 3. Event sensor PCM/FM.	
2. Loss of LH_2 Chilldown: Loss of chilldown pumping. Chilldown system valve failure. Loss of pneumatics. Loss of electrical power/command.	Loss of thrust due to inability to start engine.	3100	1. LH_2 pump inlet temp. 2. LH_2 chilldown flow rate.			Prior to engine start/restart.		1. Temp transducer PAM/FM/FM. 2. Flowmeter PAM/FM/FM.	
3. Loss of LOX chilldown: Loss of chilldown pumping. Chilldown lines valve failure. Loss of pneumatics. Loss of electrical power/command.	Loss of thrust due to inability to start engine.	2900	1. LOX pump inlet temp. 2. LOX chilldown flow rate.			Prior to engine start/restart.		1. Temp transducer PAM/FM/FM. 2. Flowmeter PAM/FM/FM.	
4. Loss of Engine Start Capability: Loss of pneumatics. Closed start valve. Loss of electrical power. Loss of start command.	Loss of thrust due to inability to start engine.	5000	1. Start tank press. 2. PU valve position. 3. Start valve position. 4. Engine bus voltage.			Prior to start/restart.		1. Press transducer PAM/FM/FM. 2. Position transducer PAM/FM/FM. 4. Voltage network PAM/FM/FM.	

2.5 - 2.7

LOSS OF THRUST

MALFUNCTION DETECTION SYSTEM SUMMARY

FAILURE		CRITI-CALITY NUMBER	MEASURING PARAMETER	TIME DEPENDENCY OF FAILURE			ABORT MODE	SIGNAL	REMARKS
TYPE/MODE	EFFECT			L/V LIMIT	LES LIMIT	FLIGHT TIME			
5. Loss of LH_2 Tank Pressurization: Open fill and drain valve. Open ullage pressure system valves. Ducting leakage. Loss of electrical power/command. Loss of pneumatics.	No engine start or premature cutoff.	820	LH_2 tank ullage pressure.			Prior to programmed first cutoff.		Pressure transducer PAM/FM/FM.	
6. Loss of LH_2 Tank Repressurization Capability: Open pressurization system valves. Loss of flow or leakage of He. Loss of electrical power/command.	No engine start or premature cutoff.	660	Repress He quantity.			Prior to programmed second cutoff.		None.	
7. Loss of LOX Tank Pressurization: Open fill and drain valve. Open ullage pressure system valves. Duct leakage. Loss of electrical power/command. Loss of pneumatics.	No engine start or premature cutoff.	1400	LOX tank ullage pressure.			Prior to programmed first cutoff.		Pressure transducer PAM/FM/FM.	

2.8 - 2.11

LOSS OF THRUST

MALFUNCTION DETECTION SYSTEM SUMMARY

FAILURE		CRITI-CALITY NUMBER	MEASURING PARAMETER	TIME DEPENDENCY OF FAILURE			ABORT MODE	SIGNAL	REMARKS
TYPE/MODE	EFFECT			L/V LIMIT	LES LIMIT	FLIGHT TIME			
8. Loss of LOX Tank Repressurization Capability: Open pressure system valves. Loss of flow or leakage of He. Loss of electrical power/command.	No engine start or premature cutoff.	720	Repress He quantity.			Prior to programmed second cutoff.		None.	
9. Loss of LH_2 Feed: Closed LH_2 shutoff valve. Loss of pneumatics. Loss of electrical power/command.	No engine start or premature cutoff.	710	1. LH_2 flow rate. 2. Pre-valve open/closed. 3. Shutoff valve open/closed.			Prior to programmed 1st or 2nd cutoff.		1. Flowmeter PAM/FM/FM. 2. Event sensor PAM/FM/FM. 3. Event sensor PAM/FM/FM.	
10. Loss of LOX Feed: Closed LOX shutoff valve. Loss of pneumatics. Loss of electrical power/command.	No engine start or premature cutoff.	930	1. LOX flow rate. 2. Pre-valve open/closed. 3. Shutoff valve open/closed.			Prior to programmed 1st or 2nd cutoff.		1. Flowmeter PAM/FM/FM. 2. Event sensor PAM/FM/FM. 3. Event sensor PAM/FM/FM.	
11. High LH_2 Temperature: Loss of bypass regulator. Loss of electrical power. Loss of command to open bypass regulator.	No engine start or premature cutoff.	340	1. LH_2 tank temp. 2. LH_2 tank ullage gas temp.			Prior to programmed 1st or 2nd cutoff.		1. Temp transducer PAM/FM/FM. 2. Temp transducer PAM/FM/FM.	

2.12 - 2.14

LOSS OF THRUST

MALFUNCTION DETECTION SYSTEM SUMMARY

FAILURE		CRITI-CALITY NUMBER	MEASURING PARAMETER	TIME DEPENDENCY OF FAILURE			ABORT MODE	SIGNAL	REMARKS
TYPE/MODE	EFFECT			L/V LIMIT	LES LIMIT	FLIGHT TIME			
12. Propellant Sloshing: Loss of continuous venting. Loss of electrical power/command.	Premature engine cutoff.	460	1. Cont vent operation. 2. Cont vent shutoff valve open/closed.			During engine burn.		1. Pressure transducer PAM/FM/FM. 2. Event sensor PAM/FM/FM.	
13. LH_2 Depletion: Open or leaking LH_2 fill and drain valve. Leaking LH_2 ducts. Open main LH_2 valve. Open gas generator valve.	Premature engine cutoff.	33	LH_2 quantity.			During engine burn.		Liquid level sensor PAM/FM/FM.	
14. LOX Depletion: Open or leaking LOX fill and drain valve. Leakage of LOX ducting. Open main LOX valve. PU valve driven closed.	Premature engine cutoff.	330	LOX quantity.			During engine burn.		Liquid level sensor PAM/FM/FM.	

2.15-2.16

LOSS OF THRUST

MALFUNCTION DETECTION SYSTEM SUMMARY

FAILURE		CRITI-CALITY NUMBER	MEASURING PARAMETER	TIME DEPENDENCY OF FAILURE			ABORT MODE	SIGNAL	REMARKS
TYPE/MODE	EFFECT			L/V LIMIT	LES LIMIT	FLIGHT TIME			
15. Vapor in LOX Lines: Open chilldown shutoff valve. Loss of pneumatics. Loss of control signals to pneumatics.	Premature engine cutoff.	740	1. Chilldown shutoff valve open/closed. 2. Cold He pressure. 3. Control He supply.			During engine burn.		1. Event sensor PAM/FM/FM. 2. Pressure transducer PAM/FM/FM. 3. Pressure transducer PAM/FM/FM.	
16. Premature Engine Cutoff Initiation: Closed propellant shutoff valves. Loss of pneumatics. Faulty engine operation. Premature range safety (RS) charging. Loss of electrical power. Spurious cutoff signal.	Premature engine cutoff.	2.00	1. Cutoff signal. 2. RS arm/cutoff signal. 3. Shutoff valves open/closed. 4. Fwd 1 bus voltage. 5. Aft 1 bus voltage.			During engine burn.		1. Event sensor PAM/FM/FM. 2. Event sensor PAM/FM/FM. 3. Event sensor PAM/FM/FM. 4. Voltage network PAM/FM/FM. 5. Voltage network PAM/FM/FM.	

2.17 – 2.20

LOSS OF FLIGHT CONTROL

MALFUNCTION DETECTION SYSTEM SUMMARY

FAILURE		CRITI-CALITY NUMBER	MEASURING PARAMETER	TIME DEPENDENCY OF FAILURE			ABORT MODE	SIGNAL	REMARKS
TYPE/MODE	EFFECT			L/V LIMIT	LES LIMIT	FLIGHT TIME			
17. Loss of Hydraulic Pressure: Hydraulic pump failure. Air or fluid leakage. Accumulator failure. Loss of fluid temp. control. Loss of electrical power/control.	No thrust vector control.	2400	1. Hydraulic pressure. 2. Hydraulic fluid quantity. 3. Hydraulic fluid temperature.			During engine burn.		1. Pressure transducers PAM/FM/FM. 2. Liquid level sensor PAM/FM/FM. 3. Temperature transducer PAM/FM/FM.	
18. Loss of Steering Control: Hydraulic actuator failure. Loss of electrical power/control.	No thrust vector control.	1300	Actuator Position.			During engine burn.		Position pots PAM/FM/FM.	
19. Loss of Attitude Control: Failure of auxiliary propulsion system (APS) to thrust. APS engine burnthrough. Loss of electrical power/control.	No APS attitude control.	2300	Pitch, roll, and yaw attitude.			During coast phases.		None.	
20. Depletion of APS Propellants: Propellant leakage. Failure to shut off propellant flow. Excessive control requirements. Spurious signals to APS.	No APS attitude control.	140	Hypergolic propellant quantities.			During all flight phases.		Displacement transducer PAM/FM/FM.	

SECTION II

MALFUNCTION DETECTION SYSTEM SUMMARY (SUMMARY)

2.21 - 2.24

LOSS OF FLIGHT CONTROL

MALFUNCTION DETECTION SYSTEM SUMMARY

FAILURE		CRITI-CALITY NUMBER	MEASURING PARAMETER	TIME DEPENDENCY OF FAILURE			ABORT MODE	SIGNAL	REMARKS
TYPE/MODE	EFFECT			L/V LIMIT	LES LIMIT	FLIGHT TIME			
21. Loss of Lower Stage Flight Control: Erroneous gyro or accelerometer outputs. Loss of control by Instrument Unit. Loss of electrical power/control.	Improper trajectory.	260	None.			Prior to S-II/ S-IVB separation		None.	
22. Premature Separation: Premature operation of severance EBW firing units.	Improper trajectory.	2	1. Angle of attack. 2. Firing of EBW's.			Prior to programmed separation.		1. None. 2. None.	
23. Failure to Separate: Premature operation of retro rocket EBW firing units.	Improper trajectory.	58	1. Extensiometer meas. 2. Firing of EBW's.			At programmed separation time.		1. Extension transducer PAM/FM/FM & PCM/FM. 2. None.	
24. Loss of Engine Shutdown Sequencing: Loss of electrical power. Loss of engine cutoff controls.	Improper trajectory.	340	Forward battery 1 load.			At programmed 1st or 2nd cutoff.		Voltage network PAM/FM/FM.	

2.25

LOSS OF FLIGHT CONTROL

MALFUNCTION DETECTION SYSTEM SUMMARY

FAILURE		CRITI-CALITY NUMBER	MEASURING PARAMETER	TIME DEPENDENCY OF FAILURE			ABORT MODE	SIGNAL	REMARKS
TYPE/MODE	EFFECT			L/V LIMIT	LES LIMIT	FLIGHT TIME			
25. Degraded Engine Performance: Loss of engine bus power. Loss of propellant utilization (PU) power. Spurious control signal. Failure of PU system.	Improper trajectory.	5900	1. Engine control bus voltage. 2. PU valve control voltage. 3. PU inverter-converter voltage. 4. PU valve position.			During engine burn.		1. Voltage network PAM/FM/FM. 2. Voltage network PCM/FM. 3. Voltage network PAM/FM/FM. 4. Position transducer PAM/FM/FM.	

2.26 – 2.28

VEHICLE BREAKUP

MALFUNCTION DETECTION SYSTEM SUMMARY

FAILURE		CRITI-CALITY NUMBER	MEASURING PARAMETER	TIME DEPENDENCY OF FAILURE			ABORT MODE	SIGNAL	REMARKS
TYPE/MODE	EFFECT			L/V LIMIT	LES LIMIT	FLIGHT TIME			
26. Engine Ignition Prior to Staging: Premature energization of engine start control.	Structural damage.	13	1. Thrust chamber spark sys. on. 2. Engine start on. 3. Extensiometer meas.			Prior to Programmed 1st ignition.		1. Event sensor PAM/FM/FM & PCM/FM. 2. Event sensor PAM/FM/FM & PCM/FM. 3. Extension transducer PAM/FM/FM & PCM/FM.	
27. Fire: Motor/engine burst or burnthrough: Hypergolic propellant leakage.	Structural damage.	870	1. APS chamber pressure. 2. Ullage rocket chamber pressure. 3. Retro rocket chamber pressure.			All flight phases.		1. Pressure transducers PAM/FM/FM & PCM/FM. 2. Pressure transducers PAM/FM/FM & PCM/FM. 3. Pressure transducer.	
28. Explosion: Motor/engine burst or burnthrough. Open LH_2 fill & drain valve. Propellant leakage.	Structural damage.	850	1. LH_2 fill & drain valve open/closed. 2. Chamber pressures			All flight phases.		1. Event sensor PAM/FM/FM. 2. Same as OFN 28: Fire.	

2.29 – 2.30

VEHICLE BREAKUP

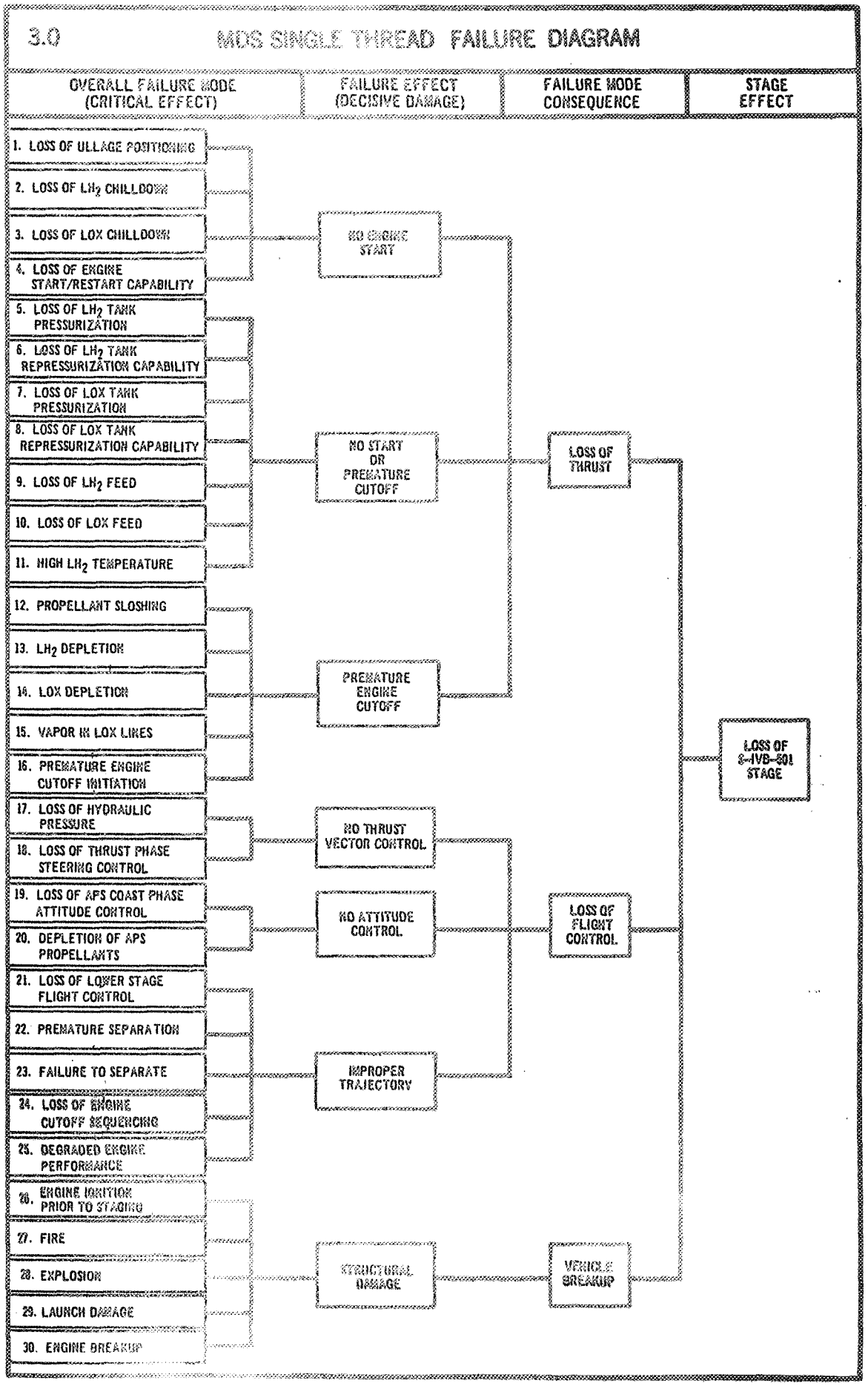
MALFUNCTION DETECTION SYSTEM SUMMARY

FAILURE		CRITI-CALITY NUMBER	MEASURING PARAMETER	TIME DEPENDENCY OF FAILURE			ABORT MODE	SIGNAL	REMARKS
TYPE/MODE	EFFECT			L/V LIMIT	LES LIMIT	FLIGHT TIME			
29. Launch Damage: Improper disconnection of umbilicals.	Structural damage.	6	None.			At lift-off.		None.	
30. Engine Breakup: Closed LH_2 shutoff valve. Turbopump disintegration. Gas generator leakers or burnthrough.	Structural damage.	210	LH_2 & LOX turbopump speeds.			During engine burn.		Tachs PAM/FM/FM & PCM/FM.	

SECTION III

SINGLE THREAD FAILURE DIAGRAM (STD) CAUSE/EFFECT ANALYSIS

3.0 MDS SINGLE THREAD FAILURE DIAGRAM



3.1 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	1. LOSS OF ULLAGE POSITIONING
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	CD/D CDEF/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-02.25.11	SEQUENCER	NO OUTPUT	C/D	15	
42-02.25.12	SEQUENCER	OUTPUT WHEN NOT REQUIRED	C/D	4	
42-02.25.12	SEQUENCER	NO OUTPUT	C/D	15	
42-02.43.01	SEQUENCER	NO OUTPUT	CD/D CDEF/F	19	
42-03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42-04.32.03	28V AFT PWR DIST	NO OUTPUT	EF/F	37	
42-04.42.02	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	3	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	8	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D CDEF/F	9	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43-08	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	

3.2 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
23.01-01	CHILLDOWN PUMP	FAILURE TO DELIVER	C/D CDE/F	1500	
23.01-01	CHILLDOWN PUMP	NO START	E/F	10	
23.01-02	CHILL SHUTOFF VALVE	FAILURE TO REMAIN OPEN	C/D CDE/F	1	
23.01-02	CHILL SHUTOFF VALVE	FAILURE TO OPEN	E/F		
23.01-03	CHILL SYS STRAINER	CLOGGED	C/D CDE/F	1	
23.01-04	CHILL CHECK VALVE	FAILURE TO OPEN	E/F	4	
23.01-04	CHILL CHECK VALVE	FAILURE TO CLOSE	DE/F	1	
23.01-04	CHILL CHECK VALVE	LEAKAGE	DE/F	1	
23.01-05	SHUTOFF VALVE	FAILURE TO CLOSE	E/F	20	
23.01-05	SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	C/D CE/F	144	
23.01-05	SHUTOFF VALVE	INTERNAL LEAKAGE	C/D CE/F	33	2. LOSS OF LH_2 CHILLDOWN
23.01-07	CHILL RETURN CHECK VALVE	FAILURE TO OPEN	E/F	4	
24-01	He CONT DISCONNECT	FAILURE TO DISENGAGE PROP	C/D	1	
24-02.02	PNEU CONT DUMP VALVE	FAILURE TO REMAIN CLOSED	C/D CDE/F	1	
24-02.02	PNEU CONT DUMP VALVE	LEAKAGE	C/D CDE/F	4	
24-02.03	PNEU CONT RELIEF VALVE	FAILURE TO REMAIN CLOSED	CD/F	1	
24-04	REPRESS He STORAGE TANK	LEAKAGE	C/D CDE/F	1	
24-05.01	PNEU CONT He FILTER	CLOGGED	C/D CDE/F	1	
24-05.02	PNEU CONT PRESS REGULATOR	INADEQUATE PRESSURE	C/D CDE/F	44	
24-05.03	PNEU CONT SHUTOFF VALVE	FAILURE TO REMAIN OPEN	C/D CDE/F	1	
24-05.04	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-06	PNEU CONT SURGE TANK	LEAKAGE	C/D CDE/F	1	
24-08.02	PURGE LINE SHUTOFF VALVE	FAILURE TO CLOSE	E/F	1	
24-08.02	PURGE LINE SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
24-08.02	PURGE LINE SHUTOFF VALVE	LEAKAGE	CDE/F	2	
24-11.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-11.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-12.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-12.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-13.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-13.01	PNEU CONT PILOT VALVE	FAILURE TO CLOSE	E/F	2	
24-13.01	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	C/D CDE/F	1	
24-13.02	PNEU CONT PILOT VALVE	FAILURE TO REMAIN OPEN	C/D E/F	5	

3.2 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

PATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
24-13.02	PNEU CONT PILOT VALVE	FAILURE TO OPEN	E/F	2	2. LOSS OF LH_2 CHILLDOWN
24-13.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-14.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-14.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-15.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
25-15.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-16.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-16.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-17	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	2	
24-32	PNEU CONT MED PRESS SWITCH	OUTPUT WHEN NOT REQUIRED	C/D CDE/F	30	
26-01	J2 ENGINE	NO FLOW	C/D CDE/F	130	
41.01-01	FWD NO. 1 BATTERY	NO POWER	C/D E/F	7	
41.01-03	AFT NO. 1 BATTERY	NO POWER	C/D E/F	58	
41.01-04	AFT NO. 2 BATTERY	NO POWER	C/D CDE/F	93	
41.02-02	CHILLDOWN INVERTER	INCORRECT OUTPUT	C/D CDE/F	390	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	C/D CDE/F	100	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	C/D CDE/F	122	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-02.23.01	SEQUENCER	NO OUTPUT	C/D CE/F	40	
42-02.23.02	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CDE/F	29	
42-02.26.06	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CDE/F	5	
42-02.43.01	SEQUENCER	NO OUTPUT	C/D CDE/F	13	
42-03.42.01	SEQUENCER	NO OUTPUT	C/D E/F	1	
42-03.42.10	SEQUENCER	PREMATURE TRANSFER	C/D E/F	2	
42-04.24.01	28V AFT PWR DIST	OUTPUT WHEN NOT REQUIRED	C/D CDE/F	14	
42-04.42.02	28V AFT PWR DIST	NO OUTPUT	C/D E/F	2	
42-04.42.30	28V AFT PWR DIST	PREMATURE TRANSFER	C/D E/F	4	
42-04.43.03	28V AFT PWR DIST	OUTPUT WHEN NOT REQUIRED	C/D CDE/F	6	
42-05.23.11	56V AFT PWR DIST	OUTPUT WHEN NOT REQUIRED	DE/F	21	
42-05.23.11	56V AFT PWR DIST	NO OUTPUT	C/D CDE/F	48	
42-05.23.12	56V AFT PWR DIST	NO OUTPUT	C/D CDE/F	4	
42-05.23.21	56V AFT PWR DIST	OUTPUT WHEN NOT REQUIRED	DE/F	21	
42-05.23.21	56V AFT PWR DIST	NO OUTPUT	C/D CDE/F	48	
42-05.42.40	56V AFT PWR DIST	PREMATURE TRANSFER	C/D E/F	20	

3.2 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
42-05.43.04	56V AFT PWR DIST	NO OUTPUT	C/D CDE/F	14	2. LOSS OF LH_2 CHILLDOWN
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	C/D CDE/F	4	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	C/D CDE/F	5	
43-08	FWD CABLE	IMPROPER CONNECTION	C/D CDE/F	7	
43-09	AFT CABLE	IMPROPER CONNECTION	C/D CDE/F	23	

3.3 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
23.02-01.01	CIRCULATION PUMP	FAILURE TO START	E/F	10	3. LOSS OF LOX CHILLDOWN
23.02-01.01	CIRCULATION PUMP	FAILURE TO DELIVER	C/D CDE/F	1500	
23.02-01.02	PUMP SEALS	LEAK OF LOX SEAL	C/D CDE/F	10	
23.02-02	CHILL SHUTOFF VALVE	FAILURE TO OPEN	E/F	5	
23.02-02	CHILL SHUTOFF VALVE	FAILURE TO REMAIN OPEN	C/D CDE/F	1	
23.02-03	CHILL SYS STRAINER	CLOGGED	C/D CE/F	1	
23.02-05	LOX TANK SHUTOFF VALVE	FAILURE TO CLOSE	E/F	20	
23.02-05	LOX TANK SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	C/D CE/F	14	
23.02-05	LOX TANK SHUTOFF VALVE	INTERNAL LEAKAGE	C/D CE/F	33	
23.02-07	CHILL CHECK VALVE	FAILURE TO OPEN	E/F	4	
23.02-08	CHILL CHECK VALVE	FAILURE TO OPEN	E/F	4	
23.02-08	CHILL CHECK VALVE	FAILURE TO CLOSE	DE/F	2	
23.02-08	CHILL CHECK VALVE	LEAKAGE	DE/F	3	
24-01	He CONTROL DISC	FAILURE TO DISENGAGE PROPERLY	C/D C/F	1	
24-02.02	PNEU CONT DUMP VALVE	FAILURE TO REMAIN CLOSED	C/D CDE/F	1	
24-02.02	PNEU CONT DUMP VALVE	LEAKAGE	C/D CDE/F	4	
24-02.03	PNEU CONT RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
24-02.03	PNEU CONT RELIEF VALVE	LEAKAGE	CDE/F	3	
24-04	REPRESS He STORAGE TANK	LEAKAGE	C/D CDE/F	1	
24-05.01	PNEU CONT He FILTER	CLOGGED	C/D CDE/F	1	
24-05.02	PNEU CONT PRESS REGULATOR	INADEQUATE PRESSURE	C/D CDE/F	44	
24-05.03	PNEU CONT SHUTOFF VALVE	FAILURE TO REMAIN OPEN	C/D CDE/F	1	
24-05.04	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-06	PNEU CONT SURGE TANK	LEAKAGE	C/D CDE/F	1	
24-08.02	PURGE LINE SHUTOFF VALVE	FAILURE TO CLOSE	E/F	1	
24-08.02	PURGE LINE SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
24-08.02	PURGE LINE SHUTOFF VALVE	LEAKAGE	CDE/F	2	
24-11.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-11.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-12.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-12.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-13.01	PNEU CONT PILOT VALVE	FAILURE TO CLOSE	E/F	2	
24-13.01	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	C/D CDE/F	1	

3.3 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
24-13.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-13.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-13.02	PNEU CONT PILOT VALVE	FAILURE TO OPEN	E/F	4	
24-13.02	PNEU CONT PILOT VALVE	FAILURE TO REMAIN OPEN	C/D CE/F	4	
24-14.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-14.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-15.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-15.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-16.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-16.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDE/F	4	
24-17	PNEU CONT He PIPING	LEAKAGE	C/D CDE/F	2	
24-32	PNEU CONT MED PRESS SWITCH	OUTPUT WHEN NOT REQUIRED	C/D CDE/F	30	3.LOSS OF LOX CHILLDOWN
26-01	J2 ENGINE	NO FLOW	C/D CDE/F	130	
41.01-01	FWD BATTERY NO. 1	NO POWER	C/D EF/F	7	
41.01-03	AFT BATTERY NO. 1	NO POWER	C/D E/F	37	
41.01-04	AFT BATTERY NO. 2	NO POWER	C/D CDE/F	93	
41.02-03	CHILLDOWN INVERTER	INCORRECT OUTPUT	C/D CDE/F	390	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	C/D CDE/F	100	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	C/D CDE/F	122	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-02.23.01	SEQUENCER	NO OUTPUT	C/D CE/F	40	
42-02.23.02	SEQUENCER	OUTPUT WHEN NOT REQUIRED	C/D CDE/F	29	
42-02.26.06	SEQUENCER	OUTPUT WHEN NOT REQUIRED	C/D E/F	5	
42-02.43.01	SEQUENCER	NO OUTPUT	C/D CDE/F	13	
42-03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	C/D E/F	2	
42-04.24.01	28V AFT PWR DIST	OUTPUT WHEN NOT REQUIRED	CDE/F	14	
42-04.42.02	28V AFT PWR DIST	NO OUTPUT	C/D EF/F	2	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	C/D EF/F	4	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	C/D CDE/F	6	
42-05.23.22	56V AFT PWR DIST	NO OUTPUT	C/D CDE/F	4	
42-05.42.40	56V AFT PWR DIST	PREMATURE TRANSFER	C/D E/F	20	
42-05.43.04	56V AFT PWR DIST	NO OUTPUT	C/D CDE/F	14	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	C/D CDE/F	4	

3.3 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
43-07	TUNNEL CABLE	IMPROPER CONNECTION	C/D CDE/F	5	3. LOSS OF LOX CHILLDOWN
43-08	FWD CABLE	IMPROPER CONNECTION	C/D CDE/F	7	
43-09	AFT CABLE	IMPROPER CONNECTION	C/D CDE/F	23	

3.4 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
24-05.06	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	C/D CDEF/F	1	4. LOSS OF ENGINE START CAPABILITY
24-08.02	PNEU CONT PURGE LINE S/O VALVE	FAILURE TO OPEN	E/F	1	
24-08.02	PNEU CONT PURGE LINE S/O VALVE	FAILURE TO REMAIN OPEN	E/F	4	
24-30	PNEU CONT PUMP PURGE SWITCH	OUTPUT WHEN NOT REQUIRED	E/F	68	
24-30	PNEU CONT PUMP PURGE SWITCH	NO OUTPUT	E/F	5	
26-01	J2 ENGINE	COMPONENT FAILURE	CD/D E/F	3000	
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	
41.01-03	AFT BATTERY NO. 1	NO POWER	C/D E/F	37	
41.02-01	PU INVERTER-CONVERTER	NO. 49/117.5/21 VDC OUTPUTS	C/D DE/F	110	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	CD/D CDEF/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-02.23.01	SEQUENCER	OUTPUT WHEN NOT REQUIRED	C/D E/F	17	
42-02.26.01	SEQUENCER	NO OUTPUT	D/D F/F	52	
42-02.26.02	SEQUENCER	OUTPUT WHEN NOT REQUIRED	C/D E/F	60	
42-02.26.06	SEQUENCER	NO OUTPUT	E/F	12	
42-02.43.01	SEQUENCER	NO OUTPUT	CD/D CDEF/F	19	
42-03.42.01	FWD PWR DIST	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42-03.46.02	FWD PWR DIST	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	2	
42-04.26.07	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	33	
42-04.26.08	28V AFT PWR DIST	NO OUTPUT	CD/D DEF/F	24	
42-04.42.02	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	3	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	8	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D CDEF/F	9	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43-08	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	
48-09	PU ELECTRONICS	PU VALVE DRIVER CLOSED	CDEF/F	223	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MSFC MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
21.01-02	FILL & DRAIN VALVE	FAILURE TO REMAIN CLOSED	C/D CDEF/F	1	5. LOSS OF LH_2 PRESSURIZATION
21.01-02	FILL & DRAIN VALVE	INTERNAL LEAKAGE	C/D CDEF/F	10	
21.01-03	FILL & DRAIN DUCT	LEAKAGE	C/D CDE/F	1	
22.01-01	LH_2 TANK PRESS DISCONNECT	FAILURE TO DISENGAGE PROP	C/D C/F	3	
22.01-03.01	LH_2 TANK PRESS CHECK VALVE	FAILURE TO OPEN	D/D F/F	8	
22.01-03.02	LH_2 TANK PRESS CONTROL VALVE	FAILURE TO OPEN	D/D	1	
22.01-03.02	LH_2 TANK PRESS CONTROL VALVE	FAILURE TO REMAIN OPEN	CD/D	1	
22.01-03.03	LH_2 TANK STEP PRESS VALVE	FAILURE TO OPEN	F/F	1	
22.01-03.03	LH_2 TANK STEP PRESS VALVE	FAILURE TO REMAIN OPEN	CEF/F	1	
22.01-04	LH_2 TANK ULLAGE PRESS PIPING	LEAKAGE	CD/D CDEF/F	3	
22.01-05	HI PERF PRESS SWITCH	OUTPUT WHEN NOT REQUIRED	D/D	28	
22.01-08	LH_2 TANK VENT & RELIEF VALVE	FAILURE TO REMAIN CLOSED – VENT	CD/D DEF/F	1	
22.01-08	LH_2 TANK VENT & RELIEF VALVE	FAILURE TO REMAIN CLOSED – RELIEF	CD/D DEF/F	1	
22.01-08	LH_2 TANK VENT & RELIEF VALVE	INTERNAL LEAKAGE	CD/D CDEF/F	24	
22.01-09	LH_2 TANK RELIEF VALVE	FAILURE TO REMAIN CLOSED	CD/D DEF/F	40	
22.01-09	LH_2 TANK RELIEF VALVE	INTERNAL LEAKAGE	CD/D CDEF/F	36	
22.01-17.01	CONT VENT SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	C/D	1	
22.01-17.01	CONT VENT SHUTOFF VALVE	INTERNAL LEAKAGE	C/D	7	
22.01-17.03	BYPASS REGULATOR	FAILURE TO REMAIN CLOSED	C/D CDE/F	16	
22.01-17.03	BYPASS REGULATOR	LEAKAGE	C/D CDE/F	13	
22.01-17.04	BYPASS REGULATOR SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	C/D CDE/F	1	
22.01-17.04	BYPASS REGULATOR SHUTOFF VALVE	INTERNAL LEAKAGE	C/D CDE/F	8	
22.01-20	CHILL SYS CHECK VALVE	FAILURE TO OPEN	D/D F/F	8	
23.01-06	LH_2 FEED DUCT	LEAKAGE	CD/D CDEF/F	3	
24-11.01	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	C/D CDEF/F	1	
24-14.01	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	C/D CDEF/F	1	
26-01	J2 ENGINE	LEAKAGE	CD/D	6	
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-01	SWITCH SELECTOR	NO OUTPUT – SINGLE CHANNEL	CD/D CDEF/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT – ALL CHANNELS	C/D E/F	12	
42-02.22.11	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CD/D	7	
42-02.22.13.01	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CD/D DEF/F	27	
42-02.22.16.01	SEQUENCER	OUTPUT WHEN NOT REQUIRED	C/D CDE/F	21	

MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

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MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
42–02.22.16.02	SEQUENCER	NO OUTPUT	E/F	37	5. LOSS OF LH_2 PRESSURIZATION
42–02.22.17.01	SEQUENCER	OUTPUT WHEN NOT REQUIRED	C/D	3	
42–02.43.01	SEQUENCER	NO OUTPUT	CD/D CDEF/F	19	
42–03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42–03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42–04.42.02	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	3	
42–04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	8	
42–04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D CDEF/F	9	
43–05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43–07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43–08	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43–09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
22.01-06	HI PERF PRESSURE SWITCH	OUTPUT WHEN NOT REQUIRED	CDEF/F	130	
22.01-14	REPRESS He STORAGE TANK	INTERNAL LEAKAGE	CDE/F	1	
22.01-16.01	REPRESS He FILTER	CLOGGED	E/F	1	
22.01-16.02	REPRESS COLD He CONTROL VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
22.01-16.02	REPRESS COLD He CONTROL VALVE	INTERNAL LEAKAGE	CDE/F	11	
22.01-16.03	REPRESS COLD He CONTROL VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
22.10-16.03	REPRESS COLD He CONTROL VALVE	INTERNAL LEAKAGE	CDE/F	11	
22.01-16.04	He CONTROL RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
22.01-16.04	He CONTROL RELIEF VALVE	INTERNAL LEAKAGE	CDE/F	11	
22.01-16.05	COLD He CONTROL VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
22.01-16.05	COLD He CONTROL VALVE	INTERNAL LEAKAGE	CDE/F	11	
22.01-17.03	BYPASS REGULATOR	FAILURE TO CLOSE	E/F	23	6. LOSS OF LH_2 TANK REPRESSURIZATION CAPABILITY
22.01-17.03	BYPASS REGULATOR	FAILURE TO REMAIN CLOSED	CDE/F	16	
22.01-17.03	BYPASS REGULATOR	LEAKAGE	CDE/F	13	
22.01-17.04	BYPASS REG SHUTOFF VALVE	FAILURE TO CLOSE	E/F	5	
22.01-17.04	BYPASS REG SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
22.01-17.04	BYPASS REG SHUTOFF VALVE	INTERNAL LEAKAGE	CDE/F	8	
41.01-01	FWD BATTERY NO. 1	NO POWER	EF/F	5	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CDEF/F	85	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	CDEF/F	98	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	E/F	12	
42-02.22.12	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CDE/E	11	
42-02.22.15	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CDE/F	58	
42-02.22.15	SEQUENCER	NO OUTPUT	E/F	94	
42-02.43.01	SEQUENCER	NO OUTPUT	CDEF/F	12	
42-03.22.02	FWD PWR DIST	NO OUTPUT	CDE/F	2	
42-03.42.01	FWD PWR DIST	NO OUTPUT	E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	EF/F	2	
42-03.43.02	FWD PWR DIST	NO OUTPUT	CEF. F	2	
42-04.42.02	28V AFT PWR DIST	NO OUTPUT	EF/F	2	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	EF/F	3	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CDEF/F	6	
43-05	28V AFT PWR DIST	IMPROPER CONNECTION	CDEF/F	4	

MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

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MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
43–07	TUNNEL CABLE	IMPROPER CONNECTION	CDEF/F	6	6 · LOSS OF LH_2 TANK REPRESSURIZATION CAPABILITY
43–08	FWD CABLE	IMPROPER CONNECTION	CDEF/F	6	
43–09	AFT CABLE	IMPROPER CONNECTION	CDEF/F	20	

MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

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MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
21.02-02	FILL & DRAIN VALVE	FAILURE TO REMAIN CLOSED	CD/D CDEF/F	1	
21.02-02	FILL & DRAIN VALVE	INTERNAL LEAKAGE	CD/D CDEF/F	12	
21.02-03	LOX FILL DUCT	LEAKAGE	CD/D CDEF/F	1	
22.02-05	HI PERF PRESSURE SWITCH	NO OUTPUT	CDEF/F	46	
22.02-01	COLD He DISCONNECT	FAILURE TO DISENGAGE	C/D C/F	3	
22.02-04.01	He SPHERE RELIEF VALVE	FAILURE TO REMAIN CLOSED	C/D CDEF/F	1	
22.02-04.01	He SPHERE RELIEF VALVE	INTERNAL LEAKAGE	CD/D CDEF/F	25	
22.02-04.02	COLD He DUMP VALVE	FAILURE TO REMAIN CLOSED	CD/D CDEF/F	1	
22.02-04.02	COLD He DUMP VALVE	INTERNAL LEAKAGE	C/D CDEF/F	24	
22.02-05	LOX PRESS He SPHERE	EXTERNAL LEAKAGE	CD/D CDEF/F	5	
22.02-06	HI PERF PRESSURE SWITCH	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	34	
22.02-08.01	He PRE REG FILTER	CLOGGED	CD/D DF/F	1	7. LOSS OF LOX TANK PRESSURIZATION
22.02-08.02	He PRESSURE REGULATOR	INADEQUATE PRESSURE	CD/D DF/F	210	
22.02-08.03	COLD He SHUTOFF VALVE	FAILURE TO CLOSE	CE/F	11	
22.02-08.03	COLD He SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CE/F	1	
22.02-08.03	COLD He SHUTOFF VALVE	INTERNAL LEAKAGE	C/D CE/F	15	
22.02-08.04	COLD He SHUTOFF VALVE	FAILURE TO CLOSE	CE/F	11	
22.02-08.04	COLD He SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CE/F	1	
22.02-08.04	COLD He SHUTOFF VALVE	INTERNAL LEAKAGE	C/D CE/F	15	
22.01-08.05	COLD He CONTROL VALVE	FAILURE TO OPEN	D/D DF/F	2	
22.02-08.05	COLD He CONTROL VALVE	FAILURE TO REMAIN OPEN	C/D CDEF/F	1	
22.02-08.06	COLD He FILTER	CLOGGED	CD/D DF/F	1	
22.02-09	COLD He SURGE TANK	EXTERNAL LEAKAGE	CD/D CDEF/F	1	
22.02-10	HI PERF PRESS SWITCH	OUTPUT WHEN NOT REQUIRED	CD/D DEF/F	140	
22.02-14	LOX PIPING	LEAKAGE	CD/D CDEF/F	3	
22.02-15	VENT & RELIEF VALVE	FAILURE TO REMAIN CLOSED - VENT	CD/D DEF/F	1	
22.02-15	VENT & RELIEF VALVE	INTERNAL LEAKAGE	CD/D CDEF/F	24	
22.02-16	LOX TANK RELIEF VALVE	FAILURE TO REMAIN CLOSED	CD/D DEF/F	40	
22.02-16	LOX TANK RELIEF VALVE	INTERNAL LEAKAGE	CD/D CDEF/F	36	
23.02-06	LOX FEED DUCT	LEAKAGE	CD/D CDEF/F	4	
24-12.01	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	CD/D CDEF/F	1	
24-16.01	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	CD/D DEF/F	1	
26-01	J2 ENGINE	LEAKAGE	CD/D	5	
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	

3.7

MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	CD/D CDEF/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-02.22.21	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CE/F	77	
42-02.22.21	SEQUENCER	NO OUTPUT	CD/D F/F	81	
42-02.22.22	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	58	
42-02.22.23	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CD/D DEF/F	27	
42-02.43.01	SEQUENCER	NO OUTPUT	CD/D CDEF/F	19	
42-03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42-04 42 02	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	3	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	8	7. LOSS OF LOX TANK PRESSURIZATION
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D CDEF/F	9	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-07	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43-08	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	

MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

PATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
22.02-05	HI PERF PRESSURE SWITCH	NO OUTPUT	CDE/F	46	
22.02-05	HI PERF PRESSURE SWITCH	OUTPUT WHEN NOT REQUIRED	CDE/F	34	
22.02-17.01	REPRESS He FILTER	CLOGGED	E/F	1	
22.02-17.02	COLD He CONTROL VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
22.02-17.02	COLD He CONTROL VALVE	INTERNAL LEAKAGE	CDE/F	11	
22.02-17.03	COLD He CONTROL VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
22.02-17.03	COLD He CONTROL VALVE	INTERNAL LEAKAGE	CDE/F	11	
22.02-17.04	He CONTROL RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
22.02-17.04	He CONTROL RELIEF VALVE	INTERNAL LEAKAGE	CDE/F	11	
22.02-17.05	COLD He CONTROL VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
22.02-17.05	COLD He CONTROL VALVE	INTERNAL LEAKAGE	CDE/F	11	
22.02-17.06	VENT PURGE CHECK VALVE	INTERNAL LEAKAGE	CDE/F	5	8. LOSS OF LOX REPRESSURIZATION CAPABILITY
22.02-18	REPRESS He STORAGE TANK	EXTERNAL LEAKAGE	CDE/F	1	
22.02-20	REPRESS He CHECK VALVE	FAILURE TO OPEN	E/F	4	
22.02-20	REPRESS He CHECK VALVE	INTERNAL LEAKAGE	CD/F	5	
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	5	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	CD/D CDEF/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-02.22.26	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	6	
42-02.22.26	SEQUENCER	NO OUTPUT	E/F	26	
42-02.43.01	SEQUENCER	NO OUTPUT	CD/D CDEF/F	19	
42-03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42-04.22.01	28V AFT PWR DIST	NO OUTPUT	CDE/F	3	
42-04.42.02	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	3	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	8	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D CDEF/F	9	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43-08	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	

3.9 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
23.01-05	LH_2 SHUTOFF VALVE	FAILURE TO REMAIN OPEN	CD/D EF/F	1	9. LOSS OF LH_2 FEED
24-01	He CONT DISCONNECT	FAILURE TO DISENGAGE	C/D C/F	1	
24-02.02	PNEU CONT DUMP VALVE	FAILURE TO REMAIN CLOSED	C/D CDEF/F	1	
24-02.02	PNEU CONT DUMP VALVE	LEAKAGE	C/D CDEF/F	4	
24-02.03	PNEU CONT RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
24-02.03	PNEU CONT RELIEF VALVE	LEAKAGE	CDE/F	3	
24-04	REPRESS He STORAGE TANK	LEAKAGE	C/D CDEF/F	1	
24-05.01	PNEU CONT He FILTER	CLOGGED	C/D CDEF/F	1	
24-05.02	PNEU CONT PRESS REGULATOR	INADEQUATE PRESSURE	C/D CDEF/F	44	
24-05.03	PNEU CONT SHUTOFF VALVE	FAILURE TO REMAIN OPEN	C/D CDEF/F	1	
24-05.04	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-06	PNEU CONT SURGE TANK	LEAKAGE	C/D CDEF/F	1	
24-08.02	PURGE LINE SHUTOFF VALVE	FAILURE TO CLOSE	E/F	1	
24-08.02	PURGE LINE SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
24-08.02	PURGE LINE SHUTOFF VALVE	LEAKAGE	CDE/F	2	
24-11.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-11.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-12.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-13.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-13.02	PNEU CONT PILOT VALVE	FAILURE TO CLOSE	C/D E/F	7	
24-13.02	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	CD/D EF/F	1	
24-13.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-14.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-14.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-15.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-15.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-16.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-16.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-17	PNEU CONT He PIPING	LEAKAGE	C/D CDEF/F	4	
24-32	PNEU CONT MED PRESS SWITCH	OUTPUT WHEN NOT REQUIRED	C/D CDEF/F	30	
26-01	J2 ENGINE	COMPONENT FAILURE	D/D F/F	130	
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-01	SWITCH SELECTOR	NO OUTPUT – SINGLE CHANNEL	CD/D CDEF/F	177	

3.9 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

PATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
42–01	SWITCH SELECTOR	NO OUTPUT – ALL CHANNELS	C/D E/F	12	9. LOSS OF LH_2 FEED
42–02.23.01	SEQUENCER	OUTPUT WHEN NOT REQUIRED	D/D EF/F	16	
42–02.26.05	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CDE/F	5	
42–03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42–03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
43–05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43–07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43–08	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43–09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	

3.10 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
23.02–05	LOX TANK SHUTOFF VALVE	FAILURE TO OPEN	C/D	310	10. LOSS OF LOX FEED
23.02–05	LOX TANK SHUTOFF VALVE	FAILURE TO REMAIN OPEN	CD/D EF/F	1	
24–01	He CONT DISCONNECT	FAILURE TO DISENGAGE	C/D C/F	1	
24–02.02	PNEU CONT DUMP VALVE	FAILURE TO REMAIN CLOSED	C/D CDEF/F	1	
24–02.02	PNEU CONT DUMP VALVE	LEAKAGE	C/D CDEF/F	4	
24–02.03	PNEU CONT RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDEF/F	1	
24–02.03	PNEU CONT RELIEF VALVE	LEAKAGE	CDE/F	3	
24–04	REPRESS He STORAGE TANK	LEAKAGE	C/D CDEF/F	1	
24–05.01	PNEU CONT He FILTER	CLOGGED	C/D CDEF/F	1	
24–05.02	PNEU CONT PRESS REGULATOR	INADEQUATE PRESSURE	C/D CDEF/F	44	
24–05.03	PNEU CONT SHUTOFF VALVE	FAILURE TO REMAIN OPEN	C/D CDEF/F	1	
24–05.04	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–06	PNEU CONT SURGE TANK	LEAKAGE	C/D CDEF/F	1	
24–08.02	PURGE LINE SHUTOFF VALVE	FAILURE TO CLOSE	E/F	1	
24–08.02	PURGE LINE SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
24–08.02	PURGE LINE SHUTOFF VALVE	LEAKAGE	CDE/F	2	
24–11.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–11.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–12.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–12.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–13.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–13.02	PNEU CONT PILOT VALVE	FAILURE TO CLOSE	C/D E/F	7	
24–13.02	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	CD/D EF/F	1	
24–13.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–14.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–14.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–15.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–15.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–16.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–16.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24–17	PNEU CONT He PIPING	LEAKAGE	C/D CDEF/F	2	
24–32	PNEU CONT MED PRESS SWITCH	OUTPUT WHEN NOT REQUIRED	C/D CDEF/F	30	
26–01	J2 ENGINE	COMPONENT FAILURE	D/D F/F	30	

3.10 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	10. LOSS OF LOX FEED
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	CD/D CDEF/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-02.23.01	SEQUENCER	OUTPUT WHEN NOT REQUIRED	D/D EF/F	14	
42-02.26.06	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CDE/F	5	
42-03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D CDEF/F	9	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43-08	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	

3.11

MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
22.01-17.03	BYPASS REGULATOR	FAILURE TO OPEN	E/F	23	11. HIGH LH_2 TEMPERATURE
22.01-17.04	BYPASS REG SHUTOFF VALVE	FAILURE TO OPEN	E/F	5	
22.01-17.04	BYPASS REG SHUTOFF VALVE	FAILURE TO REMAIN OPEN	E/F	2	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-02.22.16.01	SEQUENCER	NO OUTPUT	E/F	46	
42-02.22.16.02	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CDE/F	21	
42-02.43.01	SEQUENCER	NO OUTPUT	CD/D CDEF/F	19	
42-04.42.02	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	3	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	8	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D CDEF/F	9	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-08	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	

MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

3.12

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
22.01-17.01	CONT VENT SHUTOFF VALVE	FAILURE TO OPEN	E/F	1	12. PROPELLANT SLOSHING
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	CD/D CDEF/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-02.22.17.01	SEQUENCER	NO OUTPUT	E/F	13	
42-02.43.01	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	19	
42-03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42-04.42.02	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	3	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	8	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D CDEF/F	6	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43-08	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	

3.13 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
21.01-02	FILL & DRAIN VALVE	FAILURE TO REMAIN CLOSED	C/D	CDEF/F	1
21.01-02	FILL & DRAIN VALVE	INTERNAL LEAKAGE	C/D	CDEF/F	10
21.01-03	FILL & DRAIN VALVE	LEAKAGE	C/D	CDEF/F	1
23.01-06	LH_2 FEED DUCT	LEAKAGE	CD/D	CDEF/F	3
24-11.01	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	C/D	CDEF/F	1
26-01	J2 ENGINE	COMPONENT FAILURE	CD/D	EF/F	17

13. LH_2 DEPLETION

3.14

MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

BATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
21.02-02	FILL & DRAIN VALVE	FAILURE TO REMAIN CLOSED	CD/D CDEF/F	1	14. LOX DEPLETION
21.02-02	FILL & DRAIN VALVE	INTERNAL LEAKAGE	CD/D CDEF/F	12	
21.02-03	LOX FILL DUCT	LEAKAGE	CD/D CDEF/F	1	
23.02-06	LOX FEED DUCT	LEAKAGE	CD/D CDEF/F	4	
24-12.01	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	CD/D CDEF/F	1	
26-01	J2 ENGINE	COMPONENT FAILURE	CD/D EF/F	170	
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	CD/D CDEF/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43-08	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	
46-03	PU ELECTRONICS	VALVE DRIVEN CLOSED	CDE/F	223	

3.15 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
23.02-02	LOX CHILL SHUTOFF VALVE	FAILURE TO CLOSE	E/F	5	
23.02-02	LOX CHILL SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	EF/F	1	
23.02-02	LOX CHILL SHUTOFF VALVE	INTERNAL LEAKAGE	EF/F	6	
24-01	He CONTROL DISCONNECT	FAILURE TO DISENGAGE	C/D C/F	1	
24-02.02	PNEU CONT DUMP VALVE	FAILURE TO REMAIN CLOSED	C/D CDEF/F	1	
24-02.02	PNEU CONT DUMP VALVE	LEAKAGE	C/D CDEF/F	4	
24-02.03	PNEU CONT RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
24-02.03	PNEU CONT RELIEF VALVE	LEAKAGE	CDE/F	3	
24-04	REPRESS He STORAGE TANK	LEAKAGE	C/D CDEF/F	1	
24-05.01	PNEU CONT He FILTER	CLOGGED	C/D CDEF/F	1	
24-05.02	PNEU CONT PRESS REGULATOR	INADEQUATE PRESSURE	C/D CDEF/F	44	15. VAPOR IN LOX FEED LINES
24-05.03	PNEU CONT SHUTOFF VALVE	FAILURE TO REMAIN OPEN	C/D CDEF/F	1	
24-05.04	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-06	PNEU CONT SURGE TANK	LEAKAGE	C/D CDEF/F	1	
24-08.02	PURGE LINE SHUTOFF VALVE	FAILURE TO CLOSE	E/F	1	
24-11.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-11.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-12.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-12.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-13.01	PNEU CONT PILOT VALVE	FAILURE TO OPEN	E/F	2	
24-13.01	PNEU CONT PILOT VALVE	FAILURE TO REMAIN OPEN	EF/F	5	
24-13.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-13.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-14.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-14.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-15.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-15.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-16.01	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-16.02	PNEU CONT PILOT VALVE	LEAKAGE	C/D CDEF/F	4	
24-17	PNEU CONT He PIPING	LEAKAGE	C/D CDEF/F	2	
24-32	PNEU CONT MED PRESS SWITCH	OUTPUT WHEN NOT REQUIRED	C/D CDEF/F	30	
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	
41.01-03	AFT BATTERY NO. 1	NO POWER	CD/D EF/F	100	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	15. VAPOR IN LOX FEED LINES
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	CD/D CDEF/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-02.23.02	SEQUENCER	NO OUTPUT	EF/F	29	
42-02.26.06	SEQUENCER	OUTPUT WHEN NOT REQUIRED	CDE/F	5	
42-02.43.01	SEQUENCER	NO OUTPUT	CD/D CDEF/F	19	
42-03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42-04.42.02	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	3	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	8	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D CDEF/F	9	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43-08	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43-09	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	

3.16 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
23.01–05	LH_2 TANK SHUTOFF VALVE	FAILURE TO REMAIN OPEN	CD/D EF/F	1	16. PREMATURE ENGINE SHUTDOWN INITIATION
23.02–05	LOX TANK SHUTOFF VALVE	FAILURE TO REMAIN OPEN	CD/D EF/F	1	
24–13.02	PNEU CONT PILOT VALVE	FAILURE TO REMAIN CLOSED	CD/D EF/F	1	
26–01	J2 ENGINE	COMPONENT FAILURE	CD/D EF/F	1900	
41.01–01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	
41.01–03	AFT BATTERY NO. 1	NO POWER	CD/D EF/F	100	
42–01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D EF/F	91	
42–01	SWITCH SELECTOR	NO OUTPUT – SINGLE CHANNEL	CD/D EF/F	123	
42–01	SWITCH SELECTOR	NO OUTPUT – ALL CHANNELS	D/D F/F	63	
42–02.26.02	SEQUENCER	OUTPUT WHEN NOT REQUIRED	D/D F/F	230	
42–03.42.01	FWD PWR DIST	NO OUTPUT	CD/D EF/F	1	
42–03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42–03.43.02	FWD PWR DIST	NO OUTPUT	EF/F	1	
81–09	RANGE SAFETY SYS 1 CONTROLLER	PREMATURE CHARGING	CD/D EF/F	17	
81–10	RANGE SAFETY SYS 2 CONTROLLER	PREMATURE CHARGING	CD/D EF/F	17	
42–04.24.01	28V AFT PWR DIST	OUTPUT WHEN NOT REQUIRED	F/F	4	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
31-01.01	AUX HYDRAULIC PUMP	FAILURE TO DELIVER	C/D CDE/F	870	17. LOSS OF HYDRAULIC PRESSURE
31-01.01	AUX HYDRAULIC PUMP	LEAKAGE	C/D CDE/F	32	
31-01.04	AUX PUMP CHECK VALVE	FAILURE TO OPEN	DE/F	4	
31-01.05	AUX PUMP HYDRAULIC FILTER	CLOGGED	CD/D CDEF/F	1	
31-01.07	AUX PUMP RELIEF VALVE	FAILURE TO REMAIN CLOSED	CD/D CDEF/F	1	
31-01.07	AUX PUMP RELIEF VALVE	LEAKAGE	CD/D CDEF/F	25	
31-01.08	AUX PUMP CHECK VALVE	FAILURE TO OPEN	D/D F/F	6	
31-01.09	HYDRAULIC BLEEDER VALVE	LEAKAGE	CD/D CDEF/F	1	
31-01.10	AUX PUMP RELIEF VALVE	FAILURE TO OPEN	C/D CDE/F	7	
31-01.11	AUX PUMP CHECK VALVE	FAILURE TO OPEN	C/D CDE/F	7	
31-01.12	AUX PUMP PRESSURE REGULATOR	INADEQUATE PRESSURE	C/D CDE/F	21	
31-01.13	AUX PUMP RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/F	1	
31-01.13	AUX PUMP RELIEF VALVE	LEAKAGE	CDE/F	11	
31-02.01	COMPRESSED AIR TANK	LEAKAGE	CDE/F	1	
31-03.01	HYDRAULIC PUMP	FAILURE TO DELIVER	D/D DF/F	170	
31-03.01	HYDRAULIC PUMP	FAILURE TO LIMIT PRESSURE	D/D DF/F	120	
31-03.01	HYDRAULIC PUMP	LEAKAGE	CD/D CDEF/F	85	
31-03.02	HYD PUMP HI PRESS CHECK VALVE	FAILURE TO OPEN	DE/F	4	
31-03.02	HYD PUMP HI PRESS CHECK VALVE	FAILURE TO CLOSE	D/D DF/F	1	
31-03.02	HYD PUMP HI PRESS CHECK VALVE	LEAKAGE	D/D DF/F	4	
31-03.03	HYD PUMP HI PRESS CHECK VALVE	FAILURE TO OPEN	D/D DF/F	2	
31-03.03	HYD PUMP HI PRESS CHECK VALVE	FAILURE TO CLOSE	DE/F	1	
31-03.03	HYD PUMP HI PRESS CHECK VALVE	LEAKAGE	DE/F	3	
31-03.04	HYD BLEEDER VALVE	LEAKAGE	CD/D CDEF/F	1	
31-04.01	HYDRAULIC ACCUMULATOR	LOSS OF PRECHARGE	CD/D CDEF/F	15	
31-04.01	HYDRAULIC ACCUMULATOR	JAMMED PISTON	CD/D CDEF/F	15	
31-04.01	HYDRAULIC ACCUMULATOR	LEAKAGE	CD/D CDEF/F	89	
31-04.02	HYD ACCUMULATOR RESERVOIR	JAMMED PISTON	CD/D EF/F	7	
31-04.02	HYD ACCUMULATOR RESERVOIR	LEAKAGE	CD/D CDEF/F	8	
31-04.03	HYD MAIN SYS FILTER	CLOGGED	CD/D EF/F	1	
31-04.04	HYD ACCUM HI PRESS RELIEF VALVE	FAILURE TO REMAIN CLOSED	CD/D EF/F	2	
31-04.04	HYD ACCUM HI PRESS RELIEF VALVE	LEAKAGE	CD/D CDEF/F	35	
31-04.05	HYD BLEEDER VALVE	LEAKAGE	CD/D CDEF/F	1	

3.17 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
31-05	HYD TEMP CONT THERMAL SWITCH	OUTPUT WHEN NOT REQUIRED	CDE/F	120	17. LOSS OF HYDRAULIC PRESSURE
31-05	HYD TEMP CONT THERMAL SWITCH	NO OUTPUT	CDE/F	33	
31-06.02	HYDRAULIC ACTUATOR	LEAKAGE	CD/D CDEF/F	6	
31-06.04	HYD ACT PRE FILTRATION VALVE	LEAKAGE	CD/D CDEF/F	1	
31-06.05	HYD ACT BYPASS VALVE	LEAKAGE	CD/D CDEF/F	1	
31-06.06	HYDRAULIC BLEEDER VALVE	LEAKAGE	CD/D CDEF/F	1	
31-07.02	HYDRAULIC ACTUATOR	LEAKAGE	CD/D CDEF/F	6	
31-07.04	HYD ACT PRE FILTRATION VALVE	LEAKAGE	CD/D CDEF/F	1	
31-07.05	HYD ACT BYPASS VALVE	LEAKAGE	CD/D CDEF/F	1	
31-07.06	HYDRAULIC BLEEDER VALVE	LEAKAGE	CD/D CDEF/F	1	
31-08	HYDRAULIC PIPING	LEAKAGE	CD/D CDEF/F	4	
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	
41.01-04	AFT BATTERY NO. 2	NO POWER	C/D E/F	35	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	CD/D CDEF/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	C/D E/F	12	
42-03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42-05.31.01	55V AFT PWR DIST	NO OUTPUT	C/D CDE/F	660	
42-05.42.40	55V AFT PWR DIST	PREMATURE TRANSFER	C/D E/F	20	
42-05.43.04	55V AFT PWR DIST	NO OUTPUT	C/D CDE/F	14	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
31-06.01	HYD ACTUATOR SERVO VALVE	FAILURE TO POSITION ACTUATOR	D/D F/F	330	
31-06.01	HYD ACTUATOR SERVO VALVE	FAILURE TO MAINTAIN ACTUATOR POSITION	CD/D CDEF/F	210	
31-06.02	HYDRAULIC ACTUATOR	JAMMING	CD/D EF/F	7	
31-06.03	HYD ACTUATOR FLUID FILTER	CLOGGED	CD/D EF/F	1	
31-07.01	HYD ACTUATOR SERVO VALVE	FAILURE TO POSITION ACTUATOR	D/D F/F	330	
31-07.01	HYD ACTUATOR SERVO VALVE	FAILURE TO MAINTAIN ACTUATOR POSITION	CD/D CDEF/F	210	
31-07.02	HYDRAULIC ACTUATOR	JAMMING	CD/D EF/F	7	18. LOSS OF STEERING CONTROL
31-07.03	HYD ACTUATOR FLUID FILTER	CLOGGED	CD/D EF/F	1	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CD/D CDEF/F	148	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D CDEF/F	6	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D CDEF/F	8	
43-08	FWD CABLE	IMPROPER CONNECTION	CD/D CDEF/F	10	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D CDEF/F	33	

3.19 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
32.01-01.02	APS 1 He DUMP VALVE	LEAKAGE	CDE/E CDEFG/G	26	19. LOSS OF ATTITUDE CONTROL
32.01-01.02	APS 1 He DUMP VALVE	FAILURE TO REMAIN CLOSED	CDE/E EFG/G	2	
32.01-01.03	APS 1 He RELIEF VALVE	LEAKAGE	CDE/E CDEFG/G	26	
32.01-01.03	APS 1 He RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/E CDEFG/G	2	
32.01-02	APS 1 He TANK	LEAKAGE	CDE/E CDEFG/G	1	
32.01-03.01	APS 1 He FILTER	CLOGGED	DE/E EFG/G	1	
32.01-03.02	PRIMARY PRESSURE REGULATOR	INADEQUATE PRESSURE	CDE/E EFG/G	180	
32.01-03.03	SECONDARY PRESSURE REGULATOR	INADEQUATE PRESSURE	CDE/E EFG/G	19	
32.01-05.02	APS 1 Lo PRESS He RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/E EFG/G	2	
32.01-05.02	APS 1 Lo PRESS He RELIEF VALVE	LEAKAGE	CDE/E CDEFG/G	26	
32.01-06	APS 1 He FILTER	CLOGGED	DE/E EFG/G	1	
32.01-08.02	APS 1 Lo PRESS He RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/E EFG/G	2	
32.01-08.02	APS 1 Lo PRESS He RELIEF VALVE	LEAKAGE	CDE/E CDEFG/G	26	
32.01-09	APS 1 He FILTER	CLOGGED	DE/E EFG/G	1	
32.01-10.01	APS 1 PRESSURE TANK	LEAKAGE	CDE/E CDEFG/G	1	
32.01-10.02	APS 1 EXPULSION BLADDER	LEAKAGE	CDE/E CDEFG/G	130	
32.01-10.02	APS 1 EXPULSION BLADDER	RUPTURE	CDE/E FG/G	360	
32.01-12.01	APS 1 PRESSURE TANK	LEAKAGE	CDE/E CDEFG/G	1	
32.01-12.02	APS 1 EXPULSION BLADDER	LEAKAGE	CDE/E CDEFG/G	130	
32.01-12.02	APS 1 EXPULSION BLADDER	RUPTURE	CDE/E EFG/G	360	
32.01-14	APS 1 He PIPING	LEAKAGE	CDE/E CDEFG/G	2	
32.01-15.01	APS 1 Ox FILTER	CLOGGED	DE/E FG/G	1	
32.01-18.01	APS 1 FUEL FILTER	CLOGGED	DE/E FG/G	1	
32.01-22.04	APS 1 FUEL SCREEN	CLOGGED	DE/E FG/G	1	
32.01-22.05	APS 1 Ox SCREEN	CLOGGED	DE/E FG/G	1	
32.01-23.04	APS 1 FUEL SCREEN	CLOGGED	DE/E FG/G	1	
32.01-23.05	APS 1 Ox SCREEN	CLOGGED	DE/E FG/G	1	
32.01-24.04	APS 1 FUEL SCREEN	CLOGGED	E/E G/G	1	
32.01-24.05	APS 1 Ox SCREEN	CLOGGED	E/E G/G	1	
32.01-30	APS He DISCONNECT	FAILURE TO DISENGAGE	C/D THRU G	1	
32.02-01.02	APS 2 He DUMP VALVE	LEAKAGE	CDE/E CDEFG/G	26	
32.02-01.02	APS 2 He DUMP VALVE	FAILURE TO REMAIN CLOSED	CDE/E CDEFG/G	2	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
32.02-01.03	APS 2 He RELIEF VALVE	LEAKAGE	CDE/E CDEFG/G	26	19. LOSS OF ATTITUDE CONTROL
32.02-01.03	APS 2 He RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/E CDEFG/G	2	
32.02-02	APS 2 He TANK	LEAKAGE	CDE/E CDEFG/G	1	
32.02-03.01	APS 2 He FILTER	CLOGGED	DE/E EFG/G	1	
32.02-03.02	PRIMARY PRESSURE REGULATOR	INADEQUATE PRESSURE	CDE/E EFG/G	190	
32.02-03.03	SECONDARY PRESSURE REGULATOR	INADEQUATE PRESSURE	CDE/E EFG/G	19	
32.02-05.02	APS 2 Lo PRESS He RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/E EFG/G	2	
32.02-05.02	APS 2 Lo PRESS He RELIEF VALVE	LEAKAGE	CDE/E CDEFG/G	26	
32.02-06	APS 2 He FILTER	CLOGGED	DE/E EFG/G	1	
32.02-08.02	APS 2 Lo PRESS He RELIEF VALVE	FAILURE TO REMAIN CLOSED	CDE/E EFG/G	2	
32.02-08.02	APS 2 Lo PRESS He RELIEF VALVE	LEAKAGE	CDE/E CDEFG/G	26	
32.02-09	APS 2 He FILTER	CLOGGED	DE/E EFG/G	1	
32.02-10.01	APS 2 PRESSURE TANK	LEAKAGE	CDE/E CDEFG/G	1	
32.02-10.02	APS 2 EXPULSION BLADDER	LEAKAGE	CDE/E CDEFG/G	130	
32.02-10.02	APS 2 EXPULSION BLADDER	RUPTURE	CDE/E FG/G	360	
32.02-12.01	APS 2 PRESSURE TANK	LEAKAGE	CDE/E CDEFG/G	1	
32.02-12.02	APS 2 EXPULSION BLADDER	LEAKAGE	CDE/E CDEFG/G	130	
32.02-12.02	APS 2 EXPULSION BLADDER	RUPTURE	CDE/E EFG/G	360	
32.02-14	APS 2 He PIPING	LEAKAGE	CDE/E CDEFG/G	2	
32.02-15.01	APS 2 Ox FILTER	CLOGGED	DE/E FG/G	1	
32.02-18.01	APS 2 FUEL FILTER	CLOGGED	DE/E FG/G	1	
32.02-22.04	APS 2 FUEL SCREEN	CLOGGED	DE/E FG/G	1	
32.02-22.05	APS 2 Ox SCREEN	CLOGGED	DE/E FG/G	1	
32.02-23.04	APS 2 FUEL SCREEN	CLOGGED	DE/E FG/G	1	
32.02-23.05	APS 2 Ox SCREEN	CLOGGED	DE/E FG/G	1	
32.02-24.04	APS 2 FUEL SCREEN	CLOGGED	E/E G/G	1	
32.02-24.05	APS 2 Ox SCREEN	CLOGGED	E/E G/G	1	
41.01-03	AFT BATTERY NO. 1	NO POWER	E/E G/G	50	

3.19 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
42-03.43.02	FWD PWR DIST	NO OUTPUT	CEF/F	2	19. LOSS OF ATTITUDE CONTROL
42-04.32.01	28V AFT PWR DIST	NO OUTPUT	E/E EFG/G	33	
42-04.32.02	28V AFT PWR DIST	NO OUTPUT	CDE/E EFG/G	33	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	E/E G/G	8	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	6	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CD/D EF/F	4	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D EF/F	6	
43-08	FWD CABLE	IMPROPER CONNECTION	CD/D EF/F	7	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D EF/F	21	

MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

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MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
26-01	J2 ENGINE	INTERNAL LEAKAGE	CDE/E CDEFG/G	1	20. APS PROPELLANT DEPLETION
32.01-21	APS 1 PROPELLANT PIPING	LEAKAGE	CDE/E CDEFG/G	1	
32.01-25.01	APS 1 SHUTOFF VALVE	FAILURE TO CLOSE	E/E F/G	1	
32.01-25.01	APS 1 SHUTOFF VALVE	LEAKAGE	CDE/E CDEFG/G	3	
32.01-25.01	APS 1 SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CDE/E FG/G	8	
32.01-25.02	APS 1 ULLAGE ENGINE SHUTOFF VALVE	FAILURE TO CLOSE	E/E F/G	2	
32.01-25.02	APS 1 ULLAGE ENGINE SHUTOFF VALVE	LEAKAGE	CDE/E CDEFG/G	24	
32.01-25.02	APS 1 ULLAGE ENGINE SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CDE/E FG/G	16	
32.02-21	APS 2 PROPELLANT PIPING	LEAKAGE	CDE/E CDEFG/G	1	
32.02-25.01	APS 2 SHUTOFF VALVE	FAILURE TO CLOSE	E/E F/G	1	
32.02-25.01	APS 2 SHUTOFF VALVE	LEAKAGE	CDE/E CDEFG/G	3	
32.02-25.01	APS 2 SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CDE/E FG/G	8	
32.02-25.02	APS 2 ULLAGE ENGINE SHUTOFF VALVE	FAILURE TO CLOSE	E/E F/G	2	
32.02-25.02	APS 2 ULLAGE ENGINE SHUTOFF VALVE	LEAKAGE	CDE/E CDEFG/G	24	
32.02-25.02	APS 2 ULLAGE ENGINE SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CDE/E FG/G	16	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CDE/E E/F FG/G	135	
42-04.32.03	28V AFT PWR DIST	OUTPUT WHEN NOT REQUIRED	CDE/E E/F FG/G	31	

3.21 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
41.01-03	AFT BATTERY NO. 1	NO POWER	C/C	7	21. LOSS OF LOWER STAGE FLIGHT CONTROL
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	C/C	32	
42.02.43.01	SEQUENCER	NO OUTPUT	C/C	14	
42-02.44.01	SEQUENCER	NO OUTPUT	C/C	2	
42-02.44.02	SEQUENCER	NO OUTPUT	C/C	2	
42-03.42.20	FWD PWR DIST	NO OUTPUT	C/C	21	
42-04 42.02	28V AFT PWR DIST	NO OUTPUT	C/C	1	
42.04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	C/C	2	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	C/C	5	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	C/C	23	
43-06	AFT INTERSTAGE CONN	IMPROPER CONNECTION	C/C	45	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	C/C	28	
43-08	FWD CABLE	IMPROPER CONNECTION	C/C	12	
43-09	AFT CABLE	IMPROPER CONNECTION	C/C	32	
44-01	RATE GYRO	ERRONEOUS OUTPUT	C/C	21	
44-02	ACCELEROMETER	ERRONEOUS OUTPUT	C/C	12	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
61-01	SEVERANCE EBW FIRING UNIT	PREMATURE OPERATION	C/C	1	22. PREMATURE SEPARATION
61-02	SEVERANCE EBW FIRING UNIT	PREMATURE OPERATION	C/C	1	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
62-01	RETRO ROCKET EBW FIRING UNIT	PREMATURE OPERATION	C/D	7	23. FAILURE TO SEPARATE
62-02	RETRO ROCKET EBW FIRING UNIT	PREMATURE OPERATION	C/D	7	

3.24 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
26-01	J2 ENGINE	DEENERGIZED	D/D F/F	310	24. LOSS OF ENGINE SHUTDOWN SEQUENCING
41.01-01	FWD BATTERY NO. 1	NO POWER	CD/D EF/F	10	
42-01	SWITCH SELECTOR	NO OUTPUT - SINGLE CHANNEL	D/D F/F	177	
42-01	SWITCH SELECTOR	NO OUTPUT - ALL CHANNELS	D/D F/F	12	
42-02.26.02	SEQUENCER	NO OUTPUT	E/E G/G	51	
42-02.43.01	SEQUENCER	NO OUTPUT	CD/D EF/F	13	
42-03.42.01	FWD PWR DIST	NO OUTPUT	C/D E/F	1	
42-03.42.10	FWD PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	3	
42-04.42.02	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	3	
42-04.42.30	28V AFT PWR DIST	TRANSFER TO EXTERNAL	CD/D EF/F	8	
42-04.43.03	28V AFT PWR DIST	NO OUTPUT	CD/D EF/F	6	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CD/D EF/F	6	
43-08	FWD CABLE	IMPROPER CONNECTION	CD/D EF/F	7	
43-09	AFT CABLE	IMPROPER CONNECTION	CD/D EF/F	21	

3.25 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
26-01	J2 ENGINE	COMPONENT FAILURE	D/D F/F	1700	25. DEGRADED ENGINE PERFORMANCE
41.01-01	FWD BATTERY NO. 1	NO POWER	EF/F	5	
41.01-02	FWD BATTERY NO. 2	NO POWER	CDEF/F	150	
41.02-01	PU INVERTER -CONVERTER	NO 49/117.5/21 VDC OUTPUTS	CDEF/F	340	
41.02-01	PU INVERTER -CONVERTER	NO 115 VDC OR 5 V P-P OUTPUT	CDEF/F	330	
42-01	SWITCH SELECTOR	OUTPUT WHEN NOT REQUIRED	CDEF/F	85	
42-01	SWITCH SELECTOR	NO OUTPUT – SINGLE CHANNEL	CDEF/F	98	
42-03.42.01	FWD PWR DIST	NO OUTPUT	E/F	1	
42-03.42.10	FWD PWR DIST	NO OUTPUT	E/F	1	
42-03.42.20	FWD PWR DIST	TRANSFER TO EXTERNAL	CDEF/F	21	
42-03.46.01	FWD PWR DIST	NO OUTPUT	CDEF/F	35	
42-03.46.02	FWD PWR DIST	NO OUTPUT	CDEF/F	35	
42-03.46.03	FWD PWR DIST	OUTPUT WHEN NOT REQUIRED	EF/F	15	
42-03.46.03	FWD PWR DIST	NO OUTPUT	CD/F	21	
43-05	FWD INTERSTAGE CONN	IMPROPER CONNECTION	CDEF/F	4	
43-07	TUNNEL CABLE	IMPROPER CONNECTION	CDEF/F	5	
43-08	FWD CABLE	IMPROPER CONNECTION	CDEF/F	6	
43-09	AFT CABLE	IMPROPER CONNECTION	CDEF/F	20	
46-01	LOX MASS PROBE	OPEN OR SHORT CIRCUIT	CDEF/F	100	
46-02	LH_2 MASS PROBE	OPEN OR SHORT CIRCUIT	CDEF/F	110	
46-03	PU ELECTRONICS	NO OUTPUT	CDEF/F	1900	
46-03	PU ELECTRONICS	VALVE DRIVEN OPEN	CDEF/F	670	
46-03	PU ELECTRONICS	VALVE DRIVEN CLOSED	CDEF/F	223	

3.26 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
26-01	J2 ENGINE	ENERGIZED ENGINE START CONT	C/C	13	26. IGNITION PRIOR TO STAGING

3.27 MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
26-01	J2 ENGINE	COMPONENT FAILURE - BURNTHROUGH	D/D F/F	150	27. FIRE
25-22.02	ULLAGE ROCKET MOTOR	BURST OR BURNTHROUGH	C/D CD/D	8	
25-23.02	ULLAGE ROCKET MOTOR	BURST OR BURNTHROUGH	C/D CD/D	8	
32.01-21	APS 1 PROPELLANT PIPING	LEAKAGE	C/C	1	
32.01-22.03	APS 1 ENGINE	BURNTHROUGH	D/D E/E F/F G/G	30	
32.01-23.03	APS 1 ENGINE	BURNTHROUGH	DE/E FG/G	30	
32.01-24.03	APS 1 ENGINE	BURNTHROUGH	E/E G/G	27	
32.01-25.01	APS 1 SHUTOFF VALVE	LEAKAGE	B C/C	3	
32.01-25.01	APS 1 SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	B C/C	9	
32.01-25.03	APS 1 ENGINE	BURNTHROUGH	E/E F/F	81	
32.02-21	APS 2 PROPELLANT PIPING	LEAKAGE	C/D CD/D	1	
32.02-22.03	APS 2 ENGINE	BURNTHROUGH	D/D	30	
32.02-23.03	APS 2 ENGINE	BURNTHROUGH	DE/E FG/G	30	
32.02-24.03	APS 2 ENGINE	BURNTHROUGH	E/E G/G	27	
32.02-25.01	APS 2 SHUTOFF VALVE	LEAKAGE	B C/C	3	
32.02-25.01	APS 2 SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	B C/C	9	
32.02-25.03	APS 2 ENGINE	BURNTHROUGH	E/E F/F	1	
62-24.02	RETRO ROCKET MOTOR	BURST OR BURNTHROUGH	D/D	120	
62-25.02	RETRO ROCKET MOTOR	BURST OR BURNTHROUGH	D/D	120	
62-26.02	RETRO ROCKET MOTOR	BURST OR BURNTHROUGH	D/D	120	
62-27.02	RETRO ROCKET MOTOR	BURST OR BURNTHROUGH	D/D	120	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
21.01-02	LH_2 FILL & DRAIN VALVE	FAILURE TO REMAIN CLOSED	C/C	1	28. EXPLOSION
21.01-02	LH_2 FILL & DRAIN VALVE	INTERNAL LEAKAGE	C/C	80	
21.01-03	LH_2 FILL & DRAIN DUCT	LEAKAGE	C/C	1	
23.01-06	LH_2 FEED DUCT	LEAKAGE	C/C	3	
24-11.01	PNEU CONT FILL & DRAIN PILOT VALVE	FAILURE TO REMAIN CLOSED	C/C	1	
25-22.02	ULLAGE ROCKET MOTOR	BURST OR BURNTHROUGH	C/C CD/D	8	
25-23.02	ULLAGE ROCKET MOTOR	BURST OR BURNTHROUGH	C/C CD/D	8	
26-01	J2 ENGINE	COMPONENT FAILURE – BURNTHROUGH	D/D F/F	150	
32.01-22.03	APS 1 ENGINE	BURNTHROUGH	D/D E/E F/F G/G	30	
32.01-23.03	APS 1 ENGINE	BURNTHROUGH	DE/E FG/G	30	
32.01-24.03	APS 1 ENGINE	BURNTHROUGH	DE/E FG/G	27	
32.01-25.03	APS 1 ENGINE	BURNTHROUGH	E/E F/F	1	
32.02-22.03	APS 2 ENGINE	BURNTHROUGH	DE/E FG/G	30	
32.02-23.03	APS 2 ENGINE	BURNTHROUGH	DE/E FG/G	30	
32.02-24.03	APS 2 ENGINE	BURNTHROUGH	D/D E/E F/F G/G	27	
32.02-25.03	APS 2 ENGINE	BURNTHROUGH	E/E F/F	1	
62-24.02	RETRO ROCKET MOTOR	BURST OR BURNTHROUGH	D/D	120	
62-25.02	RETRO ROCKET MOTOR	BURST OR BURNTHROUGH	D/D	120	
62-26.02	RETRO ROCKET MOTOR	BURST OR BURNTHROUGH	D/D	120	
62-27.02	RETRO ROCKET MOTOR	BURST OR BURNTHROUGH	D/D	120	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
43-01	FWD UMBILICAL CONN	IMPROPER DISCONNECT	C/CDF	3	29. LAUNCH DAMAGE
43-02	AFT UMBILICAL CONN	IMPROPER DISCONNECT	C/CDF	3	

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MDS SINGLE THREAD CAUSE/EFFECT ANALYSIS

MATH MODEL NUMBER	ITEM	FAILURE TYPE	PHASE	CRITICALITY NUMBER	OVERALL FAILURE MODE (CRITICAL EFFECT)
23.01–05	LH_2 SHUTOFF VALVE	FAILURE TO REMAIN OPEN	CD/D EF/F	1	30. ENGINE BREAKUP
24–13.02	PNEU CO NT SHUTOFF VALVE	FAILURE TO REMAIN CLOSED	CD/D EF/F	1	
26–01	J2 ENGINE	COMPONENT FAILURE	CD/D EF/F	110	

BIBLIOGRAPHY