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QUARTERLY PROGRESS REPORT

October - December 1971

SPACE SHUTTLE PROPULSION SYSTEMS ON-BOARD CHECKOUT AND MONITORING SYSTEM DEVELOPMENT STUDY

Contract NAS8-25619
CDRL No. 187, Rev. A
Line Item No. 2 (Issue 5)

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MARTIN MARIETTA CORPORATION
Denver Division
Denver, Colorado 80201

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Approved by:

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Program Manager

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Denver, Colorado 80201

FOREWORD

This quarterly progress report is submitted in accordance with the requirements of Contract NAS8-25619, "Space Shuttle Propulsion Systems On-board Checkout and Monitoring System Development Study".

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STATUS SUMMARY

1. Program reviews were conducted at MSFC in October and December. Primary emphasis was placed on in-depth reviews and discussions of preliminary drafts of Sections 1 and 3 of the Guidelines Document prepared under Task II. General concurrence and agreement were reached on the format and content of this material.

2. Section 1 and Section 3 of the Guidelines Document (Task II) were completed in draft form and are included herein for final review. Definitions of terms were prepared and also are included. Sections 2, 4 and 5.2 are being drafted.

3. Under the Task III effort, the analysis of checkout and monitoring requirements of the Titan III L expendable booster propulsion systems was completed, and the techniques for accomplishing the requisite checkout and monitoring functions were determined. Documentation of this task is presented herein.

4. The status and results of Task 1 were presented at the December program review. This effort on this task is continuing.

I. INTRODUCTION

This quarterly progress report describes and presents the results of work performed by the Martin Marietta Corporation under Contract NAS8-25619 during the October through December, 1971, reporting period. The effort, which was initiated in May, 1971, as an extension to the basic contract, is comprised of three tasks. Task I consists of updating the results of the basic study by reviewing and evaluating the results of certain related studies in the area of propulsion system checkout and monitoring. Task II consists of the preparation of a document, "Guidelines for Incorporation of the Onboard Checkout and Monitoring Function for The Space Shuttle." These guidelines will be used by NASA and the Space Shuttle contractors to incorporate the onboard checkout and monitoring function into the basic design of the propulsion systems and associated interfacing systems. Task III consists of the evaluation of the propulsion checkout and monitoring requirements of an expendable booster for Space Shuttle. Figure I-1 shows the schedule milestones of the study.

The subsequent chapters of this report summarize the status of the tasks and present the documented results of the work accomplished during the reporting period. This documentation includes a draft of that portion of the Guidelines Document that has been reviewed by NASA. The documentation also includes the Task III configuration definition and systems analysis results.

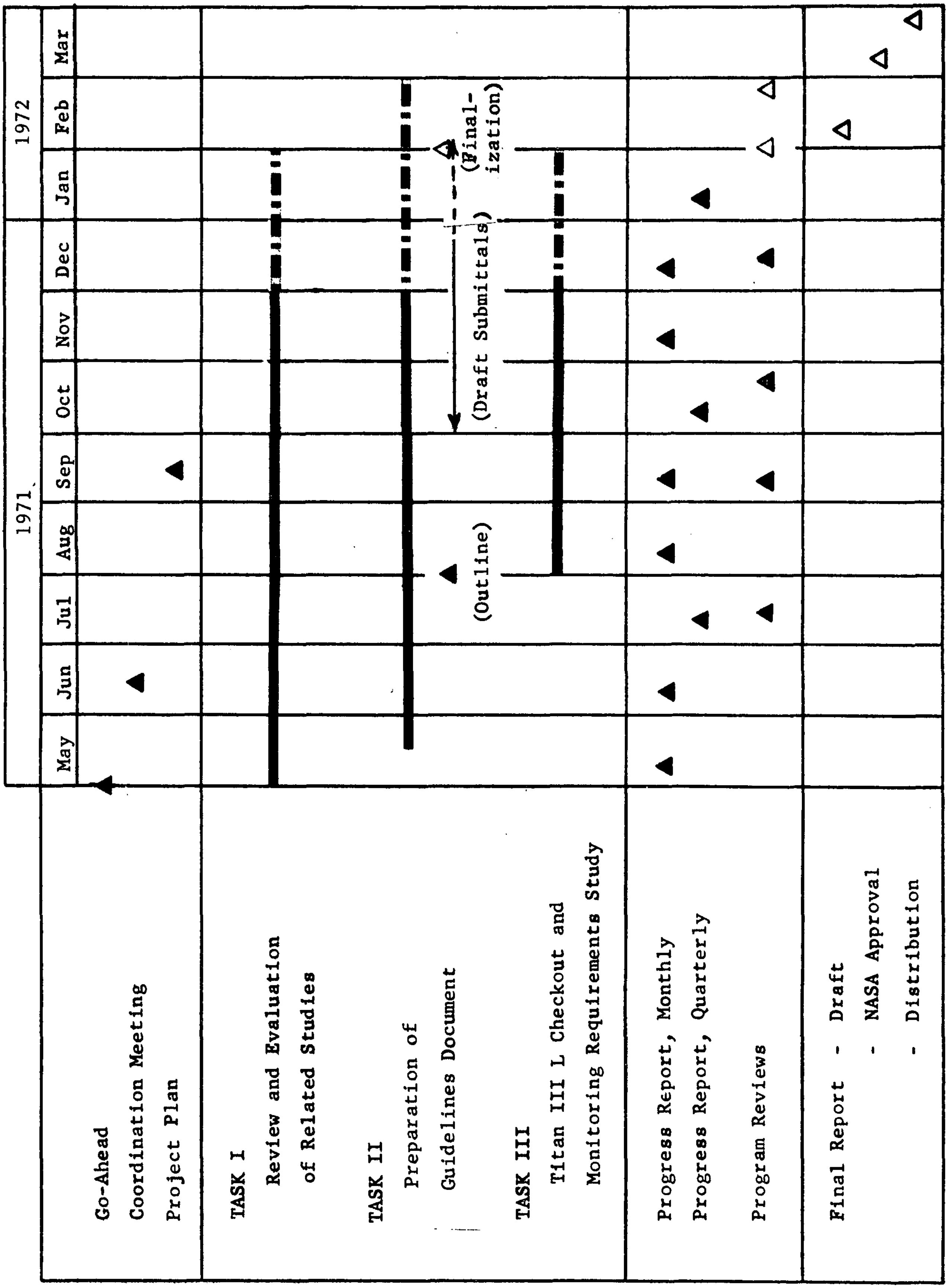

Figure I-1 Project Schedule

II. STATUS AND RESULTS - TASK I

The effort on Task I during this reporting period has been comprised of: The resolution of open items in the last quarterly progress report; a partial review of the final report of Contract NAS9-10960; the acquisition of data on bearing incipient failure detectors from SKF[1] and General Electric[2]; a discussion of leakage detection by ultrasonic techniques with Pearce Associates[3]; and the presentation of a summary of all data collected and evaluated to date at the Midterm Review held in mid-December at NASA-MFSC.

Table II-1 summarizes the status of this task. The asterisks identify the studies on which data summaries were presented at the Midterm Progress review.

1. SKF Industries, Inc., Engineering and Research Center, 1100 First Avenue, King of Prussia, Pa. 19406. (Mr. Paul Howard).
2. General Electric Co., Aerospace Instruments and Control Systems Dept., P. O. Box 5000, Binghamton, N. Y. 13902. (Mr. N. Gula).
3. J. L. Pearce & Associates, Dynamatec Corp., 101 N. Atlantic Ave., Cocoa Beach, Florida 32931. (Mr. J. C. Janus).

TABLE II-1

TASK I STATUS SUMMARY

STUDY	CONTRACTOR	STATUS
PHASE B SYSTEM STUDIES		
* NAS8-26016	MDC	Orbiter Technical Summaries received.
* NAS9-10960	NR	Orbiter data management system partially reviewed.
PHASE B MAIN ENGINE STUDIES		
NAS8-26186	P & W	No documentation available.
NAS8-26187	Rocketdyne	Cursory reading; no evaluation.
NAS8-26188	ALRC	No documentation available.
DATA BUS TECHNIQUIS		
NAS8-26378	SCI	Only have Phase I report. No review.
RELATED STUDIES		
* NAS10-7258	MMC	Reviewed basic study. Tracking follow-on.
* NAS10-7291	Dynamatec	Reviewed Phases I & II. Tracking Phase III
* NAS10-7145	GE	Reviewed basic study. Tracking follow-on.
NAS9-11330	LMSC	Review in progress.

III. STATUS AND RESULTS - TASK II

During the month of October the preliminary draft of Sections 1.0 and 3.1 were reviewed with NASA. The comments and recommendations were subsequently incorporated and presented in the October Progress Report.

The remainder of Section 3.0 was then drafted and submitted to NASA. Sections 1.0 and 3.0 were reviewed in their entirety at the Midterm Review in mid-December. A number of valuable comments and recommendations were obtained during that review and subsequently incorporated for presentation herein. We welcome further comments on this material.

In addition, a portion of Section 5.0 has been drafted for presentation at this time. The draft of the balance of the document is in progress.

GUIDELINES FOR INCORPORATION OF THE ONBOARD CHECKOUT AND MONITORING FUNCTION ON THE SPACE SHUTTLE

1.0 SCOPE

- 1.1 Content
- 1.2 Applicability
- 1.3 Intended Use

2.0 APPLICABLE DOCUMENTS

3.0 REQUIREMENTS

- 3.1 Performance
  - 3.1.1 Checkout and Monitoring Functions
    - 3.1.1.1 Checkout
      - 3.1.1.1.1 Prestart Checkout
        - 3.1.1.1.1.1 Status Verification
        - 3.1.1.1.1.2 Redundancy Verification
        - 3.1.1.1.1.3 Avionics Checks
        - 3.1.1.1.1.4 Functional Testing
      - 3.1.1.1.2 Postflight Checkout
      - 3.1.1.1.3 Maintenance Retest
    - 3.1.1.2 Monitoring
      - 3.1.1.2.1 Fault Detection
      - 3.1.1.2.2 Fault Isolation
      - 3.1.1.2.3 Trend Analysis
      - 3.1.1.2.4 Data Recording
      - 3.1.1.2.5 Display
    - 3.1.1.3 Control
    - 3.1.1.4 Postflight Evaluation
      - 3.1.1.4.1 Postflight Data Evaluation
      - 3.1.1.4.2 Postflight Inspection
  - 3.1.2 Systems Analysis Approach
    - 3.1.2.1 Propulsion System Definition
      - 3.1.2.1.1 Functional and Operational Criteria
      - 3.1.2.1.2 Propulsion Hardware Definition
      - 3.1.2.1.3 Control Sequence & Operational Logic Diagrams (CSOLD)

3.1.2.2 System Analysis

3.1.2.2.1 Line Replaceable Unit Identification
3.1.2.2.2 Failure Modes and Effects Analysis
3.1.2.2.3 Checkout and Monitoring Functional Requirements Analysis

3.1.2.2.3.1 Description of Results
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3.1.2.2.4 Measured Parameter and Sensor Selection

3.2 Checkout and Monitoring Function Implementation

3.2.1 Elements Related to Checkout and Monitoring

3.2.1.1 Propulsion System Elements
3.2.1.2 Sensors
3.2.1.3 Interfaces
3.2.1.4 Ground Support Equipment (GSE)
3.2.1.5 Data Management and Control (DM&C) Subsystem

3.2.1.5.1 Central Computer Complex (CCC)
3.2.1.5.2 Digital Data Bus
3.2.1.5.3 Subsystem Interface Unit (SIU)

3.2.1.6 Dedicated Remote Processors
3.2.1.7 Recorders
3.2.1.8 Crew Controls and Displays

3.2.2 Allocation of Functional Capabilities

3.2.2.1 Capability Requirements and Implementation Candidates

3.2.2.1.1 Data Acquisition
3.2.2.1.2 Data Processing
3.2.2.1.3 Electrical Stimuli
3.2.2.1.4 Data Storage
3.2.2.1.5 Data Reporting

3.2.2.2 Capability Allocation Criteria

3.2.2.2.1 Sensors
3.2.2.2.2 Subsystem Interface Units
3.2.2.2.3 Remote Processors
3.2.2.2.4 Recorders
3.2.2.2.5 Displays
3.2.2.2.6 Data Bus
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4.0 QUALITY ASSURANCE

5.0 NOTES

5.1 Definitions

5.2 Abbreviations

5.3 Supplementary Information

GUIDELINES FOR INCORPORATION OF THE ON-BOARD CHECKOUT AND MONITORING FUNCTION ON THE SPACE SHUTTLE

1.0 SCOPE

1.1 Content - This document provides guidelines for incorporation of the On-board Checkout and Monitoring Function into the designs of the Space Shuttle propulsion systems. Hereinafter, the On-board Checkout and Monitoring Function is referred to as OCMF. These guidelines consist of and identify supporting documentation; requirements for formulation, implementation and integration of OCMF; associated quality assurance techniques and requirements; and OCMF terminology and nomenclature.

1.2 Applicability - These guidelines are directly applicable to the incorporation of OCMF into the design of Space Shuttle propulsion systems and the equipment with which the propulsion systems interface. The techniques and general approach as identified herein also are generally applicable to OCMF incorporation into the design of other Space Shuttle systems.

1.3 Intended Use - These guidelines shall be used by the National Aeronautics and Space Administration and the Space Shuttle contractors during the basic design phase of the Space Shuttle program. These guidelines shall be used to insure that the OCMF is incorporated into the basic design of the propulsion systems and associated interfacing systems. The applicable hardware, software and system design criteria documents and specifications shall incorporate the requirements of this document.

2.0 APPLICABLE DOCUMENTS

2.1 Specifications

2.2 Standards

2.3 Other Documents

(These titles are presented at this time for continuity only. The text of this section will be derived from Sections 3.0 and 4.0 subsequent to their completion.)

3.0 REQUIREMENTS

This section specifies the approach, constraints and considerations that shall be used in the definition and implementation of the OCMF.

3.1 Performance - This section specifies the functions that the OCMF shall perform, and the system analysis that shall be conducted to define the checkout and monitoring requirements.

3.1.1 Checkout and Monitoring Functions - The primary functions that comprise the OCMF for the Space Shuttle propulsion system are checkout, monitoring, control, and postflight evaluation.

Checkout shall be performed prior to each functional operation of the propulsion system (whether in flight or on the ground), during postflight safing and purging, and during maintenance operations.

Monitoring shall be performed during all phases of the Shuttle mission; that is, during preflight, inflight, postflight safing and purging, and maintenance operations.

Control shall be provided during all mission phases to start, stop, or otherwise regulate the operation of the propulsion systems.

Postflight evaluation shall be conducted during the interval between landing and maintenance operations. It is comprised of postflight evaluation of inflight data, inspections of the flight hardware, and checkout during postflight safing and purging.

3.1.1.1 Checkout - Checkout of the propulsion system consists of verifying its status, redundancy and operability. Checkout shall be performed prior to each start of propulsion system functional operation, during postflight safing and purging, and during maintenance operations.

3.1.1.1.1 <u>Prestart Checkout</u> - Prestart checkout shall verify that the propulsion system will meet its functional requirements during its next operation. The prestart checkout function is applicable to all phases (ground and flight) of the Space Shuttle mission that require propulsion system functional operations. The OCMF shall have the capability of performing verification of correct prestart status, avionics checks, redundancy verification and functional testing.

3.1.1.1.1.1 <u>Status Verification</u> - Prior to each operation of the propulsion system, the OCMF shall verify that the parameters associated with the elements of the propulsion system are within specified limits to ensure successful initiation of systems operation. Examples of such parameters include tank gas pressures and valve positions.

3.1.1.1.1.2 <u>Redundancy Verification</u> - Redundancy verification is the process of verifying that all redundant functional elements of the propulsion system and the associated OCMF elements are operable. Complete redundancy verification shall be performed prior to each flight. For mechanical elements, normal functioning of the redundant elements demonstrated in the previous flight, during postflight safing and purging, during maintenance retest, and/or during preflight operations shall be sufficient for redundancy verification. For the operational Space Shuttle vehicle, prestart checkout by functional tests for redundancy verification of mechanical elements shall be conducted only if the redundant element was not operationally verified during the operations mentioned above. However, capability shall exist in the basic design of the mechanical systems and the OCMF for redundancy verification by functional testing. The operability of the redundant paths in electrical and electronic elements shall be verified prior to flight. (This does not preclude inflight redundancy verification of electrical and electronic elements such as by self-checks.)

3.1.1.1.1.3 <u>Avionics Checks</u> - A complete prestart checkout of the electronic and electrical subsystems associated with the propulsion system and the OCMF shall be performed prior to each functional operation of the propulsion system. This checkout shall include such checks as verification of electrical power quality, data management subsystem self-checks, verification of the electrical elements of the sensors, and sequencing.

3.1.1.1.1.4 <u>Functional Testing</u> - The OCMF and the propulsion system shall have the capability for functionally testing the elements of the propulsion system prior to flight to verify redundancy and operability. The capability to test for internal and external leakage shall be included.

3.1.1.1.2 <u>Postflight Checkout</u> - Postflight checkout consists of the final assessment of the status and operability of the propulsion system before the maintenance cycle. It consists of monitoring the operation of the propulsion elements normally operated during the safing and purging operations. Verification of redundancy (of elements not used in flight) and the lack of performance degradation are the principle objectives of this checkout. Proper operation of functional elements during this phase shall be sufficient to preclude preflight functional testing of those elements to verify operability or redundancy (unless an element has been affected by maintenance actions).

3.1.1.1.3 Maintenance Retest - The OCMF shall have the capability to verify the integrity of interfaces and readiness status of the Line Replaceable Units (LRUs) that are functional elements, following their installation during maintenance operations. This capability shall include verification of functional propulsion elements affected by the LRU maintenance. Capability shall be provided to accomplish the verification by performing functional and leak tests. Capability shall also be provided to control and monitor individual functional elements in or out of normal sequences. Capability for individual component test may be waived only by formal NASA approval.

3.1.1.2 Monitoring - Monitoring is the OCMF activity of data acquisition and processing, and is applicable to all phases of the Space Shuttle mission. The monitoring function, in accordance with the following guidelines, shall consist of fault detection, fault isolation, trend analysis, data recording, and display. The parameters to be monitored, and the intervals and frequencies of monitoring, shall be derived from the analysis defined in Paragraph 3.1.2.2.

Inflight monitoring shall be accomplished by on-board equipment without reliance on a data interface external to the vehicle.

3.1.1.2.1 Fault Detection - The fault detection function shall provide data for emergency detection and for redundancy management, and for the related crew displays. Fault detection shall be accomplished by on-board equipment for all failure modes identified by the Failure Modes and Effects Analysis of Paragraph 3.1.2.2. Exceptions shall be taken only with NASA concurrence and shall be documented as such.

Emergency detection is the detection of any condition requiring automatic action to avoid a potentially catastrophic effect, or detection of any condition requiring special precautions or emergency procedures by the crew. The OCMF shall provide emergency detection for loss or impending loss of critical functions and for flight safety parameters exceeding safe limits. Emergency detection shall be accomplished within a time interval which permits the necessary actions to be taken to preclude a catastrophic effect of the failure. The emergency detection provisions, including the associated caution and warning displays, shall comply with the redundancy requirements defined by the Space Shuttle program specifications.

3.1.1.2.2 Fault Isolation - Diagnosis for fault isolation shall be accomplished with on-board equipment for the control function of redundancy management and for use in maintenance operations.

Redundancy management is comprised of reacting to the detection of a failure, impending failure, or other potential emergency condition by activating the appropriate redundant function, path or element. The capability for redundancy management shall be provided in the propulsion system and associated subsystems, including the capability for fault isolation to the lowest level (element, path or function) at which redundancy is provided. Fault isolation for redundancy management shall be accomplished as soon after fault detection as necessary to activate the redundant element, path or function before the fault progresses. Loss of redundancy shall be reported to the crew. Fault isolation shall be accomplished for maintenance operations by identifying the faulty Line Replaceable Unit (LRU) and recording the data.

3.1.1.2.3 Trend Analysis - The parameters to be monitored for trend data and the discriminants by which the data shall be evaluated shall be as identified by the analysis of Paragraph 3.1.2.2.3. The principle purpose of trend analysis shall be to identify progressive deviations or degradations in performance while the system is still within safe operating limits. The information derived from this short term trend analysis shall be used in managing redundancy by using redundant resources when trend analysis has predicted an imminent failure, and in support of maintenance operations by identifying elements which have an unacceptable probability of failure during the next operation or mission. Short term trend analysis shall be conducted by on-board equipment.

Long term trend analysis, such as the compilation of fleet trend data, can be performed by ground equipment or by on-board equipment. The extent to which each candidate is used shall be determined by conducting the tradeoff analyses of Paragraph 3.2.2.2.8.

3.1.1.2.4 Data Recording - The OCMF shall have the capability for processing and recording propulsion system performance data, trend data, fault isolation data, and component operating history data. The data recording requirements shall be as defined by the analysis of Paragraph 3.1.2.2.3. The recorded data shall be formatted and identified as to time and parameter to allow efficient postflight processing for reduction and evaluation.

3.1.1.2.5 Display - The OCMF shall have the capability for reporting information to the crew. The general guideline for inflight display is that priority shall be placed on displaying information necessary for crew action or caution and warning. Included in this category are notification of the detection or prediction of a fault when corrective actions or emergency procedures by the crew are required, and notification of any reduction in level of redundancy. Capability shall be provided to display (on a crew request basis) the fault isolation data on which automatic redundancy management decisions are made. The capability shall also be provided for displaying flight information relating to system status and performance, such as operating modes and propellant quantities.

3.1.1.3 Control - Propulsion system control is an integral part of the on-board checkout and monitoring function. Control capability shall be provided to initiate, modify, terminate or otherwise regulate the operation of the propulsion system during all phases of the Space Shuttle mission. Specific control requirements shall be derived from the analyses of Section 3.1.2. In general, the propulsion system is controlled by stimuli originating in associated subsystems, such as ignition and thrust commands originating in the avionics and/or crew subsystems. While control signals are generally low level electronic signals at their origin, propulsion elements may require high energy stimuli from other systems such as the electrical, hydraulic, or pnuematic systems, or from ordnance.

3.1.1.4 Postflight Evaluation - The OCMF shall support the postflight evaluation activities required for the propulsion system. They include postflight data evaluation, postflight inspection, and safing and purging.

3.1.1.4.1 Postflight Data Evaluation - Postflight data evaluation is the data processing and analysis activity required to transform flight recorded data into the forms required by the ultimate users. Requirements for postflight data evaluation include the processing of inflight fault isolation and trend data to identify necessary maintenance actions; processing of performance data to establish vehicle and fleet trends; and data compilation to accrue operating histories on time and cycle sensitive components.

3.1.1.4.2 Postflight Inspection - While postflight inspection is not a function of the OCMF, it is essential to the identification of potential maintenance actions on the propulsion system and to the verification of the structural integrity of the propulsion system. Postflight inspection includes visual and manual inspections of the flight hardware for evidence of anomalies such as hot gas leakage and structural damage or degradation.

To maximize the effectiveness of the ground operations, the postflight inspection requirements shall be identified during the design cycles of the propulsion system and during the checkout and monitoring requirements analyses such that they may be integrated into the designs of the propulsion system and into coordinated postflight evaluation procedures.

3.1.2 Systems Analysis Approach - The systems analysis approach specified herein shall be employed to ensure that the propulsion system design is consistent with OCMF concepts, and to define the propulsion system's checkout and monitoring requirements. The systems analysis shall be comprised of assemblage of propulsion system hardware and functional data, analyses of the propulsion systems and elements, and the derivation of propulsion parameters for measurement. An iterative process shall be employed whereby the conceptual and preliminary designs of the propulsion system shall be refined to accommodate and incorporate the checkout and monitoring functions defined in Section 3.1.1, to eliminate propulsion system elements that are not amenable to fault detection and isolation with onboard equipment, and to provide an optimized complement of measurement parameters. The quality assurance checkpoints and documentation requirements of the systems analysis are specified in Section 4.0. Figure 3.1.2-1 illustrates the systems analysis approach.

3.1.2.1 Propulsion System Definition - A thorough definition of the propulsion system shall be assembled to provide a base for the system analyses. Requirements for approval and documentation of the propulsion system definition are specified in Section 4.0. The propulsion system definition shall be changed and documented in accordance with the iterative steps in the systems analysis.

3.1.2.1.1 Functional and Operational Criteria - Functional and operational criteria shall include the following:

(a) Program Requirements: specifications, constraints, guidelines, concepts and objectives to be adhered to and pursued in the formulation of propulsion system and OSMF definition. These program requirements shall be supplied by NASA or its designee.

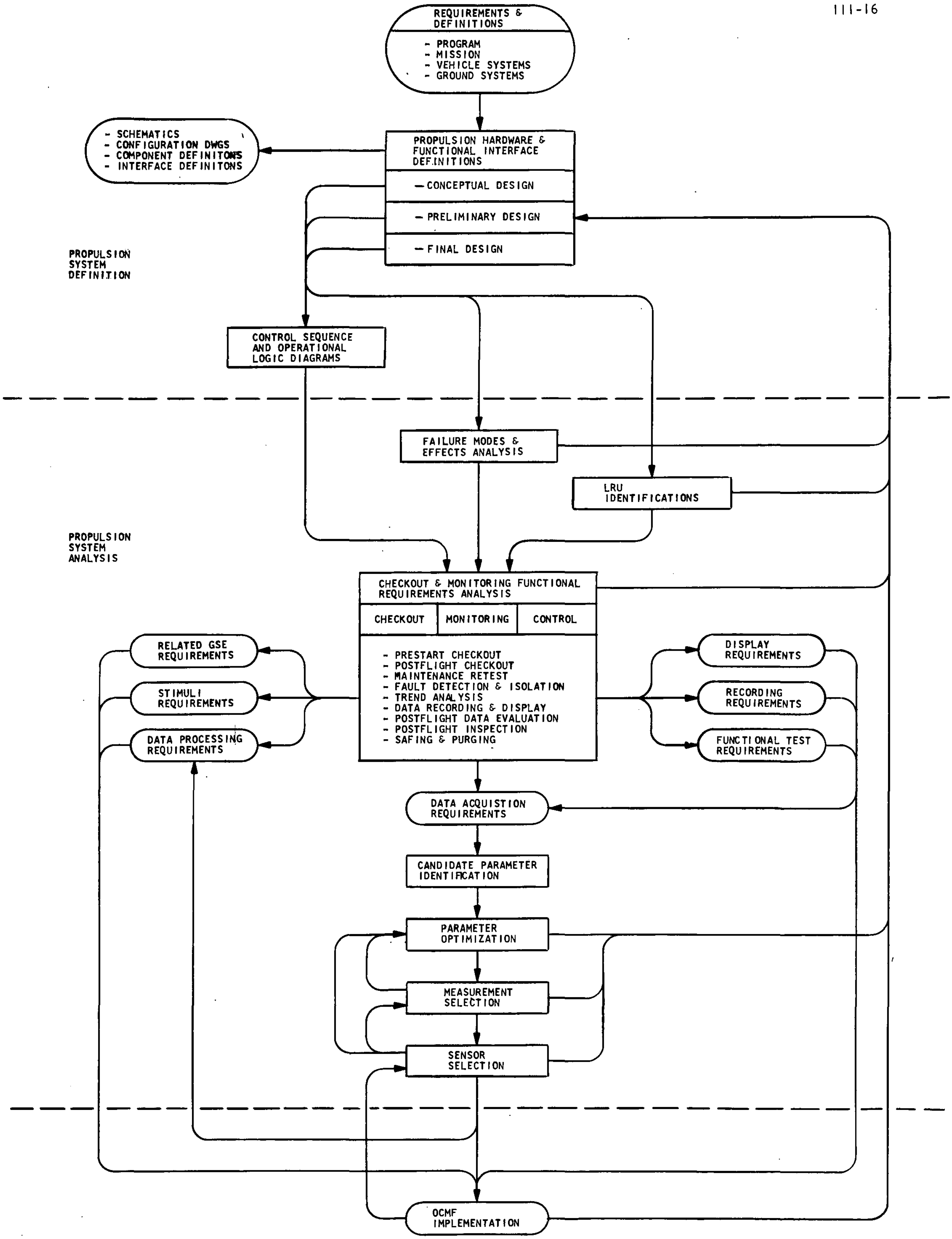


FIGURE 3.1.2-1 PROPULSION SYSTEM DEFINITON & ANALYSIS APPROACH

(b) Mission Characteristics: For each mission phase (including the turnaround cycle) full descriptions including timelines, sequences of events, and objectives. The mission characteristics shall be provided by NASA or its designee.

(c) System Operational Requirements: Complete descriptions of the propulsion system functional operating requirements on a mission phase basis. These descriptions shall include the modes of propulsion system operations and associated sequences, frequencies, and durations; the interface requirements of the propulsion system with the other vehicle systems; and the propulsion system interfaces with the launch facility, propellant loading system, and ground mechanical and electrical support equipment at the launch pad and in the maintenance areas.

3.1.2.1.2 Propulsion Hardware Definition - Hardware definition shall consist of propulsion system schematics to the component level, system configuration drawings, and component definitions. The system configuration drawings shall define propulsion system interfaces with other subsystems, and shall show the physical arrangement and locations of the propulsion hardware within the vehicle. The component definitions shall contain operating characteristics and criteria in sufficient detail to permit the conduct of the component analysis. For example, the definition of a solenoid valve shall include the following characteristics for the final iteration of the propulsion system analysis:

weight, volume and envelope

operating and/or service fluids

operating, proof and burst pressure

opening and closing response times under specified conditions

performance margins

operating and service life ratings

environmental ratings

contamination control requirements

mechanical interface requirements

electrical interface requirements

special considerations unique to the design, construction, operation and service of the component

3.1.2.1.3 Control Sequence and Operational Logic Diagrams (CSOLD) - Control sequence and operational logic diagrams shall show the detailed sequences and conditions of operation of the propulsion systems. The diagrams shall contain entries for each sequential event and each condition required for a change of system, subsystem, assembly or component state, as well as the conditions necessary for continued operation in the same state. The accuracy with which a condition must be known shall be included.

All interfaces, modes of operations and redundancies shall be incorporated into these diagrams. The diagram shall encompass prestart, start, operating, shutdown and post-operation conditions. The feedback or influence of events and conditions on each other, the system operation, and interfacing functions shall be indicated.

For example, a portion of a simplified CSOLD for the operation of an oxygen conditioning subsystem (see Figure 3.1.2-3) is illustrated by Figure 3.1.2-2. For the purposes of this example, assume that prestart checkout has been successfully completed, the subsystem isolation valves (V1, V5, and V7) have been opened and verified, that under normal conditions only one section of the subsystem operates at

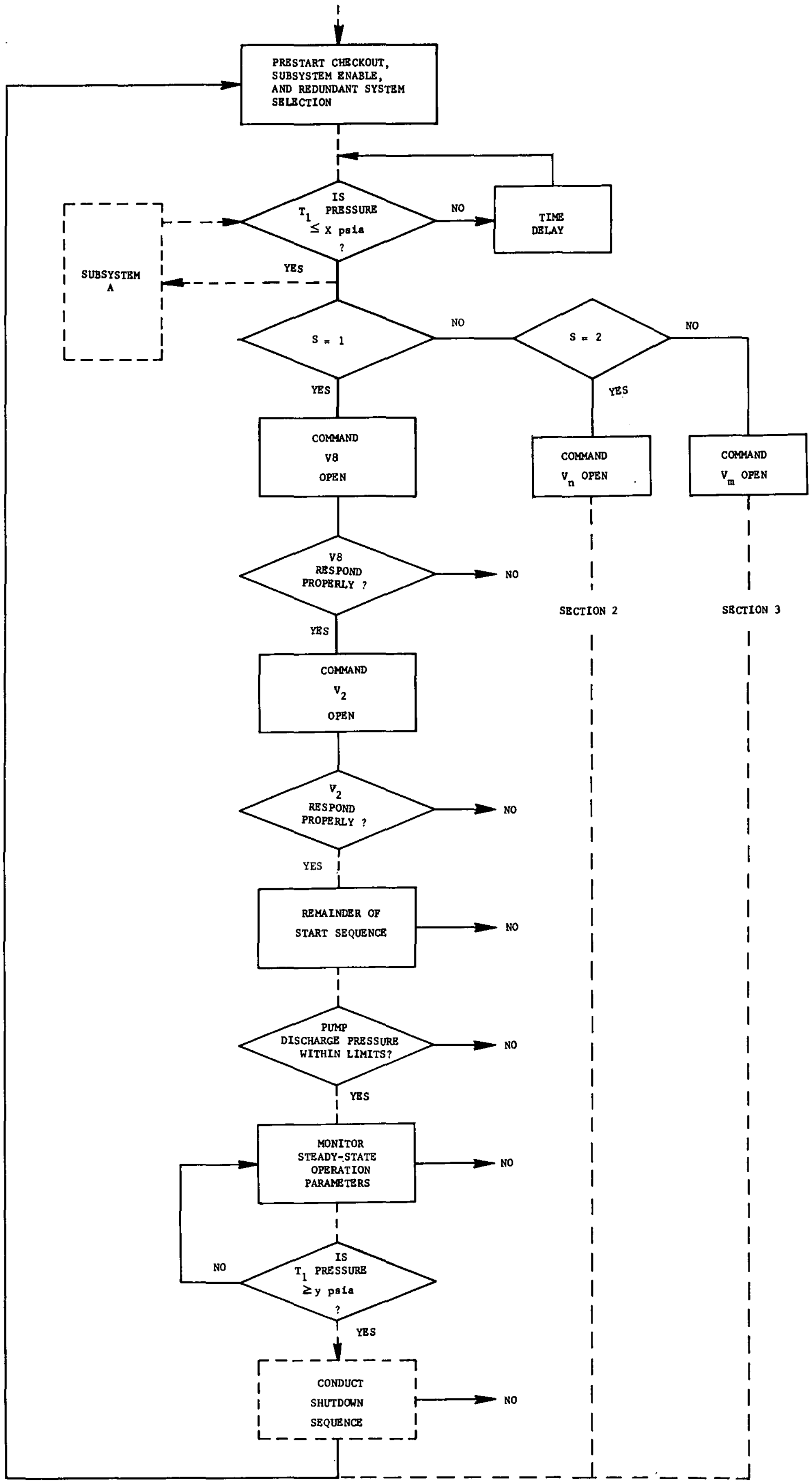


Figure 3.1.2-2 Simplified Control Sequence and Operational Logic Diagram

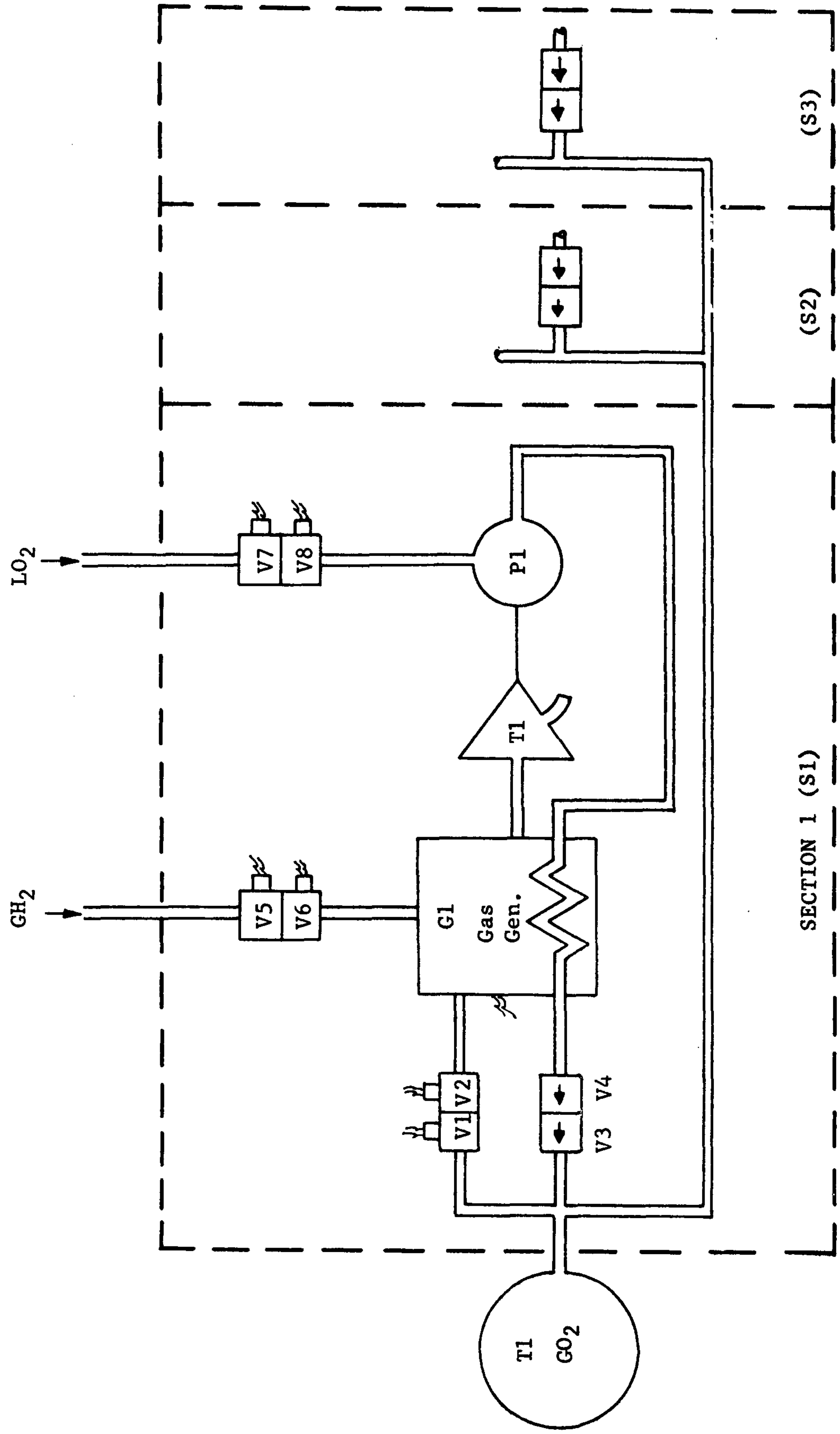


Figure 3.1.2-3 Oxygen Conditioning Subsystem

any one time, and that the sections of the subsystems are operated in progression so that each section can be expected to be operated during each flight.

The first block in Figure 3.1.2-2 represents the logic that enables the subsystem, selects the next section to be operated, conducts readiness checks, and opens the isolation valves. The start and stop times of subsystem operation are controlled by the pressure in T1. The block labeled Subsystem A indicates that the value of the pressure in T1 may be required for other reasons, such as the fault isolation of another subsystem. The value that would appear in the time delay block is determined by the frequency at which the pressure must be measured (sample rate). The operation of the selected section is initiated by opening the appropriate pump suction valve (V8 for S1). The verification of valve response may require the evaluation of parameters such as position, position versus time, line pressure, temperature, or solenoid current and/or voltage traces. The line labeled NO from the V8 Response question block (and the other unterminated NO lines) lead to fault isolation, subsystem or section shutdown and redundancy management sequences.

The start sequence is continued by commanding the gas generator oxygen feed valve (V2) open and verifying it. The remainder of the start sequence, represented by a single block, would consist of opening the fuel feed valve (V6) and igniting the gas generator in the proper sequence. The timing and other conditions required to complete the start sequence shall be identified.

To fulfill the requirements of the monitoring function, a number of parameters may be monitored during steady-state operation, such as gas generator chamber pressure and temperature; turbopump speed and discharge pressure; power train lube level, pressure and temperature; power train vibration level, power train bearing temperature, etc. Sôme or all of these same parameters may be monitored at the same or different sample rates, at other times (during start, shutdown, etc.) for different reasons, and using the same or different discriminants to evaluate them.

The steady-state operation and monitoring would continue until either the pressure in T1 attained the specified level or until a fault was detected at which time the appropriate shutdown, fault isolation and redundancy management sequence would be executed.

Fault isolation sequences shall be based on the LRU identifications (paragraph 3.1.2.2.1) and the level of redundancy of the system.

3.1.2.2 System Analysis - The checkout and monitoring requirements for the propulsion systems shall be defined by the system analyses contained herein. The analyses of the propulsion systems shall be conducted by the propulsion design personnel in a coordinated effort with all other affected personnel. These analyses include line replaceable unit identification, failure modes and effects analysis, checkout and montiroing functional requirements analysis, and measured parameter and sensor identification. In addition to the identification of the required measured parameters and their associated sensors, the system analysis shall define data processing requirements, recording and display requirements, stimuli requirements, functional and leak test requirements, inspection requirements, and requirements for ground support equipment associated with checkout and monitoring.

3.1.2.2.1 Line Replaceable Unit Identification - Propulsion line replaceable units (LRUs) shall be identified. An LRU is defined as a component, group of components, assembly or subsystem that can be removed, replaced, and retested in the maintenance area by competent mechanics within the constraints of the Space Shuttle turnaround cycle timeline. All LRUs, except those that perform no function other than providing structural integrity, must be capable of being fault isolated. Exceptions shall be made only with formal NASA approval.

The identification of the LRUs shall be determined through tradeoff studies. Selection considerations shall include accessibility, weight, volume, complexity of the structural, mechanical and electrical attachments, post-installation retest requirements, and fault isolation capability. Examples of LRU candidates are the gas generator or a valve package (V1, V2) of Figure 3.1.2-3.

3.1.2.2.2 Failure Modes and Effects Analysis - Failure modes and effects analysis (FMEA) shall be conducted to identify limitations in the propulsion system design (such as propulsion elements that are not amenable to fault detection with onboard equipment or require system break-in for checkout), to establish candidate parameters for fault detection and fault isolation, and to provide a basis for determining caution and warning display requirements. The basis for the FMEA shall be MSFC Drawing No. 85M03885, "Guidelines for Performing Failure Mode, Effects, and Criticality Analysis (FMECA) on the Space Shuttle", except that the criticality analysis defined therein is not required for propulsion system analysis for the OCMF. The FMEA tabulation format, as presented in the referenced drawing, is shown in Figure 3.1.2-4.

The FMEA shall be iterated each time that the propulsion system design is modified during the system analysis and OCMF implementation cycles.

3.1.2.2.3 Checkout and Monitoring Functional Requirements Analysis - This analysis, as outlined in Figure 3.1.2-1, shall derive the implementation requirements for the OCMF. The approach shall consist of evaluating the Propulsion System Definition (Paragraph 3.1.2.1), the LRU Identifications (Paragraph 3.1.2.2.1), and the FMEAs (Paragraph 3.1.2.2.2) to satisfy the checkout, monitoring, postflight evaluation, and control function requirements of the propulsion systems. The result of this analysis shall be the identification of requirements for display, recording, trend analysis, functional and leakage testing, data acquisition, stimuli, data processing, simulation, and related ground support equipment.

3.1.2.2.3.1 Description of Results

(a) Display Requirements - System status and hazard warning are the principal display requirements. The listing of display requirements shall identify: (1) any crew action required by the display condition; (2) the recommended type of display; (3) the mission time period or event for which the display is required; and (4) the required display redundancy based on the criticality of the condition being displayed. The derivation of the display requirements shall be accomplished per the guidelines of Paragraph 3.1.2.2.3.2.

END ITEM ____________ SUBSYSTEM ____________ FUNCTIONAL ASSEMBLY ____________

FAILURE MODE AND EFFECTS ANALYSIS

PAGE ______ OF ______ DATE ____________ BY ____________

ITEM IDENTIFICATION	FUNCTION	FAILURE MODE	FAILURE REACTION TIME	MISSION OR OPERATIONAL PHASE	FAILURE EFFECT ON				FAILURE DETECTION METHOD	CORRECTIVE ACTION	CRITICALITY CATEGORY	REMARKS
					FUNCTIONAL SUBSYSTEM OR ASSEMBLY	END ITEM OR OTHER SYSTEMS	MISSION	CREW OR VEHICLE				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)

Figure 3.1.2-4 FMEA Tabulation Format

(b) Recording Requirements - System status, system performance, fault isolation, and operating history data are the principal recording requirements. The identification of the data recording requirements shall specify: (1) the ultimate use of the recorded data; (2) the processing required (if any) prior to data recording; (3) the time of mission and period during which the indicated recording is required; (4) the peak rate at which the data must be recorded; and (5) the period for which recorded data must be retained. Recording requirements shall be derived per the guidelines of Paragraph 3.1.2.2.3.2.

(c) Functional and Leakage Testing Requirements - The checkout and monitoring functional requirements associated with functional and leakage testing shall be included in the definition of the data acquisition, stimuli, recording, display, data processing, simulation and GSE requirements defined for maintenance retest and ground checkout activities.

(d) Data Acquisition Requirements - Data acquisition requirements shall be derived in accordance with the analyses of Paragraph 3.1.2.2.3.2. The recommended format of the tabulation of these requirements and an example (T1 pressure in Figure 3.1.2-3) of the information to be entered therein is illustrated by Figure 3.1.2-5.

The initial tabulation shall be made without regard to whether a parameter shall be obtained by direct measurement (measured parameter) or whether it must be derived (derived parameter) indirectly from one or more measured parameters.

DATA ACQUISITION REQUIREMENTS

1 PARAMETER	2 PROPULSION ELEMENT	3 PARAMETER RANGE AND UNITS	4 ALLOWABLE ERROR	5 RESPONSE RATE	6 SAMPLE RATE	7 DATA USAGE	8 TIME OF DATA ACTIVITY
The entry shall uniquely identify the parameter by name, number, or identity code, and type (pressure, temperature, position, level, leakage are examples of parameter types).	The entry shall identify the propulsion component, assembly, subsystem, and system with which the parameter is associated.	The full scale range for the parameter shall be identified. Intermediate values expected under various conditions or operating modes shall also be identified. (Units specifications shall comply with the International System of Units, Reference TBS.)	Allowable error is the total system uncertainty within which the value of the parameters must be known. Allowable error may be expressed in units or percent of value. One entry shall be made for each entry of column (3).	This entry specifies the highest rate of change of the parameter which is required to be detected, measured, or reproduced. If subject to time of mission, operating mode or other conditions, separate entries shall be made for each rate. These entries may be specified in units per unit time or in frequency.	Sample rates shall be defined consistent with the response rate requirements of column (5) and with the reaction time requirements as defined by emergency detection requirements.	Entries shall be made to indicate the end usage of the data obtained from each parameter. Where data has more than one use and the time of data activity and sample rate are different for each use, a separate entry shall be made for each.	Entries shall be made for each of the previous entries describing the time interval, operation, or condition for which the data is meaningful.
EXAMPLE:							
PT1	T1	0-300 PSIA	$\pm$ 5%	20 PSIA/SEC	5 SPS	FD & FI	PS & PF C/O
		200 $\leq$ PT1 $\leq$ 240 PSIA	$\pm$ 5%	10 PSIA/SEC	5 SPS	Control	Supply Mode
		$\geq$240 PSIA	$\pm$ 5%	50 PSIA/SEC	10 SPS	Control	Resupply Mode
		$\geq$300 PSIA	$\pm$ 7.5%	50 PSIA/SEC MAX.	5 or 10 SPS	Warning Display	Anytime Prop. Loaded
		20 PSIA	$\pm$ 2 PSIA	2 PSIA/SEC	5 SPS	Control	Safe & Purge

FIGURE 3.1.2-5 FORMAT FOR DATA ACQUISITION REQUIREMENTS TABULATION

The data acquisition tabulation is a composite listing that defines the relationship between a parameter and a propulsion element, the basic discriminant for evaluating acquired data, the rationale for acquiring data, and the interval during which the data is of significance.

(e) Stimuli Requirements - Stimuli requirements are those necessary to satisfy the control function of the propulsion system elements. The specification of electrical requirements shall include signal identification, associated propulsion element, and applicable signal characteristics such as type, level, frequency, pulse width, repetition rate, duration, accuracy, time and conditions for application, maximum source impedance, minimum load impedance, and remarks that identify those conditions or characteristics not otherwise covered.

Propulsion system power requirements and sensor reference voltages are not included in these requirements. Power requirements shall be identified in the appropriate interface control documents, and sensor reference voltage requirements shall be identified from the sensor definitions of Section 3.2.

The specification of mechanical stimuli shall include all all applicable characteristics such as force, torque, pressure, etc.

(f) Data Processing Requirements - Required algorithms, computations, comparisons, or other data processing techniques shall be identified for each usage of each identified propulsion system measured parameter, and for the execution of propulsion system control. These specifications shall include the frequency at which the processing is required and any limitations that may be imposed on processing time. Data processing requirements shall be derived per the guidelines of Paragraphs 3.1.2.2.3.2. and 3.1.2.2.4.

(g) Related GSE Requirements - Ground support equipment related to the checkout and monitoring function includes those items necessary to support the ground activities of postflight checkout and evaluation, maintenance retest, and prestart checkout. The identification of these GSE requirements shall be a result of the analysis approach of Paragraph 3.1.2.2.3.2.

(h) Simulation Requirements - The validation of onboard computer programs and control sequences during preflight checkout requires the simulation of a number of propulsion parameters and conditions such as the simulation of engine thrust build-up, tank pressures, and so forth. Simulation requirements shall be identified in conjunction with the derivation of the prestart checkout requirements.

(i) Inspection Requirements - Inspection requirements shall include the definitions of the propulsion system design requirements, inspection procedures, and related support equipment necessary to conduct postflight inspection.

3.1.2.2.3.2 Derivation of Results - The results described in Paragraph 3.1.2.2.3.1 shall be derived in accordance with the analytical approach presented herein.

Checkout, monitoring, control and postflight evaluation are generally dependent functions. In most cases the requirements or capabilities necessary to perform those functions are most easily and effectively defined simultaneously. For example, the oxygen accumulator pressure in Figure 3.1.2-3 is monitored to control the operation of the oxygen conditioning subsystem in addition to being used for fault detection, fault isolation, and hazard warning display. Therefore, at the time that accumulator pressure is listed in the data acquisition tabulation, the corresponding data processing for fault detection, subsystem control, and display should be defined.

Data acquisition requirements shall be identified from two general sources. First, data acquisition parameters for fault detection, emergency detection and/or hazard warning display shall be identified for each recommended failure detection method identified from the results of the FMEA. The discriminants relating candidate parameters to specific failure modes shall be identified for each failure detection method. These discriminants are the basid source from which the corresponding data processing requirements shall be derived. Discriminants can be determined either by using the results (signatures) of extensive testing of acceptable and failed samples (including trend analysis) or by the understanding of the specific failure mechanisms determined by analytical techniques.

Second, data acquisition requirements for status and redundancy verification, functional and leakage testing, fault isolation, trend analysis, data recording and display, simulation, and control shall be derived from a phase-by-phase mission analysis using:

Control Sequence and Operational Logic Diagrams	(Para 3.1.2.1)
Propulsion System Hardware Definitions	(Para 3.1.2.1)
Propulsion System Functional and Operational Criteria	(Para 3.1.2.1)
Checkout and Monitoring Function Definitions	(Para 3.1.1)
LRU Identifications	(Para 3.1.2.2)

Associated display, recording, data processing, ground support equipment and stimuli shall be identified concurrently with the derivation of the data acquisition requirements.

The tabulation of candidate data acquisition parameters shall be optimized through the process defined in Paragraph 3.1.2.2.4. (The optimization consists of measured parameter and sensor selection, and may include the iteration of the propulsion system design to add to or modify the propulsion hardware or modify operating sequences for the purpose of implementing the OCMF.) The tabulation shall include operational conditions such as crew control positions, mission elapsed time, burn time, or any other condition(s) that must be sensed to execute the checkout, control, and monitoring functions.

The following paragraphs and figures illustrate the derivation of the checkout and monitoring requirements on an individual function basis.

(a) <u>Prestart Checkout</u> - The prestart checkout function is defined in Paragraph 3.1.1.1.1.

The matrix shown in Figure 3.1.2-6 shall be used as a guideline to derive the OCMF capabilities required for the prestart checkout function. The analyses indicated by this matrix shall be performed on a step-by-step basis for each mission phase in which prestart checkout is applicable.

The primary rows identify the requirements associated with the prestart checkout function (status verification, redundancy verification, etc.) and the columns identify the checkout and monitoring capabilities necessary to satisfy those requirements. The secondary rows (data source column) identify the source material that must be analyzed to make this derivation. Notes providing supplementary information and definitions of the data source code acronyms are provided at the bottom of the figure.

The use of the matrix is illustrated below using the subsystem of Figure 3.1.2-3 as an example. The purpose of the examples in the following material is to demonstrate the analysis techniques and to create an awareness of the type of information to look for and consider. The examples should not be construed as conclusions or recommended solutions to specific requirements.

The X in the data acquisition column for status verification indicates that an examination of the control sequence and

FUNCTION REQUIREMENTS	DATA SOURCE / CAPABILITY	DATA ACQUISITION	DATA PROCESSING	RECORDING	DISPLAY	STIMULUS	SIMULATION	GROUND SUPPORT EQUIPMENT
STATUS VERIFICATION	CSOLD, PHD	X						
	MSP		X					
REDUNDANCY VERIFICATION[1]	CSOLD, PHD	X						
	MPSP		X					
	PR			X	X			
	CMFD			X	X			
FUNCTIONAL TESTING[1,2]	CSOLD, PHD	X				X	X	X
	MPSP		X					
	PR			X	X			
	CMFD			X	X			X
	PHD					X		X
FAULT DETECTION[3]	FMEA	X	X					
	MPSP		X					
FAULT ISOLATION[3]	FMEA	X						X
	LRU	X		X				X
	CSOLD, PHD	X				X		
	MPSP		X					
	PR				X			
	CMFD				X			
	PHD					X		
REDUNDANCY MANAGEMENT[3]	CSOLD, PHD		X			X		
	MPSP		X					
	PR			X	X			
	CMFD			X	X			
	PHD					X		

NOTES:

1. PREFLIGHT.
2. DEPENDENT ON OPERATING HISTORY OF LAST FLIGHT AND ON MAINTENANCE RETEST ACTIVITIES.
3. REQUIRED IF ANOMALY IS FOUND WHILE PERFORMING FIRST THREE FUNCTIONS.

DATA SOURCE CODES:

CSOLD: CONTROL SEQUENCE AND OPERATIONAL LOGIC DIAGRAMS
MPSP: MEASURED PARAMETER SEL. PROCESS
PR: PROGRAM REQUIREMENTS
CMFD: CHECKOUT AND MONITORING FUNCTION DEFINITIONS
PHD: PROPULSION HARDWARE DEFINITIONS
LRU: LINE REPLACEABLE UNIT DEFINITIONS
FMEA: FAILURE MODES AND EFFECTS ANALYSIS

FIGURE 3.1.2-6 PRESTART CHECKOUT FUNCTION REQUIREMENTS DERIVATION MATRIX operational logic diagrams and the propulsion hardware definitions (schematics in this case) are necessary to derive the parameters needed to verify subsystem status is within specified limits to initiate operation. The parameters in this case would be the positions of the six solenoid valves (closed), the pressures and temperatures of the GO_2, GH_2, and LO_2 supplies, gas generator igniter supply voltage (less than x), and possibly igniter current (less than w) and pump discharge pressure (y $\pm$ z) or temperature.

The X under data processing for the parameters identified above would be derived from the measured parameter selection process in which a determination of whether a desired parameter can and should be measured directly or can and should be derived from one or more measured parameters. Considerations that influence this determination are whether or not it is possible to directly measure the desired parameter and the fact that the desired information may be available from alternate parameters that must be measured for other reasons. Another driving factor in this determination is the objective to define the most cost effective system that will satisfy the requirements. Examples in the subsystem under consideration are the positions of the pump suction valves (V7, V8). Assume that all that is required to be known is for all reasons that the valves are either closed or sufficiently open to allow an adequate flow of LO_2 to the pump. A number of candidates are available for consideration either individually or in combinations: (1) Discrete position indicators; in this case the data processing is at a minimum since the transducer evaluates position directly and provides a go/no-go indication. This option would be most attractive if software design and/or computer speed or memory size were the principle cost drivers and the transducers were available. (2) Solenoid current signatures and pump inlet pressure and/or temperature where the inlet parameters were required for another purpose. The data processing for this case would consist of analyzing the current signatures with the appropriate discriminants (rate, level, rise time) and the inlet conditions. This option would have appeal if suitable position indicators were unavailable and development costs were high, or were not cost effective on the basis of considerations such as weight, or were not capable of being fault isolated. (3) Ultrasonic contact sensors may be required to detect internal or external leakage. They may be used in conjunction with solenoid current signatures or with pump inlet parameters. As in example (2) above, the data processing would entail the analysis of signatures and and the evaluation of inlet parameters. The selection rationale would be similar to example (2).

Note 1 indicates that redundancy verification is required during prestart checkout prior to flight (not in flight). Paragraph 3.1.1.1.1.2 further indicates that normal functioning of redundant mechanical elements demonstrated during the previous flight, postflight safing and purging, maintenance retest, and/or during preflight operations shall be sufficient for redundancy verification. Assume that only sections 2 and 3 of the subsystem in Figure 3.1.2-3 had been operated during the previous flight. Then the operability of section 1 would require verification on the ground before the next flight. It may be verified through normal operation if that subsystem is normally started on the ground and section 1 is the next sequential section to be operated, or it may be verified by functional and leakage testing. (Capability shall be provided for functional and leakage testing in any case). Whether or not the section had operated on the previous flight the solenoid valves would probably have been functionally operated during the postflight safing and purging cycle. Therefore redundancy verification may be limited to the verification of each check valve, the ignition circuitry, the turbopump assembly, and the electrical elements of the instrumentation. The verification of the operability of the check valves may require the addition of a pressure port between the valves to facilitate check-out. In this case the propulsion system analysis would be iterated to include the new component as it would to include any modifications to the basic design to facilitate functional testing of the turbopump assembly.

The X's under data acquisition and data processing for redundancy verification have the same meaning as they do for status verification. The Xs under recording and display for redundancy verification indicate that the recording and display capabilities for redundancy status shall be identified in accordance with the program requirements and the checkout and monitoring function definitions (Section 3.1.1). For example, the loss of redundancy shall be displayed to the crew and recorded for maintenance operations in the form of faulty LRU identification.

The remainder of the matrix shall be used in a similar fashion. The derivation and implementation of the propulsion system checkout and monitoring requirements is dependent on a comprehensive understanding of the data source material, a systematic and thorough system analysis, and a coordinated effort among personnel of a variety of disciplines from the conceptual design through the final design of the propulsion and associated systems.

(b) Postflight Checkout - The postflight checkout function is defined in Paragraph 3.1.1.1.2. The capabilities required for this function are analogous to those for prestart checkout, described in paragraph (a) above, and for monitoring, described in paragraph (d) below, and shall be derived in a similar manner. An additional item to consider during postflight checkout is the potential desirability or requirement to confirm certain faults that were identified inflight. This may preclude the possible time consuming removal and replacement of acceptable hardware by conducting a relatively short checkout sequence. Or, ground fault isolation may be required for certain faults that for some reason were unable to be isolated to an LRU level inflight (such as an open electrical circuit).

(c) Maintenance Retest - The maintenance retest function is defined in Paragraph 3.1.1.4.

The checkout and monitoring capabilities required for the verification of the leakage integrity of interfaces and status of replaced propulsion system LRUs shall be derived using the same approach and from the same sources as defined for the prestart checkout and monitoring functions.

The processing requirements for maintenance retest shall include the identification of the processing necessary to update the operating history records that are used to forecast scheduled maintenance activities and to establish functional testing requirements.

Simulation requirements requisite to LRU status verification shall be derived from the control sequence and operational logic diagrams. For example, the status verification of a replaced LRU in the subsystem of Figure 3.1.2-3 may require the simulation of the build-up and decay of gas generator chamber pressure or the simulation of pump inlet temperatures, etc.

Ground support equipment requirements associated with the verification of the leakage integrity of the interfaces and status of replaced LRUs shall be identified by this analysis.

(d) Monitoring - The monitoring function is defined in Paragraph 3.1.1.2.

The matrix shown in Figure 3.1.2-7 shall be used as a guideline to derive the OCMF capabilities required for the monitoring function. The analyses indicated by this matrix shall be performed on a step-by-step basis of every mission phase.

The format and use of this matrix is analogous to that defined for the Prestart Checkout Function Requirements Matrix of Figure 3.1.2-6.

(e) Control - Stimuli requirements and data processing requirements shall be derived to satisfy the propulsion system control function of the propulsion system. Stimuli requirements are primarily derived from the propulsion component definitions described in Paragraph 3.1.2.1.2 while the data processing requirements are primarily derived from the control sequence and operational logic diagrams. The data processing requirements shall include the identification of parameter discriminants on which the control sequences are based and the dependence on such variables as mission elapsed time, operating mode, crew control positions, etc.

FUNCTION REQUIREMENTS	DATA SOURCE \ CAPABILITY	DATA ACQUISITION	DATA PROCESSING	RECORDING	DISPLAY	STIMULUS	GROUND SUPPORT EQUIPMENT	SIMULATION
FAULT DETECTION	FMEA	X	X					
	MPSP		X					
FAULT ISOLATION	FMEA	X					X	
	LRU	X		X			X	
	CSOLD, PHD	X				X		
	MPSP		X					
	PR				X			
	CMFD				X			
	PHD					X		
REDUNDANCY MANAGEMENT	CSOLD		X			X		
	MPSP		X					
	PR			X	X			
	CMFD			X	X			
	PHD					X		
CAUTION AND HAZARD WARNING	FMEA		X					
	CSOLD		X					
	MPSP		X					
	PR				X			
	CMFD				X			
TREND ANALYSIS	FMEA	X	X					
	PHD	X						
	MPSP		X					
	PR			X				
	CMFD			X				
PERFORMANCE DATA RECORDING	PHD	X						
	CSOLD	X						
	MPSP		X					
	PR			X				
	CMFD			X				
OPERATING HISTORY COMPILATION	PHD	X						
	CSOLD	X						
	CMFD	X		X				
	MPSP		X					
	PR			X				
SYSTEM OPERATION STATUS DISPLAY	CSOLD, PHD	X						
	PR	X			X			
	CMFD	X			X			
	MPSP		X					
CONTROL	CSOLD, PHD	X			X	X		
	MPSP		X					
	PR				X			
	PHD					X		
FUNCTIONAL TESTING[1]	CSOLD, PHD	X				X	X	X
	MPSP		X					
	PR			X	X			
	CMFD			X	X		X	
	PHD					X	X	

NOTES:

1. Dependent on operating history of last flight and on the maintenance retest activities.

FIGURE 3.1.2-7

MONITORING FUNCTION REQUIREMENTS DERIVATION MATRIX

DATA SOURCE CODES:

- CSOLD: Control Sequence and Operational Logic Diagrams
- FMEA: Failure Modes and Effects Analysis
- MPSP: Measured Parameter Selection Process
- LRU: Line Replaceable Unit Definitions
- PR: Program Requirements
- CMFD: Checkout and Monitoring Function Definition
- PHD: Propulsion Hardware Definitions

(f) Postflight Evaluation - The postflight evaluation function is defined in Paragraph 3.1.1.4. The onboard processing capability that shall be provided for postflight data evaluation shall be defined in conjunction with the definition of the onboard recording capabilities for fault isolation data, performance data, trend data, and operating history data. The processing capability shall be compatible with the selected recording techniques and the requirements of the data users. Related onboard control and display requirements, ground interfaces and ground support equipment shall be identified from the resultant processing implementation definitions and the data user requirements.

While postflight inspection is not a function of the OCMF, the related propulsion system design requirements, inspection procedures, and support equipment shall be identified in conjunction with the propulsion system analysis to achieve a fully integrated design and a coordinated postflight phase.

3.1.2.2.4 Measured Parameter and Sensor Selection - This process shall consist of data acquisition parameter optimization, measurement parameter selection and optimization, and candidate sensor selection.

The data acquisition parameter tabulation described in Paragraph 3.1.2.2.3.1 shall be optimized by eliminating non-essential parameters and eliminating parameters for which the same or better information is available from alternate sources. This is not a restriction on the use of redundancy either through the use of redundant sensors or by use of alternate parameters. Records shall be maintained to make visible the rationale justifying the retention or elimination of parameters.

The optimized data acquisition tabulation consists of a listing of measured parameters and derived parameters. A measured parameter list shall be generated by selecting measured parameters for the derived parameters and adding them to the measured parameters listed on the optimized data acquisition parameter tabulation. A number of candidate measured parameters may exist from which a derived parameter may be obtained. (For example, volumetric flow rate, time, and propellant temperature, i.e., density, is a set of candidate measured parameters for deriving the parameter propellant quantity). All measured parameters and sets of measured parameters which are candidates for deriving the required parameter shall be tabulated. The final selection of measured parameters for those cases where alternates exist shall be made in conjunction with the implementation tradeoffs and selections of Section 3.2. (A driving factor in this selection is the relative cost effectiveness of the available sensor candidates and the other capabilities associated with a particular implementation candidate).

The total list of measured parameters shall then be subjected to an optimization process. This process shall eliminate non-essential measured parameters and shall eliminate those entries for which better information is available and has been identified.

Candidate sensors shall be identified for each entry of the measured parameter tabulation. Final sensor selection shall be based on availability and the implementation criteria described in Section 3.2. In a case where a candidate sensor is not available, an iteration of the measured parameter tabulation is required. If alternate measured parameters cannot be identified, the baseline propulsion system shall be evaluated to determine whether or not the sensor requirement in question can be eliminated by propulsion redesign. If propulsion redesign is a viable option, then all of the foregoing analyses of this section shall be included in the iteration cycle. If propulsion redesign is not a viable option, then a sensor technology requirement shall be identified.

Fundamental data processing requirements shall be identified for each measured parameter. These requirements shall identify the discriminants by which each usage of each measured parameter shall be evaluated during the time of its significance; the frequency at which the processing for each case is required; and the restrictions on processing time for each case. The allocation of processing capability and its implementation shall be per the guidelines of Section 3.2.

3.2 Checkout and Monitoring Function Implementation - The guidelines delineated in Paragraph 3.2.2 shall be used to incorporate the propulsion checkout and monitoring function requirements into the implementation criteria of those onboard and ground equipment elements (defined in Paragraph 3.2.1) that perform or contribute to propulsion checkout, monitoring and control.

An integrated approach between the propulsion and avionics disciplines shall be followed to achieve the optimum implementation of the propulsion checkout and monitoring requirements. A coordinated effort shall be conducted to integrate the selected sensors into the propulsion system design; minimize unique propulsion stimuli and excitation requirements; minimize unique specifications that result in special sensors, measurement techniques, displays, crew operations, etc.; select measurement parameters and techniques that best satisfy the requirements; and resolve situations where the requirements of the baseline propulsion system are not amenable to available checkout and monitoring techniques. If propulsion system configuration changes are necessary to achieve the objectives of this effort, then the analyses of Section 3.1 and this section shall be iterated for the affected hardware.

3.2.1 Elements Related to Checkout and Monitoring - The propulsion checkout and monitoring function requirements shall be incorporated into the propulsion system design and into the implementation criteria of the propulsion system sensors, the data management and control (DM&C) subsystem, the crew controls and displays, interfacing systems such as the hydraulic, pneumatic, and electrical systems, and the related ground support equipment (GSE).

3.2.1.1 Propulsion System Elements - Propulsion system element additions and/or modifications shall be made as required to make the system amenable to checkout and monitoring. Examples of such configuration changes include adding a bleed port downstream of a check valve to verify check valve operation; changing a bearing type to one for which failure detection methods can be implemented; or relocating sensor installations to ensure that the selected location is satisfactory for obtaining the desired information. The propulsion system shall be continually evaluated during the derivation and implementation of the checkout and monitoring requirements to ensure that its design minimizes the checkout and monitoring requirements, and is completely compatible with the implementation of those requirements.

3.2.1.2 Sensors - Sensors respond to the measurement parameters of the propulsion subsystems and of the propulsion dedicated controls and provide outputs in a usable form to remote processors, or to the subsystem interface units of the DM&C subsystem, or directly to the vehicle central computes complex via the vehicle data bus. Basic identification of candidate sensors, including type, range, allowable system error, and response, are made for the measurement parameters identified by the analyses of Section 3.1. Generation of final sensor specifications shall be made in conjunction with the allocation of functional capabilities to the DM&C subsystem elements in accordance with the guidelines of Paragraph 3.2.2.

3.2.1.3 Interfaces - The implementation of the checkout and monitoring function for the propulsion system shall include the consideration and definition of interfaces with other onboard systems that involve propulsion checkout or control, such as the electrical and hydraulic systems.

3.2.1.4 Ground Support Equipment (GSE) - The extent to which the propulsion system checkout and monitoring function is implemented by the use of ground support equipment shall be determined using the criteria and considerations identified in Paragraph 3.2.2.

3.2.1.5 Data Management and Control (DM&C) Subsystem - The elements and configuration of the DM&C subsystem shown by bold blocks in Figure 3.2.1-1 are employed by this document to illustrate the relation of the DM&C subsystem to the pertinent vehicle and support equipment elements. The degree of applicability of this configuration or others is dependent on final criteria and requirements defined for the overall avionics system.

3.2.1.5.1 Central Computer Complex (CCC) - The central computer complex provides data processing capability for the Space Shuttle vehicle. The degree to which the CCC shall provide processing capability for propulsion system control, data evaluation, display, recording, functional testing and trend analysis shall be determined using the requirements of Section 3.1 as criteria, and the guidelines of Paragraph 3.2.2. The CCC shall store the propulsion system flight programs that are not stored in propulsion dedicated processors. It may also be used to store propulsion system data that is required to be retrievable during flight.

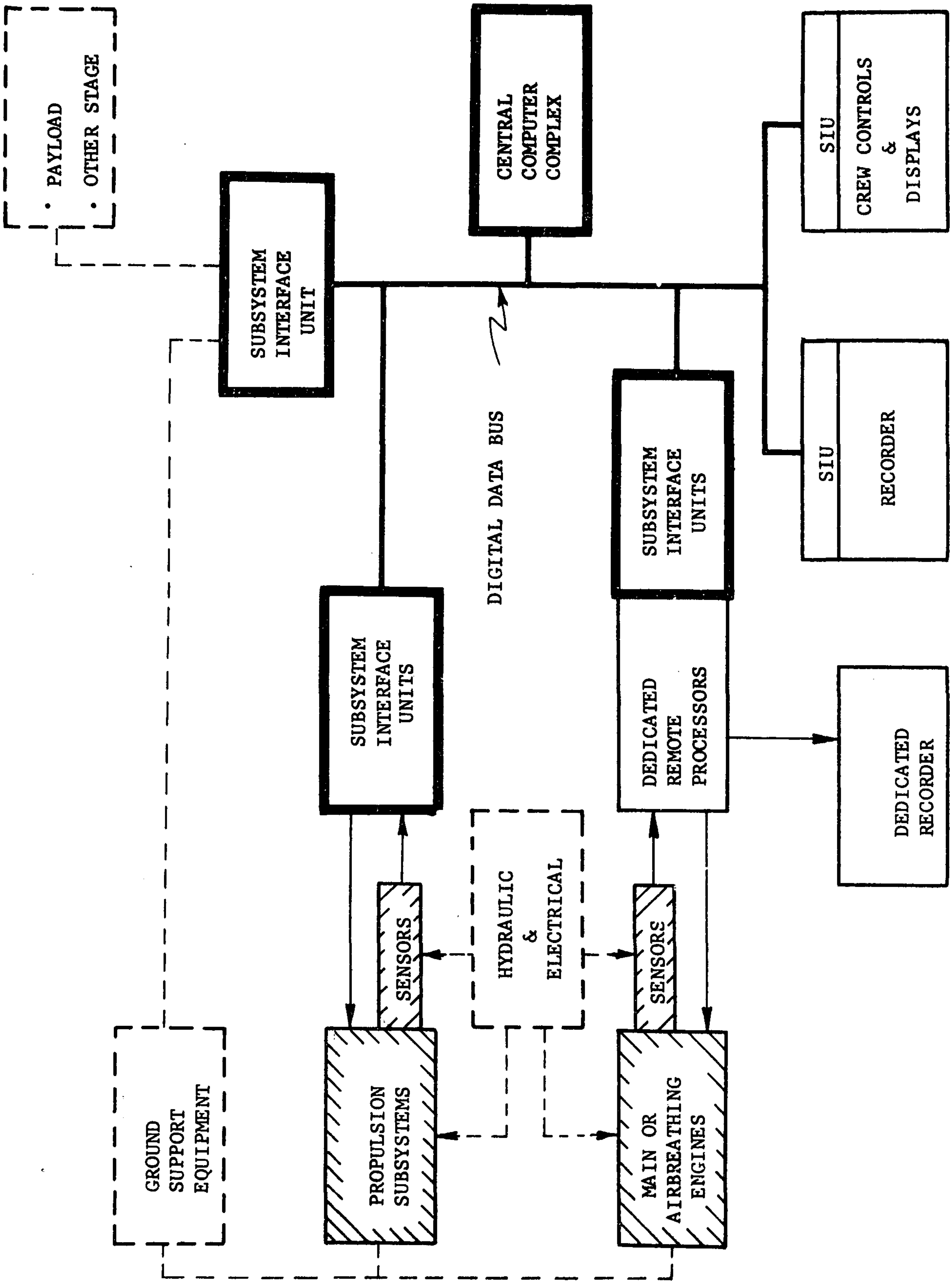


Figure 3.2.1-1 Elements Related to Propulsion System Checkout and Monitoring

3.2.1.5.2 Digital Data Bus - The vehicle data bus system provides the data communication link between the central computer complex and other DM&C subsystem units. The implementation of the digital data bus (or alternate data transportation means) shall accommodate the propulsion system requirements and shall be compatible with the allocation of capabilities as derived from Paragraph 3.2.2.

3.2.1.5.3 Subsystem Interface Unit (SIU) - SIUs form the interfaces between the digital data bus and the elements of the user subsystems, and between the digital data bus and remote units of the DM&C subsystem. The general functions of an SIU related to propulsion subsystems are control and data acquisition. For the configuration shown in Figure 3.2.1-1, these functions include capabilities to receive and decode digital data bus transmissions, generate and apply electrical stimuli to selected points of propulsion subsystems for control, acquire data from selected points of propulsion subsystems, and condition subsystem data as required to transmit intelligible responses to the CCC. Electrical power conditioning and distribution for propulsion system control reference voltages may also be implemented by SIUs.

The extent to which SIUs shall perform data processing on propulsion systems data, and the extent to which SIUs shall be required to condition propulsion system data shall be determined through trade-off analyses. Paragraph 3.2.2 contains criteria that shall be used as a guide in defining the allocation of capabilities to SIUs and in defining the number and types of SIUs.

In addition to the capabilities that an SIU may possess to implement propulsion system requirements, it may possess capabilities required by other user systems or by the DM&C subsystem such as transmission error detection and protection, electrical power conditioning and distribution for internal use, electrical power control, and self-checking. The requirements for these capabilities shall be derived from the applicable program and subsystem requirements.

3.2.1.6 Dedicated Remote Processors - Dedicated remote processors can be employed to perform the detailed checkout, monitoring, and control functions of certain major subsystems of the Space Shuttle, such as the main and airbreathing engines. The communication between remote processors and the CCC is limited to high level commands such as engine start, thrust level, and engine shutdown, and responses such as self-check status, malfunction detection data, and performance data to be recorded. The allocation of capabilities to the remote processors and their associated SIUs and sensors shall incorporate the criteria factors of Paragraph 3.2.2.

3.2.1.7 Recorders - Recording capability can be in the form of vehicle data storage devices, system or subsystem dedicated recorders, and/or CCC memory. Dedicated recorders can be used to accommodate subsystems that require recording of large quantities of performance data for postflight analysis. Similar data from other subsystems may be recorded on the vehicle data storage devices. Data that must be retrievable during flight, such as system status, shall be recorded in the CCC memory, or in the vehicle data recorder if it has inflight data retrieval capability.

3.2.1.8 Crew Controls and Displays - Crew controls for the propulsion systems provide for manual inputs such as thrust level selection for the airbreathing engines, manual control of the attitude control and maneuvering thrusters, and manual override capabilities as required. Crew displays of propulsion system data provide information to the crew relating to propulsion system status, hazard warnings and such other data as may be required to assist the crew in determining requisite actions. Visual data displays may be augmented by audio or visual alarms.

3.2.2 Allocation of Functional Capabilities - The functional capabilities that are required to perform the checkout and monitoring function for the Space Shuttle propulsion system are described in Section 3.1. The implementation of those capabilities shall be accomplished in accordance with the guidelines of this paragraph. The implementation of the checkout and monitoring function shall consist of allocating the required functional capabilities to the various onboard and ground elements that are candidates for incorporating those capabilities. The allocation of functional capabilities shall be accomplished through tradeoff analyses that include as criteria the requirements derived in Section 3.1, the Space Shuttle program requirements, vehicle subsystem requirements, and the implementation guidelines contained herein. The implementation approach is outlined in Figure 3.2.2-1.

3.2.2.1 Capability Requirements and Implementation Candidates - Section 3.1 identified data acquisition, data processing, recording, display, and stimuli generation as capabilities that are requisite to satisfying the checkout and monitoring function requirements for the

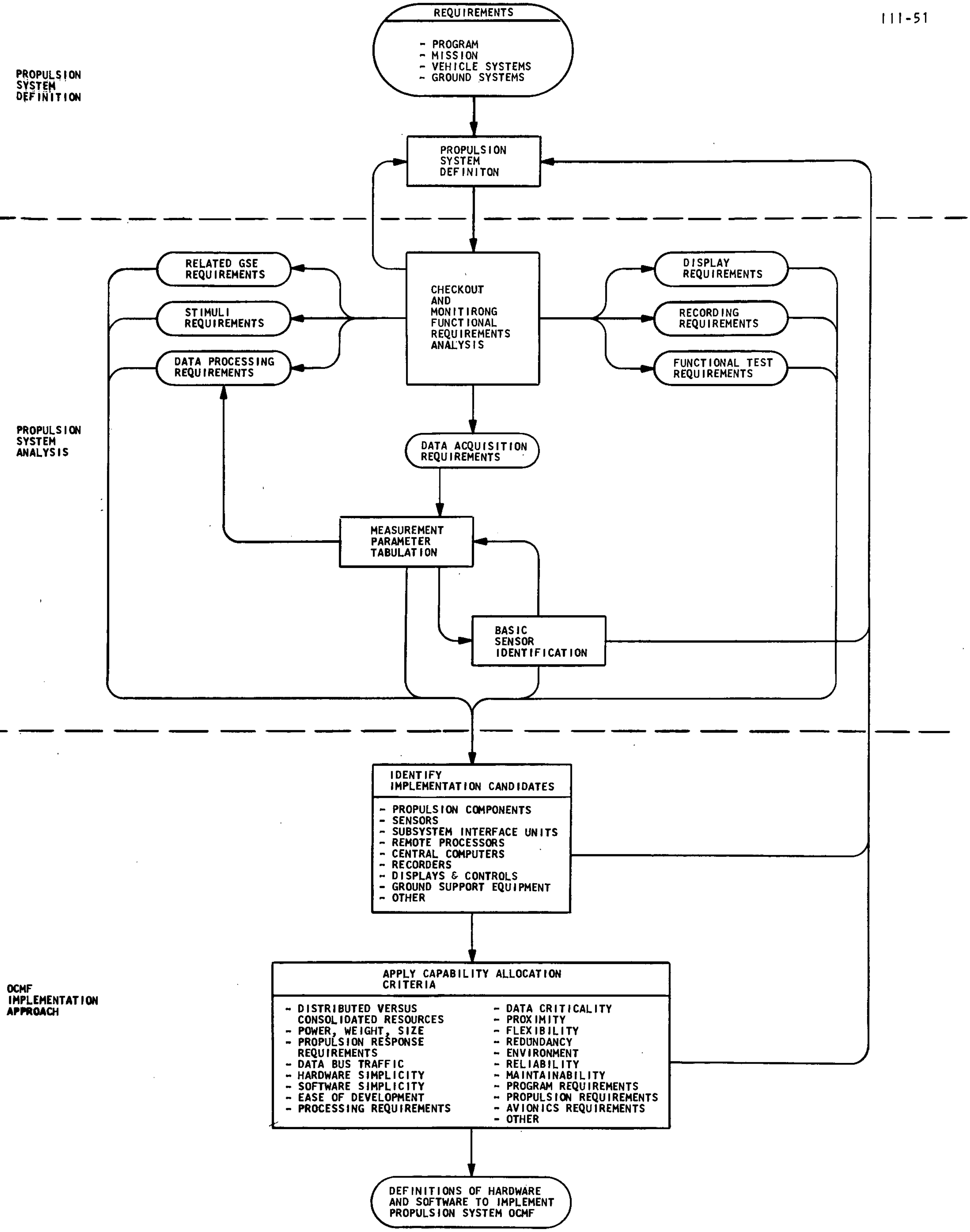


FIGURE 3.2.2-1 PROPULSION SYSTEM ANALYSIS & OCMF IMPLEMENTATION APPROACH

propulsion systems. The matrix of Figure 3.2.2-2 reduces those capabilities to their basic functions and shows the relationship between them and the elements that are candidates to incorporate them. The requirements for these basic functions and their derivations are discussed in subsequent paragraphs.

3.2.2.1.1 Data Acquisition - Data acquisition includes the sensing of a propulsion system measurement parameter (whether it is from a sensor or a crew control) and any signal conditioning required to be performed to put the data into a form which is usable in subsequent calculations or comparisons, or for another purpose such as recording or display. Calculations or comparisons may be done by a remote unit or by the central computers. Implicit in data acquisition is the transportation of data from one element to another, the conversion of data from one form to another that transporation requires, and any switching involved to acquire the desired data. The measurement parameter tabulation formulated in Paragraph 3.1.2.2.4 shall be included in the criteria to implement these fundamental functions. The translation of the entries of the measurement parameter tabulation into implementation criteria is shown in Table 3.2.2-1. For the purposes of this document, functions such as data formatting and data validation are considered the responsibility of the avionics system and shall not be further discussed herein. (While a dedicated remote processor or comparable unit may be assigned to the propulsion system, it is basically an avionics unit and its non-propulsion originated characteristics would be governed principally by avionics design criteria.)

FUNCTIONAL CAPABILITY \ FUNCTIONAL ELEMENT	SENSOR	SUBSYSTEM INTERFACE UNIT	DATA BUS	HARDWIRE	CENTRAL COMPUTER OR REMOTE PROCESSOR	DISPLAY AND ALARM	RECORDER	GROUND SUPPORT EQUIPMENT	CREW
SENSE	X	X			X			X	X
TRANSPORT			X	X				X	
CONDITION	X	X			X			X	X
SWITCH		X			X			X	
CALCULATE		X			X			X	X
COMPARE	X	X			X			X	X
STIMULATE	X	X			X			X	X
STORE		X			X	X	X	X	X
REPORT						X		X	

Figure 3.2.2-2 Capability Requirements Versus Implementation Candidates

TABLE 3.2.2-1

TRANSLATION OF MEASUREMENT PARAMETER TABULATION ENTRIES TO IMPLEMENTATION CRITERIA

PARAMETER (Column 1)	The parameter type provides identification of the basic <u>sensor</u> type.
PROPULSION ELEMENT (Column 2)	The identification of the associated propulsion element leads to the definition of the propulsion component/sensor <u>interface</u>.
RANGE AND UNITS (Column 3)	Used in the definition of required <u>sensor ranges</u> which may affect sensing <u>element type</u>; the definition of SIU, <u>remote processor</u> and/or <u>CCC range requirements</u>.
ALLOWABLE ERROR * (Column 4)	Used to define the <u>combined accuracy</u> of the sensors, SIUs, remote processors, CCCs, and displays used to acquire data. *A function of data usage.
RESPONSE RATE (Column 5)	Used to define the required sensor response, system <u>sample rates</u> and system <u>reaction times</u>.
SAMPLE RATES (Column 6)	Used to determine <u>hardware speed</u> requirement, <u>processing speed</u> and magnitude, and vehicle <u>data bus</u> rates. Sample rates are used as criteria for <u>allocation of processing capability</u> to SIUs versus central computers.
DATA USAGE (Column 7)	Used in the definition of sensor type, <u>recording and display requirements</u>, basic <u>data processing requirements</u>, and vehicle <u>data bus requirements</u>. Also affects allowable error.

TABLE 3.2.2-1

TRANSLATION OF MEASUREMENT PARAMETER TABULATION
ENTRIES TO IMPLEMENTATION CRITERIA
(CONTINUED)

TIME OF ACTIVITY (Column 8)	Used to define the intervals and magnitudes of the peak demands on vehicle resources, i.e., data bus, processors, recorders, displays, and crew. Conversely, periods of low activity or inactivity are defined during which conservation of resources may be achieved through resource management.

3.2.2.1.2 Data Processing - Data processing for the propulsion systems is basically comprised of the calculations and/or comparisons required to evaluate acquired data (whether done by a remote unit or the CCC), the calculations and/or comparisons required to determine an appropriate control signal, and the operations requisite to recording and displaying propulsion data including data tagging and routing. The fundamental data processing requirements for data evaluation shall be derived from the data use, allowable error, and response rate entries of the measurement parameter tabulation of Paragraph 3.1.2.2.4. Similarly the basic processing for propulsion system control shall be derived in conjunction with the definition of stimuli requirements. Data processing requirements for recording and display shall be derived from the recording and display requirements of Section 3.1 and the implementation of those requirements per the guidelines of this section. Other data processing requirements shall be derived from the simulation of sequences, events, and conditions during ground operations.

3.2.2.1.3 Electrical Stimuli - Control of the propulsion system requires the generation and application of external stimuli in addition to data acquisition, data processing, display, and crew action. The stimuli requirements of the propulsion elements (such as solenoid valves) are derived in accordance with Section 3.1. Additional stimuli requirements shall be derived from the final sensor specifications. Sensor stimuli may include gating commands, self-check commands, and calibration reference signals.

3.2.2.1.4 Data Storage - The recording of propulsion system status, performance data, fault isolation data, operating history data, and the storage of propulsion system algorithms and control sequences derived from the analyses of Section 3.1 comprise the data storage requirements for the propulsion systems.

3.2.1.5 Data Reporting - The propulsion system parameters and conditions for which data reporting (crew displays and alarms) is required are identified by the analyses of Section 3.1.

3.2.2.2 Capability Allocation Criteria - The general criteria that shall be considered in the allocation of capabilities to onboard and ground equipment are:

- Space Shuttle program requirements
- Space Shuttle propulsion system requirements and characteristics
- Space Shuttle avionics requirements
- Space Shuttle environmental requirements
- Minimization of
  - New development requirements
  - Ground support requirements
  - Unique hardware, software, and procedures
- Maximization of
  - Modularity
  - Commonality
  - Maintainability
  - Reliability
  - Hardware and software simplicity

Another general consideration for the allocation of functional capabilities is that of ease of subsystem development; that is, the level of development possible at the subsystem level is largely dependent on the distribution of capabilities among the system elements.

The specific implementation criteria for allocation of capabilities shall be established by conducting the tradeoff analyses defined in the following paragraphs. These analyses principally establish criteria for the allocation of signal conditioning and data processing capabilities among the sensors, subsystem interface units, remote processors and the central computers.

3.2.2.2.1 Sensors - Basic sensor criteria shall be derived from Columns 1, 2, 3, 4, 5, and 7 of the measurement parameter tabulation (see Table 3.2.2-1). A determination of whether an analog or a discrete output is required from the sensing element can be made from that criteria. The results of that determination shall be used in the definition of the signal conditioning and data processing requirements for the parameter under consideration.

Evaluation of the relative merits of consolidated (SIU or remote processor) versus distributed (sensor) signal conditioning shall be a primary factor in determining the extent of signal conditioning to be incorporated into sensors. The advantages of distributed signal conditioning are increased redundancy and the ability to trim a signal conditioner to a particular sensor. The advantages of consolidated signal conditioning are reductions in the power consumption, weight, and size of the signal conditioning equipment. The selection of sensing element type shall be done in conjunction with the definition of the signal conditioning equipment required for that sensor and shall include consideration of exposure to the propulsion system induced and natural environment.

A determination of the extent to which data evaluation capability shall be incorporated into sensors shall be performed considering the usage of the sensor output data, the sensor output interface (see next paragraph), sensor mounting options, weight, power, size, redundancy, flexibility, vehicle data bus traffic, and data processing requirements.

An evaluation shall be made to determine whether a sensor output should interface directly with the vehicle data bus, or with an SIU or remote processor. Reaction time requirements for safety and control shall be a primary consideration in this evaluation. Other criteria to consider are the reductions in hardware power, weight and size, vehicle data bus traffic, and data processing requirements when the communication capability for a number of sensors is consolidated into an SIU or a remote processor versus the increase in redundancy and system flexibility with individually addressable sensors. The results of this evaluation shall be used in the definition of sensor electrical interfaces.

Sensor electrical interfaces shall also include the definition of interfaces for sensor control commands and sensor electrical excitation. Sensor output enable and/or sensor self-check command requirements are dependent on the capabilities allocated to the sensor. The interface(s) for sensor electrical excitation depend on the power requirements of previously allocated sensor capabilities, the requirements for calibration references, and the determination of the optimum allocation of power conditioning capability.

The mechanical interfaces of sensors with the propulsion elements shall be defined considering such aspects as accessibility, maintainability, environment, the effects of location on sensitivity and fidelity, calibration requirements, mounting torque, and the moments of externally mounted assemblies.

Sensor accuracy shall be specified in conjunction with the accuracies of the other onboard elements (SIUs, remote processors, central computers, displays) such that the total allowable error specified for the associated measurement parameter is not exceeded. Error allocation shall account for error sources whether they are random or time progressive and the relative cost to design and maintain each error allocation to attain the most favorable long life/cost characteristics.

Final sensor specifications shall include: parameter type; sensing element type; range; accuracy; sensitivity; frequency response; environment(s); operational and service life; electrical and mechanical interfaces; physical limitation; self-check requirements; and calibration requirements and/or restrictions (including restrictions on adjustments).

The assignment of sensor outputs to SIUs or remote processors shall be done in conjunction with the definition of those units.

3.2.2.2.2 Subsystem Interface Units - The functional redundancy of the propulsion subsystems and proximity to those subsystems shall be primary considerations in the definition of the number of subsystem interface units (or portions thereof) assigned to service the propulsion subsystems.

Tradeoffs for the allocation of signal conditioning, data processing and stimuli generation are the principal criteria for establishing the types of SIUs that are optimum in accommodating the propulsion system requirements. Signal conditioning requirements shall be established through tradeoffs as described under sensors (Paragraph 3.2.2.2.1); that is, distributed versus consolidated signal conditioning where the results influence system power, weight, size, redundancy, flexibility, and failure detection capability. The amount of signal conditioning required shall also be considered in establishing the number of SIUs for propulsion system service.

Data processing capability shall be traded off among sensors, SIUs, and central computers considering the actions, reactions and corresponding times required for propulsion system control; vehicle data bus traffic rates; central computer processing requirements; system power, weight, and size; system reliability and redundancy; ease of fault detection, fault isolation, and redundancy management; and simplicity of software development.

The extent of electrical power conditioning and distribution by SIUs for propulsion system stimulus or excitation shall be derived from the control requirements (both functional and checkout dictated) identified in Section 3.1. The extent of electrical power conditioning and distribution for sensor electrical excitation shall be determined in conjunction with the allocation of sensor capabilities and error budgets and shall consider the relative merits of consolidated versus distributed power conditioning. The requirements for the generation of stimulus for sensor control shall also be determined in conjunction with allocation of sensor capabilities.

3.2.2.2.3 Remote Processors - The quantity and speed requirements of data processing for control and fault detection are driving factors in the determination of whether or not remote processors shall be dedicated to major propulsion subsystems. Another major consideration is that the use of remote processors permits greater development of major subsystems prior to system and vehicle integration.

The allocation of data processing, signal conditioning, stimuli generation, and electrical power conditioning and distribution capabilities to remote processors shall consider the same criteria used for the allocation of capabilities to sensors and SIUs with the exception that a remote processor should accommodate as much of the processing requirement of the associated subsystem as possible. External processing should be principally for system control or long term trend analysis and resource management.

The implementation of a remote processor shall also consider its proximity to the associated propulsion subsystem, the functional redundancy of the propulsion subsystem, the criticality of each interface with the propulsion subsystem, and the degree of flexibility that is required to accommodate potential changes in requirements.

3.2.2.2.4 Recorders - The implementation of the propulsion system recording requirements identified in Section 3.1 shall consider the peak rate of the propulsion system data to be recorded, the period of time for which data must be retained, the total recording capacity required for propulsion system data, the requirement to provide inflight retrieval of propulsion system status and fault-isolation data, the requirement to adequately tag data for postflight evaluation, and the flexibility to accommodate changes in recording requirements based on mission requirements or on system trends.

3.2.2.2.5 Displays - The implementation of the propulsion system display requirements identified in Section 3.1 shall consider the criticality of the data as a principal factor in determining the type and redundancy of the reporting device(s) to be used. In addition to data criticality, the implementation of displays for propulsion system data shall consider the mission time, event, or time duration during which the display is required, the crew action required as a result of the display, the location of a display relative to other displays on which related data is presented, and the desirability of augmenting critical displays with alarms.

3.2.2.2.6 Data Bus - In addition to fulfilling the requirements of other vehicle systems, the configuration of the vehicle data bus shall accommodate the propulsion system checkout, control, and monitoring requirements identified in Section 3.1 and shall be compatible with the allocation of functional capabilities for those requirements as determined by the guidelines of this section. The data bus design shall consider the reaction time requirements of the propulsion system, the criticality of accurate transmission of propulsion system commands and responses, the peak data traffic requirements of the propulsion system in conjunction with the requirements of the other vehicle systems, and the flexibility to accommodate changes in requirements.

3.2.2.2.7 Central Computer Complex - The implementation of the vehicle central computer complex shall use the propulsion system requirements derived in Section 3.1 and the allocation of capabilities defined in this section as criteria. The definition of central computer data processing requirements for propulsion shall be made in conjunction with the allocation of data processing capability to the sensors, SIUs, and remote processors. The propulsion system checkout, control and monitoring requirements shall be included into the criteria for determining central computer instruction repertoire, instruction execution time, memory size, redundancy, and operational flexibility.

3.2.2.2.8 Ground Support Equipment - The extent to which the checkout and monitoring function requirements of the Space Shuttle propulsion systems are implemented by ground support equipment shall be determined by tradeoff analyses considering:

- Space Shuttle turnaround time and maintenance concepts
- Space Shuttle capability to land at a remote site
- Postflight evaluation requirements
- Maintenance retest requirements
- Preflight checkout and functional testing requirements
- Inflight versus ground requirements
- Available airborne technology
- Size, weight, and power consumption of the necessary onboard equipment.
- Safety
- Crew participation

5.0 NOTES

This section lists and defines terms and abbreviations used in the document. Further, it presents background information and rationale for assistance in understanding and applying the guidelines.

5.1 Definitions - An alphabetical listing of definitions follows:

CAUTION AND WARNING DISPLAY: the technique used to alert and inform the crew of the existance of an abnormal condition.

CENTRAL COMPUTER COMPLEX: the primary system of data processing for the vehicle.

CHECKOUT: the function of determining the capability of an element or system to perform its specified functional operations.

COMPONENT OPERATING HISTORY DATA: data identifying the accumulated functional operations (such as numbers of cycles, time above a specified temperature, etc.) of a component.

CONTROL: the function of starting, stopping, changing or otherwise regulating the functional operations of an element or system.

CONTROL SEQUENCE AND OPERATIONAL LOGIC DIAGRAM: a system analysis tool that defines detailed sequences and conditions of operation of a system.

DATA ACQUISITION: the process of sensing, signal conditioning to a usable form and transporting data to its destination.

DATA PROCESSING: the calculations and/or comparisons required to evaluate acquired data and to determine appropriate commands, and the operations requisite to recording and displaying data including data identification and routing.

DERIVED PARAMETER: a parameter whose magnitude is established by applying a mathematical relationship to other parameters. An example of a derived parameter is flow rate calculated from temperature (density) and differential static pressure.

EMERGENCY DETECTION: the detection of an abnormal condition that can progress into a catastrophic effect.

FAULT DETECTION: the determination that an element or system is performing outside its specified functional operation limits.

FAULT ISOLATION: the identification of the element or group of elements that performed or is performing outside its specified functional operation limits.

FAULT PREDICTION: the determination made through trend analysis that the performance of an element or system has an unacceptably low probability of remaining within specified limits.

FLEET TRENDS: information pertaining to performance characteristics and maintenance requirements of the fleet of vehicles during successive missions.

FUNCTIONAL ELEMENT: an element that provides a function in addition to or other than structural integrity, and is capable of functional operation.

FUNCTIONAL OPERATION: the change of state or condition of an element or system such as a response to a control command.

FUNCTIONAL TESTING: checkout that is performed by inducing functional operations on an element or a sequence of functional operations on an element or system.

GROUND SUPPORT EQUIPMENT: for checkout and monitoring, the equipment that is needed, in addition to the on-board equipment, to accomplish the checkout and monitoring functions.

LINE REPLACEABLE UNIT: an element or group of elements that can be removed, replaced and retested within the constraints of the vehicle turnaround cycle timeline.

MAINTENANCE: those functions and activities associated with restoring the vehicle to an operational condition between flights.

<u>MAINTENANCE RETEST</u>: the function of verifying the capability of this system to perform its prescribed functional operations subsequent to maintenance activities.

<u>MEASUREMENT</u>: a single source of data relating to the magnitude of a parameter.

<u>MEASURED PARAMETER</u>: a parameter that can directly be measured.

<u>MISSION PHASES</u>: the repetitive set of discrete, sequential ground and flight operations of the Space Shuttle.

<u>MONITORING</u>: the function of determining whether an element or system is performing its functional operations with specified limits.

<u>PARAMETER</u>: a physical characteristic, state or condition. Examples include position, temperature, and flow rate.

<u>POSTFLIGHT EVALUATION</u>: the function of identifying elements that require maintenance either because they have not performed their functional operations within specified limits, or because their trend of performance indicates that the specified performance will not be attained during the next functional operation or flight.

<u>POSTFLIGHT SAFING AND PURGING</u>: those operations conducted after landing to place the vehicle in a safe, inert condition. This operation can include venting pressure vessels, draining propellants and purging tanks and lines, safing and removing pyrotechnic devices, etc.

<u>PRESTART</u>: a period immediately prior to initiation of a functional operation of an element or system, either on the ground or in flight.

<u>PRESTART CHECKOUT</u>: an evaluation conducted just prior to initiation of a functional operation to assess the capability of the element or system to operate within specified performance limits.

<u>POSTFLIGHT CHECKOUT</u>: checkout performed during postflight safing and purging operations.

<u>REDUNDANCY MANAGEMENT</u>: the function of reacting to the detection of an existing or potential emergency condition by activating a redundant path, function or element to alleviate the condition.

<u>REDUNDANCY VERIFICATION</u>: assessment of the capability of redundant functional elements to perform their specified functional operations.

<u>REMOTE PROCESSOR</u>: a computer which performs data processing and control sequences in response to high level commands from the central computer complex.

<u>SELF-CHECK</u>: the process by which a functional element assesses its own operational integrity and readiness.

<u>SENSOR</u>: a functional element that responds to a physical quantity or event and converts that response to transmissible data which is proportional to the magnitude of the quantity or indicates the occurence of the event.

<u>STATUS VERIFICATION</u>: verification that parameters are within specified limits or at specified values.

<u>STIMULUS</u>: an excitation or forcing function that is applied from a source external to a functional element.

<u>SUBSYSTEM INTERFACE UNIT</u>: an intermediary that interfaces a user subsystem (e.g., a propulsion subsystem) to the vehicle avionics system. An SIU performs a control function by translating avionics system commands into stimuli for the user subsystem and acquires data from the user subsystem for use by other vehicle and ground systems.

<u>TREND ANALYSIS</u>: the identification of changes in performance of an element or system during successive functional operations or flights, and the evaluation of such changes to determine the probabilities of performance degrading outside specified limits in subsequent functional operations or flights.

5.2 Abbreviations - Abbreviations used in the text of the document are defined as follows:

OCMF	On-board Checkout and Monitoring Function
LRU	Line Replaceable Unit
GSE	Ground Support Equipment
NASA	National Aeronautics and Space Administration
MSFC	Marshall Space Flight Center
DM&C	Data Management and Control
CCC	Central Computer Complex
SIU	Subsystem Interface Unit

5.3 Supplementary Information - (Any material considered to enhance the use or understanding of this document will be included in this paragraph).

IV. STATUS AND RESULTS - TASK III

Task III is directed toward the definition of the checkout and monitoring requirements of the large diameter core Titan (T-III L). The detailed objectives, guidelines, and approach for this task are presented in the Project Plan (Rev. B).

Task III has been completed during this report period and the contents are presented in the following manner.

SECTION IV-A Task III Discussion

SECTION IV-B Propulsion System Definition

SECTION IV-D Checkout and Monitoring Requirements Analyses

SECTION IV-E Checkout and Monitoring Requirements Implementation

Appendix A Titan III Propulsion Measurement Usage

The Propulsion System Definition section, presented in the July-September Quarterly Progress Report, has been updated to reflect suggested changes. This section is presented again for continuity purposes. The FMEA's, presented as appendix A of the October monthly, are not resubmitted at this time, but will be presented as a portion of the Final Report. The ground rules governing the FMEA's are presented in Section IV-C.

SECTION IV-A TASK III DISCUSSION

The objective of Task III is to define and evaluate the propulsion Checkout and Monitoring requirements for the Titan III-L expendable booster.

Task III was conducted within the following guide lines.

1. Conclusions and recommendations are to be consistent with the objective of maximizing cost effectiveness in the Space Shuttle program.

2. Maximum use will be made of the Space Shuttle Phase B Extension Study.

3. The study is restricted to the checkout and monitoring requirements of a selected baseline T-III L Propulsion Systems.

4. The analyses are limited to that of typical system, subsystems, assemblies and components.

5. This task will consider only the fully operational vehicle configuration.

6. If insufficient data is available on the orbiter or booster, appropriate assumptions will be made and documented.

The approach to Task III accomplishment is based on the methodology developed during our basic study contract and the "Guidelines For Incorporation Of The Onboard Checkout and Monitoring Function On The Space Shuttle", Task II, of the current study.

Since the "Guideline" document is being developed in parallel with this task, only the approaches and formats available during the development of each task element have been incorporated. The task was divided into four basic elements; Propulsion System Definition, Propulsion System Analyses, Checkout and Monitoring Requirements Analyses, and Checkout and Monitoring Requirements Implementation. This approach which is in accord with the Task II methodology, has been utilized in the presentation of the material in the following sections.

The result and conclusions of the Titan III L Checkout and Monitoring Requirements study are summarized as follows:

1. To maximize cost effectiveness, the checkout and monitoring techniques utilized on the operational Titan III's should be retained for the Titan III L study configuration.

2. Certain control functions, i.e., flight control, booster staging, and portions of emergency reaction controls can best be handled by the Orbiter.

3. The Onboard Checkout and Monitoring functions identified by Task II are directly applicable to the expendable Booster propulsion. Only the degree of usage and location of accomplishments are different.

4. The Checkout and Monitoring impact on the orbiter is slight. A limited amount of data is transmitted to the orbiter for crew alert (caution and warning) and emergency action.

5. The study impact on existing hardware design is of a minor nature. The direct impact is to the instrumentation, i.e., the degree of required measurements, measurement redundancy and sensor locations.

Two supporting research and technology items have been identified by the Failure Modes and effects analyses conducted during the Propulsion Systems Analysis Study. A solid rocket motor case burnthrough detector and a liquid rocket engine compartment fuel leakage or fire detetector were identified. Further evaluation of the best technical approach and the current "State-Of-The-Art" are required before a firm recommendation can be made on these items.

SECTION IV-B Propulsion System Definition

Space Shuttle Vehicle Configuration

Booster Configuration

Booster Main Propulsion System

Main Engine Subsystem

Main Propellant Management Subsystem

Main Pressurization Subsystem

Solid Rocket Motor System

Rocket Motor Subsystem

Thrust Vector Control Subsystem

Operations

A. PROPULSION SYSTEM DEFINITION

SPACE SHUTTLE VEHICLE CONFIGURATION

The selected study configuration is the Martin Marietta Corporation Baseline Vehicle on August 23, 1971, Figure IV-1. The Space Shuttle vehicle is composed of an expendable Titan III large diameter core booster (T IIIL) and the updated Grumman H-33 drop tank orbiter, Figure IV-2. The orbiter is the identical configuration to be used with the fully reusable Space Shuttle with the exception of the hydrogen drop tanks. The drop tanks are somewhat smaller when used with the expendable booster. The useful payload into a 100 nmi. design orbit is 45,000 lbs. The orbiter payload capability is increased to 65,000 lbs. when the reusable booster is used as the launch vehicle. In the selected configuration, the orbiter is attached to the booster in a piggy back fashion.

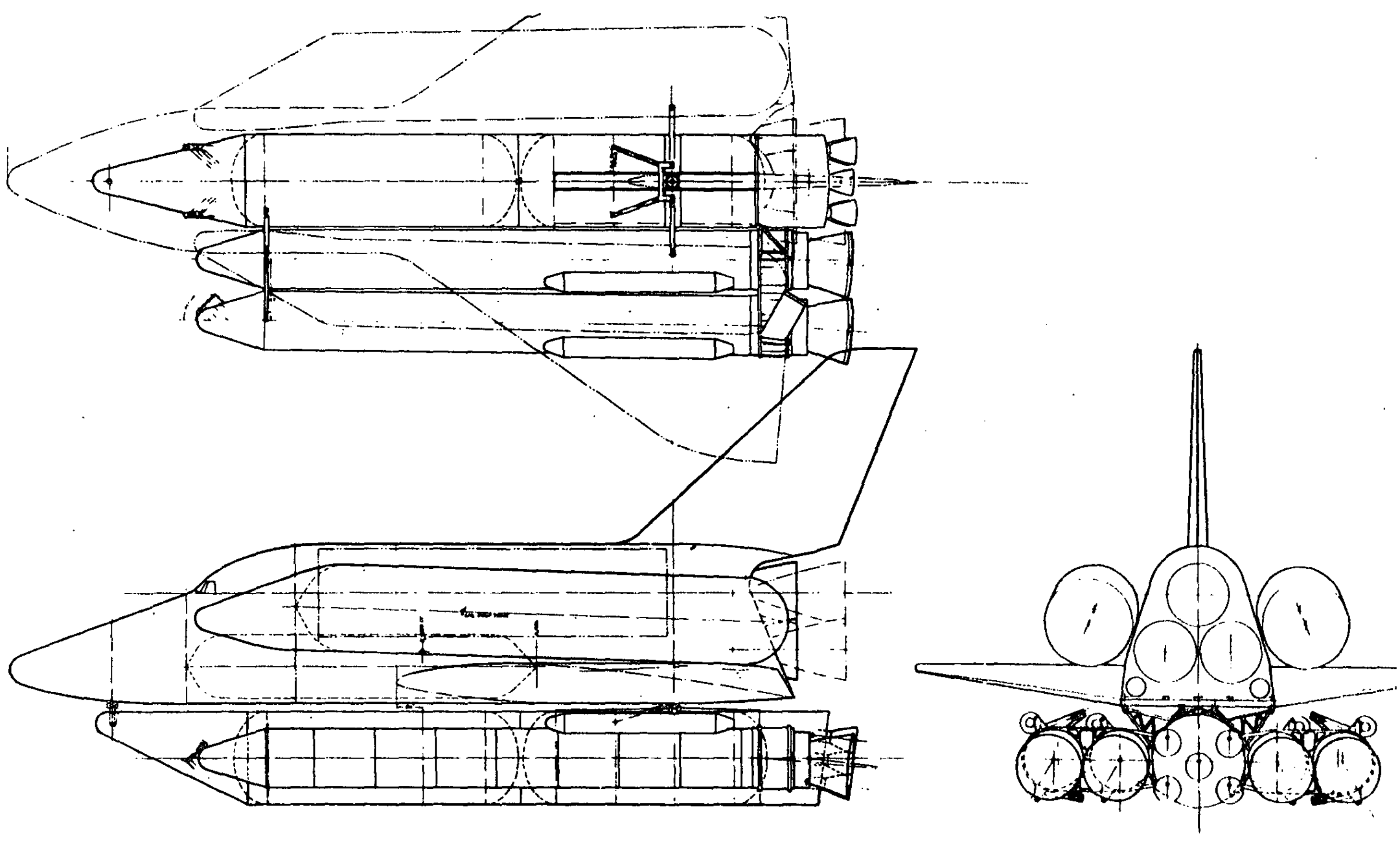


Figure IV-1 Vehicle Configuration

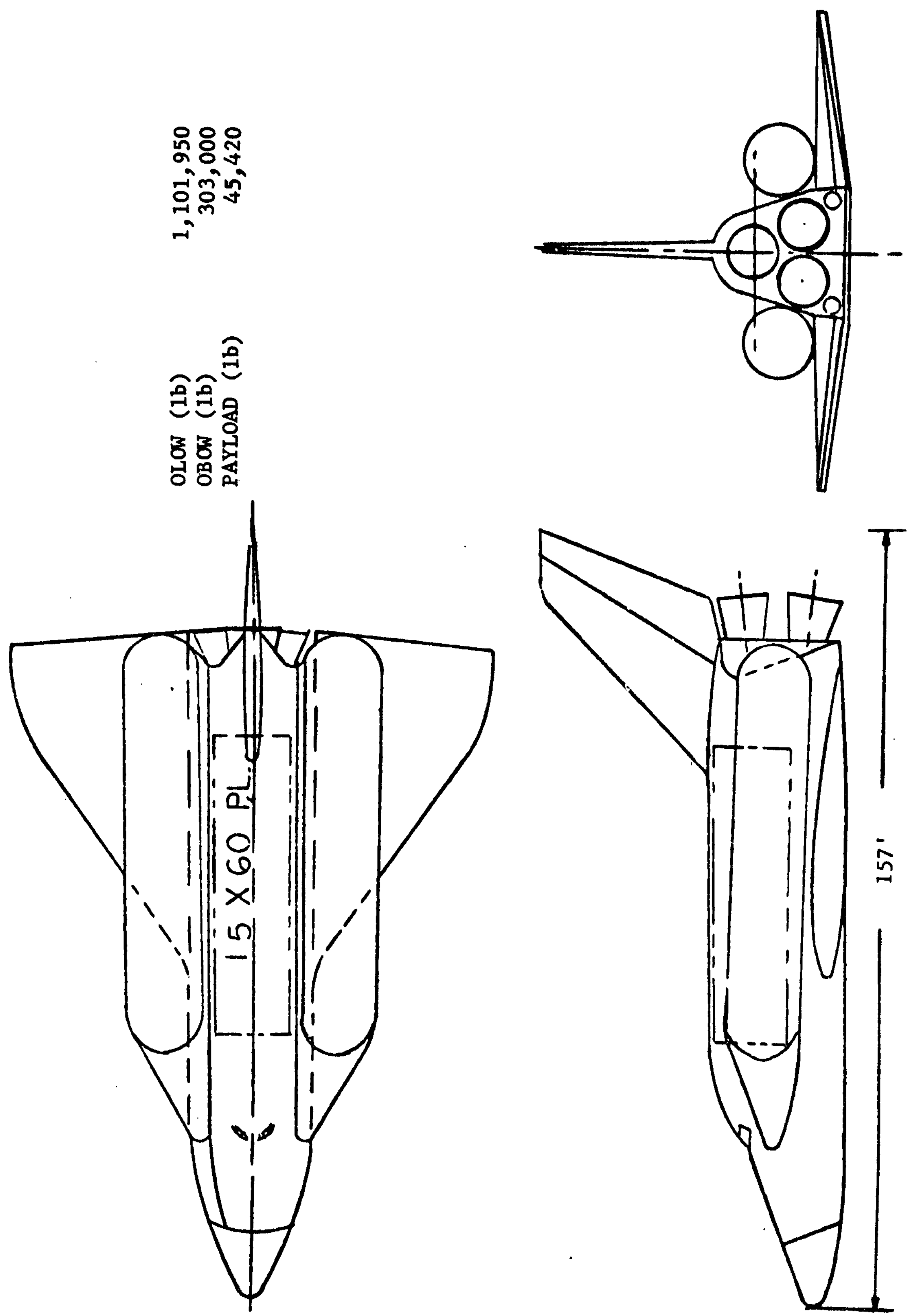
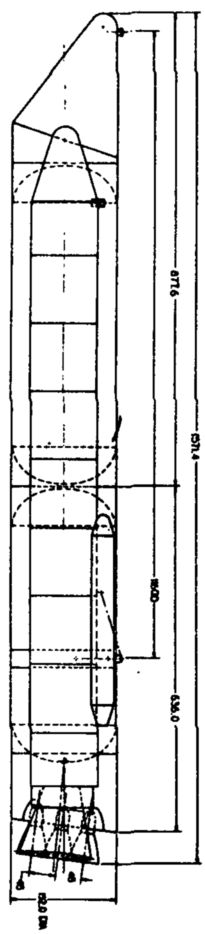


Figure IV-2 Grumman H-33 Orbiter

BOOSTER CONFIGURATION

The selected Titan IIIL booster is designated as the 1207-4 spread configuration. The booster stage consists of a sixteen foot diameter liquid fuel core with five (Aerojet Liquid Rocket Company) LR-87 engines and four 120 inch (United Technology Center) UA 1207 solid rocket motors mounted in the yaw plane, two on either side of the core. The liquid fueled core utilizes nitrogen tetroxide as an oxidizer and Aerozine-50, a solution of Hydrazine and UDMH, as a fuel. Five core engines supply a total sea level thrust of 1,133,370 pounds. The liquid rocket engines are precanted 9° in pitch to compensate for the CG Z-axis offset. The center engine is hinged in pitch to facilitate CG tracking while the outboard engines have gimbal capabilities of plus or minus 4.5 degrees in pitch and yaw. The four solid rocket motors develop a total of 5,570,400 pounds-thrust. The engine nozzles are precanted six degrees in a plane rotated 30 degrees out of pitch. The cant and rotation angles are chosen to facilitate CG tracking and to minimize the individual SRM moment arms at the end of web action time. The booster configuration is shown in Figure IV-3.



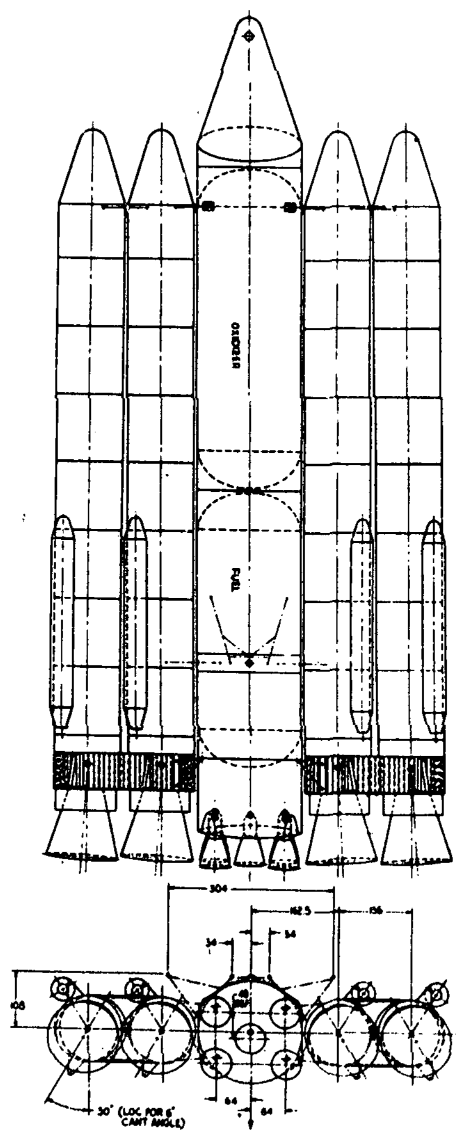


Figure IV-3 Booster Configuration

1.0 BOOSTER MAIN PROPULSION SYSTEM

The booster main propulsion system consists of 5 liquid propellant rocket engines attached to an airframe which includes the fuel and oxidizer tanks, between-tank structure, forward skirt and aft skirt. The rocket engines utilize 12:1 expansion thrust chambers, each of which is supplied propellant from its own turbine-driven pump. The fuel and oxidizer tanks are welded structures consisting of a forward dome, barrel section and aft dome. An aft heat shield encloses the Stage I engine compartment to protect main engine components from radiant heat produced by the exhaust plumes of the solid rocket motors. The boattail is aluminum and covers those portions of the engine above the thrust chamber throat. A rubber boot provides further protection for the thrust chamber assembly above the throat. Covers, made of Refrasil sandwiched between two layers of Inconel, protect each thrust chamber from injector to aft end but are not a part of the aft heat shield. Exit closures are provided to protect the thrust chamber interior from moisture. These closures are blown off when booster engine operation is initiated. Rubber covers over the turbine exhaust stacks are blown off by start cartridge gas pressure at engine start.

Thrust vector control is accomplished by gimballing the engine thrust chambers to provide pitch, yaw and roll corrections. Hydraulic actuators, driven from the engine turbopump and controlled by electrical signals from the guidance and flight control systems, provide the gimbal force. Stage I operates for approximately 276 seconds and uses 800,600 lb of nitrogen tetroxide (N_2O_4) oxidizer and 419,000 lb of 50% hydrazine and 50% UDMH fuel. The booster engines shut down when one of the propellants is exhausted. Figure IV-4 is a schematic representation of the Main Propulsion Subsystem. Table IV-1 presents the propulsion system and subsystem numerical identification.

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TABLE IV-1
PROPULSION SYSTEM AND SUBSYSTEM
NUMERICAL IDENTIFICATION
(BOOSTER)

1.0 Booster Main Propulsion System

- 1.1 Main Engine Subsystem
- 1.2 Main Propellant Management Subsystem
- 1.3 Main Pressurization Subsystem

2.0 Solid Rocket Motor System

- 2.1 Rocket Motor Subsystem
- 2.2 Thrust Vector Control Subsystem

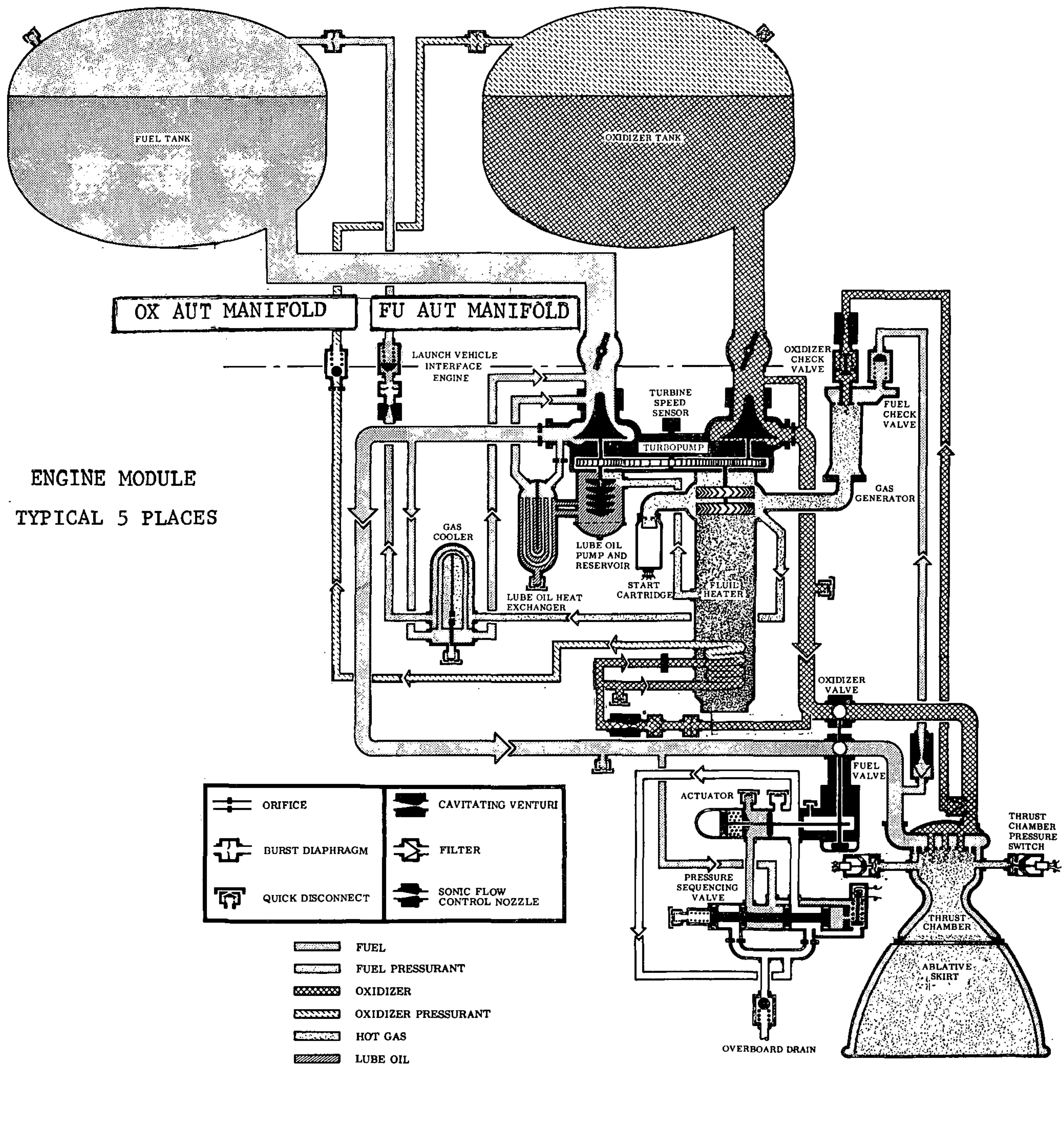

Figure IV-4 Main Propulsion Subsystem Schematic

1.1 MAIN ENGINE SUBSYSTEM

The Titan III-L main engine subsystem is a storable liquid propellant, turbopump fed configuration that develops 226,670 lb sea level and 257,750 lb altitude thrust.

The rocket engine consists of the following subassemblies: turbopump assembly, thrust chamber valve assembly, gas generator assembly, thrust chambers assembly, engines start assembly, and the TVC assembly.

The suction lines duct the fuel (Aerozine-50) and oxidizer (nitrogen tetroxide) from the propellant tank lines to the turbopumps, each of which is driven by a turbine rated at 5000 h.p. The fluid pressure is increased through the pumps by over 1000 psi to force the propellant through the discharge lines into the thrust chamber. Thrust chamber valves are utilized to control engine start and shutdown. The gas generator is operated by propellant from the discharge lines to drive the turbines which maintain propellant flow. Combustion in the thrust chamber produces gas at a pressure of 800 psia and temperature of approximately 5000°F.

Thrust vector control (pitch, yaw and roll) is achieved by pivoting the thrust chamber on gimbal bearing mounts. The gimbal action of the thrust chamber is provided by hydraulic actuators which operate in response to signals from the launch vehicle control system.

The engine is hydraulically balanced and requires no thrust controls. It is pre-set to operate at a certain level, i.e., consume propellant at a fixed rate, by the use of orifices. Balance orifices in the propellant discharge lines and cavitating venturis in the gas generator bootstrap lines determine the steady-state level. The propellant flow rate established by the discharge line orifices is a function of both upstream and downstream pressures. The cavitating venturis establish a flow rate that is sensitive only to upstream pressure, maintaining a constant flow rate over a wide range of downstream pressures. The control of propellant flow rate to the gas generator results in a stablized turbine speed. The propellants are hypergolic (they ignite on contact with one another), and, therefore, no ignition system is required to initiate combustion in the thrust chambers or gas generators.

The Main Engine Subsystem schematic is shown in Figure IV-5. Each main engine module contains the following assemblies and components.

MAIN ENGINE SUBSYSTEM

1.1.1 Thrust Chamber Assembly

- 1.1.1.1 Injector
- 1.1.1.2 Combustion Chamber
- 1.1.1.3 Ablative Skirt
- 1.1.1.4 Thrust Chamber Pressure Switch (3)

1.1.2 Thrust Chamber Valve Assembly

- 1.1.2.1 Oxidizer Thrust Chamber Valve
- 1.1.2.2 Fuel Thrust Chamber Valve
- 1.1.2.3 Pressure Sequencing Valve
- 1.1.2.4 Overboard Drain Check Valve

1.1.3 Turbopump Assembly

- 1.1.3.1 Oxidizer Pump
- 1.1.3.2 Fuel Pump
- 1.1.3.3 Gear Box
- 1.1.3.4 Lube Oil Pump
- 1.1.3.5 Lube Oil Heat Exchanger
- 1.1.3.6 Turbine
- 1.1.3.7 Exhaust Stack

1.1.4 Gas Generator Assembly

- 1.1.4.1 Gas Generator
- 1.1.4.2 Oxidizer Check Valve
- 1.1.4.3 Fuel Check Valve
- 1.1.4.4 Oxidizer Cavitating Venturi
- 1.1.4.5 Fuel Cavitating Venturi
- 1.1.4.6 Oxidizer Line Filter
- 1.1.4.7 Fuel Line Filter

1.1.5 Engine Start Assembly

- 1.1.5.1 Start Cartridge
- 1.1.5.2 Initiator

1.1.6 Thrust Vector Control Assembly

- 1.1.6.1 Gimbal Block
- 1.1.6.2 Gimbal Actuator (2)
- 1.1.6.3 Hydraulic Pump
- 1.1.6.4 Auxiliary Pump

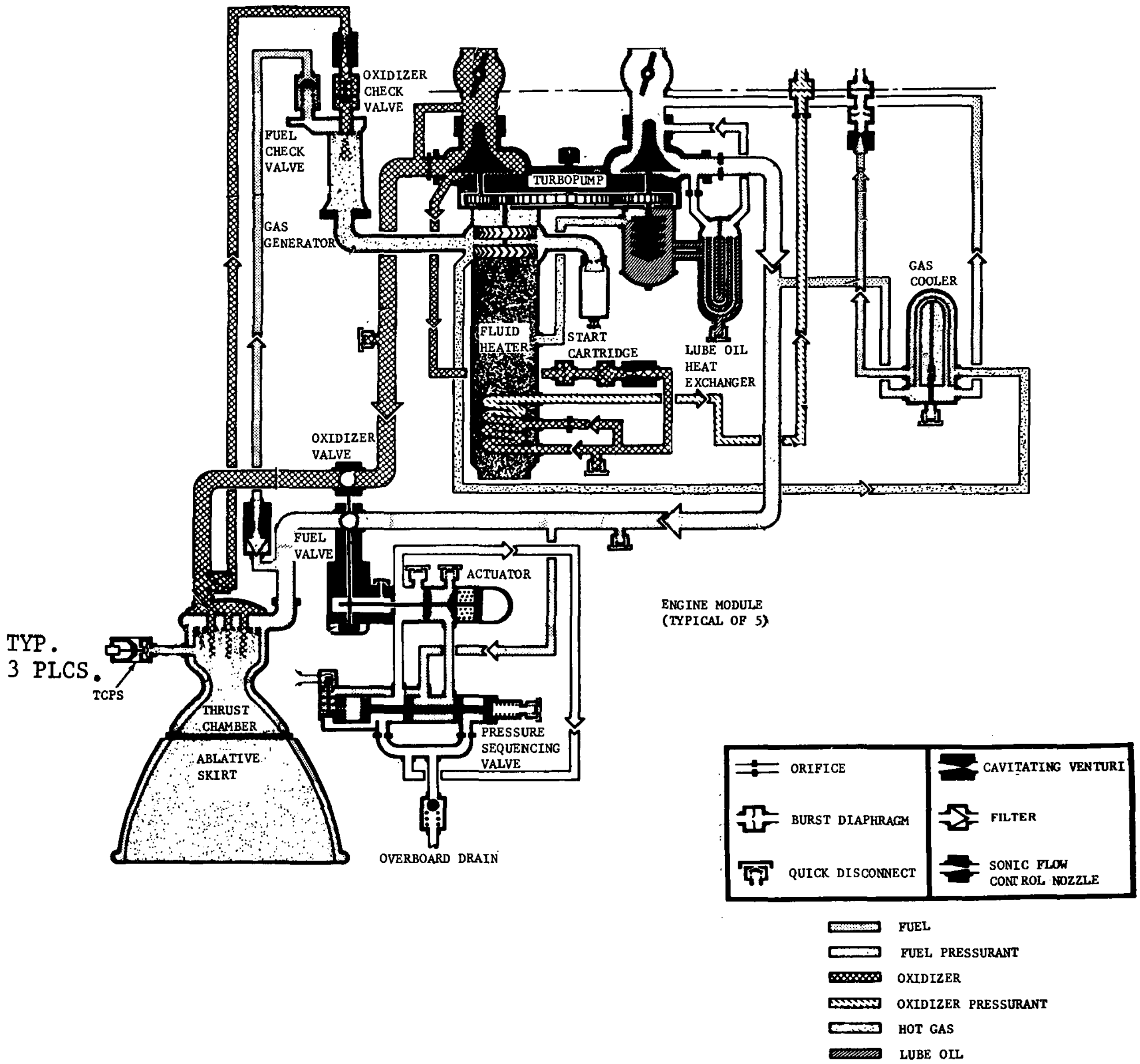

Figure IV-5 Main Engine Schematic

1.2 MAIN PROPELLANT MANAGEMENT SUBSYSTEM

The main propellant management subsystem provides feed, distribution and storage of the propellants. The propellant tanks are mounted in tandem with the oxidizer tank in front. The fuel tank has 5 internal conduits to duct the oxidizer to the rocket engines. Both tanks have an access cover in the forward dome. The between-tank structure and the skirts have welded frames to which the aerodynamic surface is riveted. Access doors are provided in the forward and aft sections and in the between-tank structure, and four longerons on the aft skirt allow for SRM attachment. All of the skin and much of the airframe stiffening structure is aluminum, and the skin is tapered and milled where possible to save weight. The oxidizer tank is 16 feet in diameter and has a 9000 ft^3 volume. Five 7 inch diameter feedlines are used to deliver oxidizer to the engines. The fuel tank is also 16 feet in diameter with 7600 ft^3 volume. Five six inch diameter feedlines are used to deliver fuel to the engines. Appropriate tank baffles and contoured outlets are provided for each tank. Figure IV-6 presents the configuration of the propellant management subsystem.

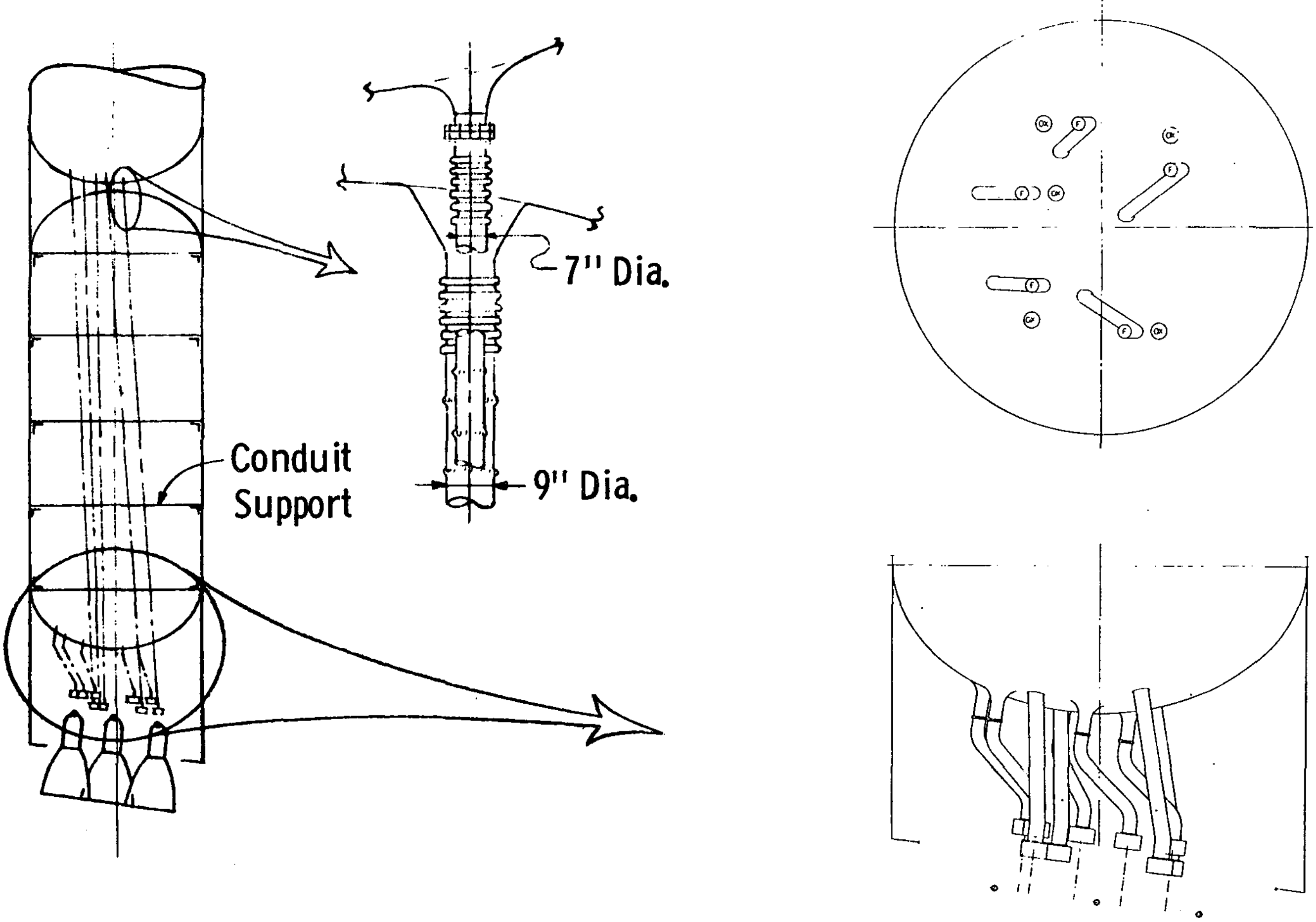

Figure IV-6 Main Propellant Management Subsystem

The Main Propellant Management Subsystem is composed of the following assemblies and components:

MAIN PROPELLANT MANAGEMENT SUBSYSTEM

1.2.1 Oxidizer Tank Assembly

- 1.2.1.1 Oxidizer Tank
- 1.2.1.2 Oxidizer Pogo Suppressor
- 1.2.1.3 Oxidizer Prevalve

1.2.2 Fuel Tank Assembly

- 1.2.2.1 Fuel Tank
- 1.2.2.2 Fuel Pogo Suppressor
- 1.2.2.3 Fuel Prevalve

1.3 MAIN PRESSURIZATION SUBSYSTEM

The main pressurization subsystem provides the necessary inlet pressure to the engine pumps for proper pump operation. The propellant tanks are pre-pressurized with nitrogen prior to engine start through the two inch tank vents. During engine operation, pressurizing gas is supplied to the tanks by the engine autogenous (self-generating) system at a controlled rate to make up for the removal of propellant from the tanks. The fuel tank is pressurized by diverting a portion of the engine gas generator output from the turbine inlet manifold to the tank. This gas must be cooled to be safely used, and cooling is accomplsihed by passing it through a heat exchanger with fuel. The fuel flows from this discharge line through the gas cooler back to the suction side of the pump. A sonic nozzle in the autogenous gas line near the engine to vehicle interface maintains a flow rate that is insensitive to tank pressure, and a 300 psid burst diaphragm prevents gas flow to the tank until gas generator operation begins.

The oxidizer tank is pressurized by heating oxidizer to the gaseous state and ducting it to the tank. Oxidizer is piped from the pump discharge flange to a heat exchanger (fluid heater) located in the turbine exhaust stack. A cavitating venturi, located at the fluid-heater inlet, maintains a constant flow rate insensitive to downstream pressure, and a burst diaphragm prevents oxidizer autogenous flow until the discharge pressure reaches approximately 300 psia. A loop in the inlet line traps air to ensure pneumatic operation of the burst diaphragm. An orificed bypass line on the fluid heater provides temperature control of the tank pressurant without affecting engine balance in the same manner as the bypass orifice in the fuel autogenous gas cooler. A back pressure orifice, located at the engine to vehicle interface, provides sufficient residence time of the oxidizer in the fluid heater to achieve the proper gas temperature of the pressurant.

The Main Pressurization Subsystem is shown schematically in Figure IV-7. The assembly and component identification follows Figure IV-7.

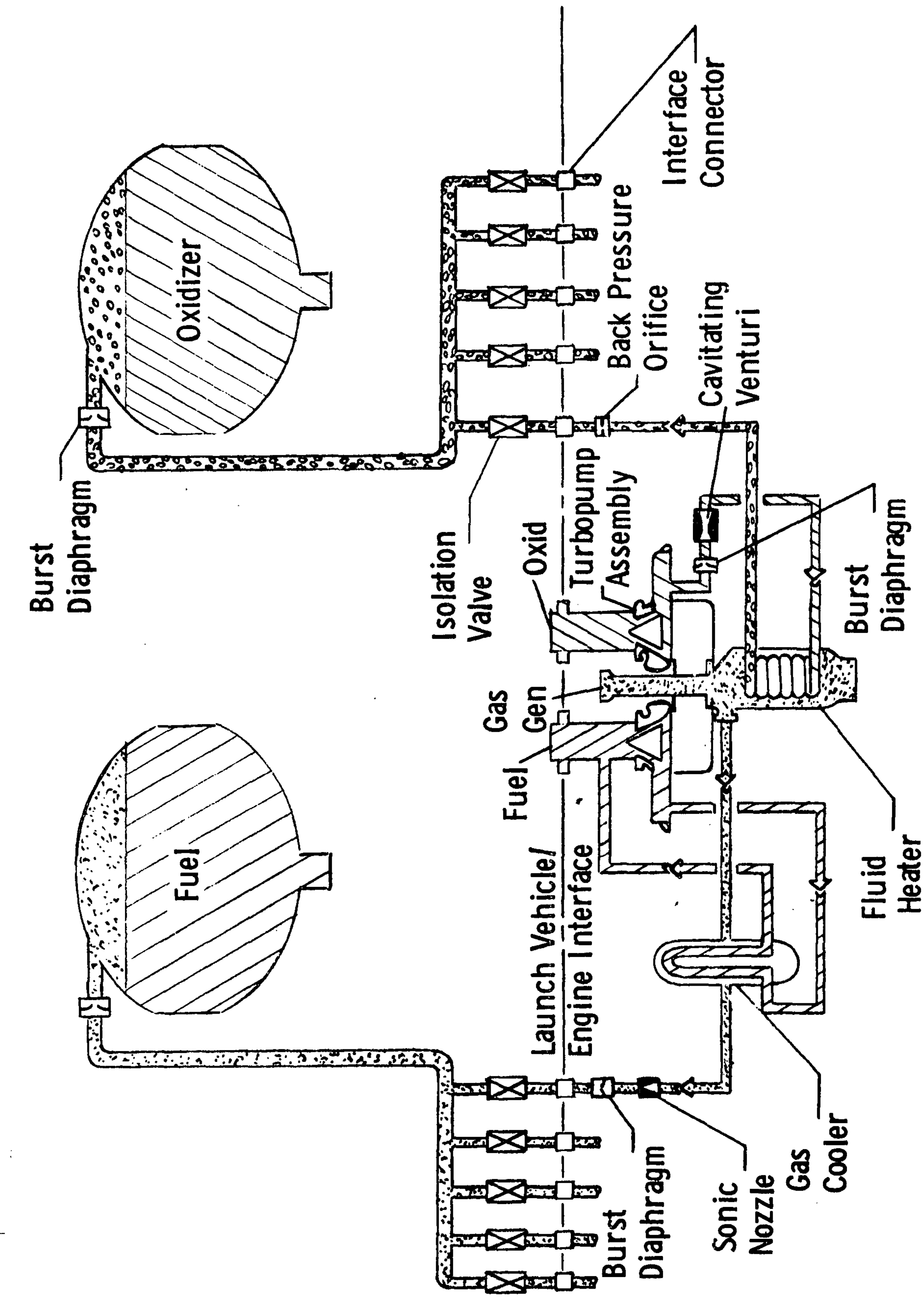

Figure IV-7 Main Pressurization Subsystem

MAIN PRESSURIZATION SUBSYSTEM

1.3.1 Oxidizer Pressurization Assembly

- 1.3.1.1 Fluid Heater
- 1.3.1.2 Cavitating Venturi
- 1.3.1.3 Back Pressure Orifice
- 1.3.1.4 Burst Diaphragm (autogenous)
- 1.3.1.5 Check Valve
- 1.3.1.6 Oxidizer Pressurization and Vent Valve
- 1.3.1.7 Oxidizer Tank Diaphragm

1.3.2 Fuel Pressurization Assembly

- 1.3.2.1 Gas Cooler
- 1.3.2.2 Sonic Nozzle
- 1.3.2.3 Burst Diaphragm (autogenous)
- 1.3.2.4 Check Valve
- 1.3.2.5 Fuel Pressurization and Vent Valve
- 1.3.2.6 Fuel Tank Diaphragm

2.0 SOLID ROCKET MOTOR SYSTEM

The solid rocket motor system consists of four solid rocket motors (SRM) and thrust vector control (TVC) subsystems. Each SRM consists of a forward closure, an aft closure, and identical, interchangeable segments. Other components include a single 6° canted nozzle, and fore and aft solid propellant staging rockets. The TVC injectant, nitrogen tetroxide, is carried in a tank mounted on the side of the motor and is pressure-fed into the nozzle exit section by nitrogen gas. Figure IV-8 illustrates components and assemblies of the Solid Rocket Motor System.

2.1 ROCKET MOTOR SUBSYSTEM

The selected motor is composed of seven segments designated as model 1207. Thrust termination capability, developed on the original T-IIIC SRM, is provided for Model 1207 through the use of ports, located at the forward end of the motor, which may be ejected on command to permit thrust termination in case mission abort becomes necessary.

The motor case (segments and closures) is constructed of D6aC steel, heat-treated to an ultimate strength of 195,000 psi. Each joint is a pin and clevis type held together by 240 cylindrical pins. During assembly of the motor, the pins are inserted by hand (rather than force fitted) and held in place thereafter by a retaining strap. A gas pressure seal between segments (and closures) is provided by an o-ring.

Each segment contains approximately 72,400 lb of polybutadiene acrylic acid acrylonitrile (PBAN) composite propellant which uses powdered aluminum fuel and ammonium perchlorate oxidizer. The plastic matrix, PBAN, also serves as a fuel. The case-bonded propellant grain has a circular port which tapers 10 inches throughout the 10-foot length of the segment. The forward end has the smaller port. The purpose of this taper is to provide the 10-second controlled tail-off at the end of web-action time. The forward end of the segment is inhibited from burning by a rubber restrictor bonded to the propellant surface. Silica-filled, butadiene acrylonitrile rubber insulation protects the motor case from combustion gas during motor operation. The insulation is thickest in the segment joint areas where there is no unburned propellant to protect the case walls.

The closures contain the same type of propellant as the segments, and the forward closure has mounting provisions for the gas generator type igniter. Instead of the cylindrical grain shape of the segment,

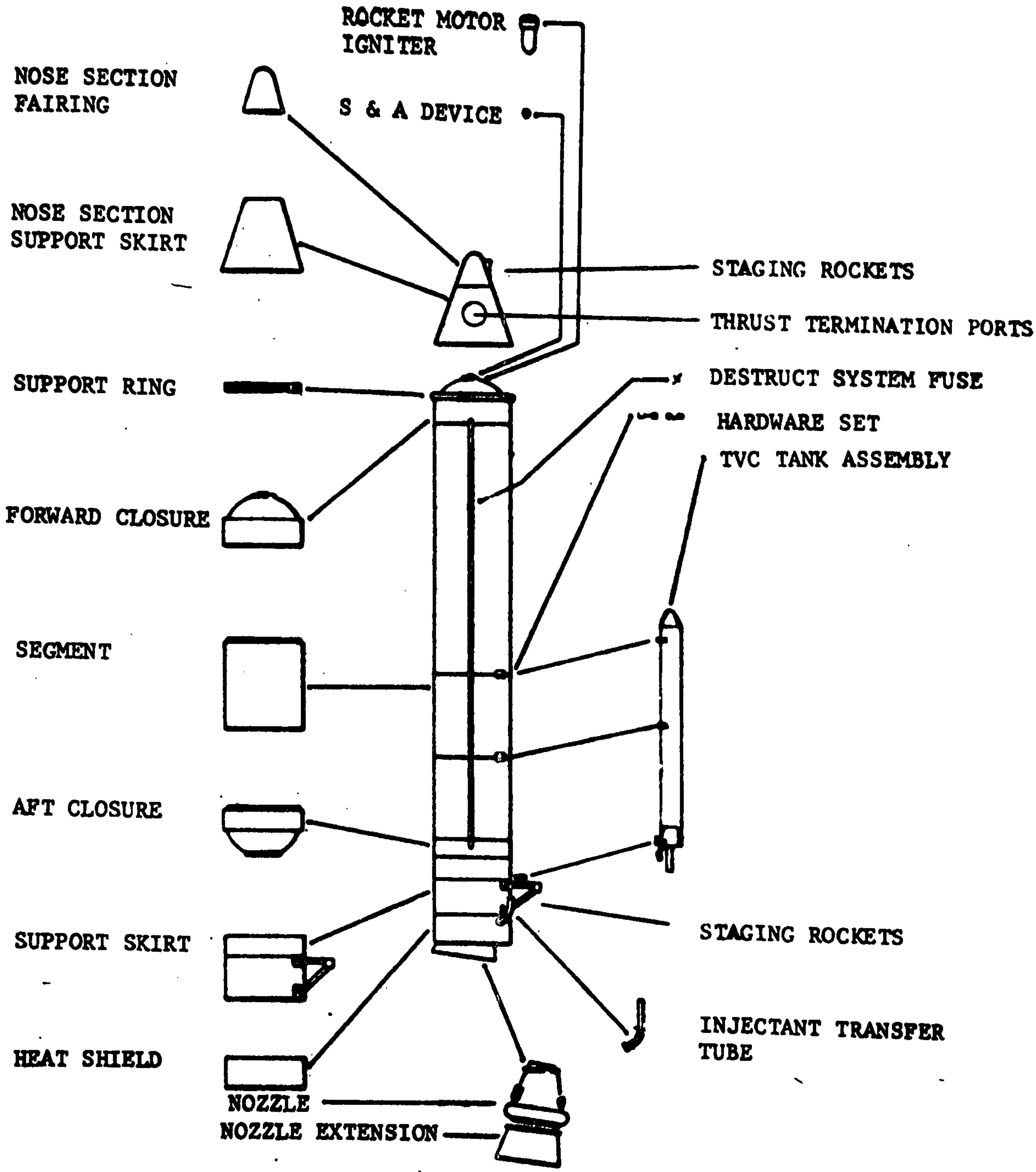

Figure IV-8 Solid Rocket Motor System

the forward closure has an 8-point star internal burning grain configuration. The forward closure of Model 1207 is 135 inches long and contains 61,000 lb of propellant. The aft closure contains approximately 20,300 lb of propellant in a straight cylindrical bore configuration and projects 64 inches from the segment joint to a 57-inch I.D. boss for nozzle attachment.

The propellant burns along the entire central port of the SRM and also on the aft end of each segment between segments. The closures also burn on their ends. Three inches of clearance are left between the grains of adjacent segments to permit this burning. The igniter burns for approximately 1 second to fill the grain bore with hot gas to ignite the motor. The SRM has a regressive thrust-time curve produced in part by the star configuration of the propellant grain in the forward closure of the motor. During the early phases of burning, this portion contributes much of the gas flow necessary to produce the high initial peak in the thrust-time curve.

The SRM nozzle consists of a throat section and a two-piece exit cone assembly. High-density graphite rings backed by a steel support shell and silica insulation are bonded in a steel housing to make up the nozzle throat section. The nozzle middle section consists of graphite and silica phenolic liners bonded to a steel outer shell. This section contains the thrust vector control injection ports. The exit section is an extension of the silica phenolic liner of the middle section except that its structural shell is aluminum honeycomb sandwiched between steel for lighter weight. The three sections are bolted together forming an assembly approximately 14.5 feet long. Nozzle expansion ratio is 9.18:1, and the half-angle is 17°. The SRM assemblies and components are listed below. Figure IV-9 depicts the subsystem.

ROCKET MOTOR SUBSYSTEM

2.1.1 SRM Assembly

- 2.1.1.1 Forward Closure
- 2.1.1.2 Segment (7)
- 2.1.1.3 Aft Closure
- 2.1.1.4 Nozzle
- 2.1.1.5 Rocket Motor Igniter
- 2.1.1.6 Thrust Terminating Device
- 2.1.1.7 Destruct Device

2.1.2 Staging Rocket Assembly

- 2.1.2.1 Staging Rocket Motor (18)
- 2.1.2.2 Staging Rocket Motor Housing

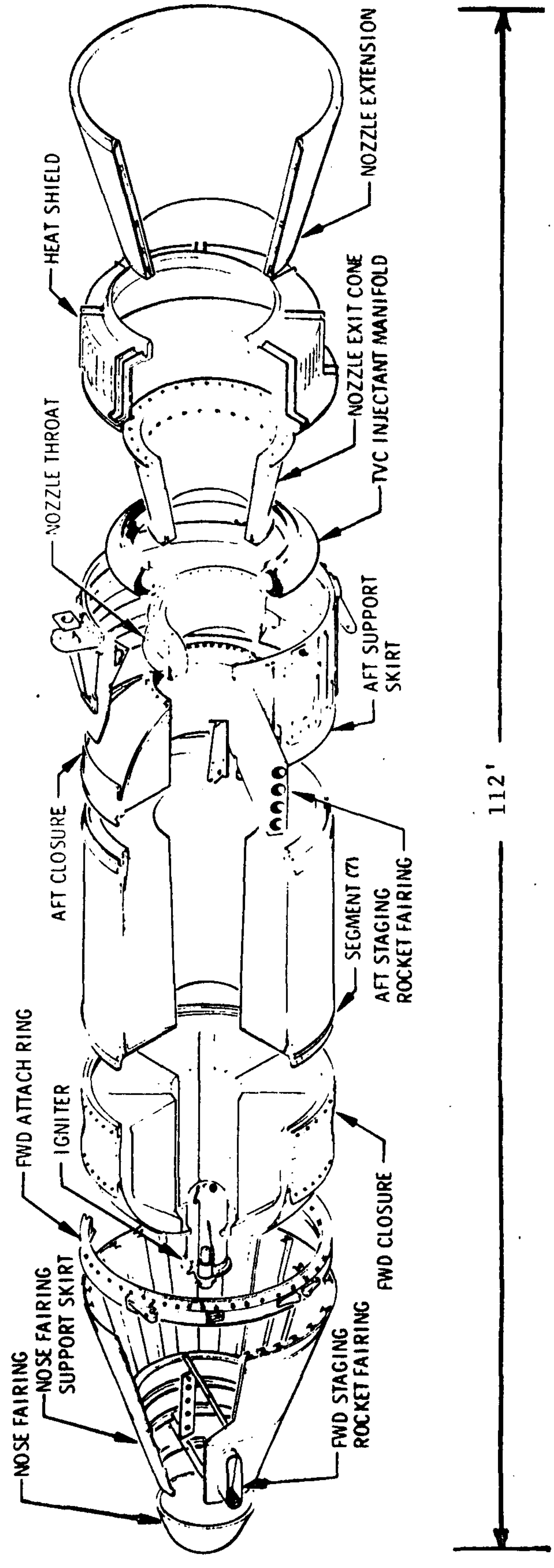

Figure IV-9 Rocket Motor Subsystem

2.2 THRUST VECTOR CONTROL SUBSYSTEM

Thrust vector control for the UA 1207 SRM is achieved through fluid injection in the nozzle exit cone. The 3.5 ft. diameter injectant tank, which is mounted on the inboard side of the SRM near the core, contains 12,000 lb of nitrogen tetroxide and is charged with nitrogen gas to a pressure of 1,100 psi. The pressure of the ullage blowdown system decays to about 500 psi during the flight duty cycle.

Nitrogen tetroxide fluid passes through an injectant transfer tube and a toroidal injectant manifold to the 24 electromechanical injectant valves. These valves are located in groups of six in the four quadrants of the nozzle exit cone and actuated electrically in response to commands from the core guidance system. The TVC subsystem can provide the required side forces with only five of the six valves operable in any quadrant.

The TVC subsystem is sized to provide vehicle steering through burning and tail-off of the SRM. The subsystem will provide a jet deflection of 0 to 4 degrees. The subsystem is designed to dump excess nitrogen tetroxide during booster operation to minimize burn-out weight, and is capable of a slew rate of 10 degrees per second at all times during SRM operation.

During countdown, pressurized fluid from the tank fills the entire TVC system through the injectant valves to aluminum cylinders and caps (pyroseals) that protrude into the nozzle exit cone. The combination of the ullage blowdown and the pyroseals permits holds of up to 30 days without recycling or refurbishing any injection hardware. The pyroseals and caps extend a short distance into the nozzle and are burned off at ignition by the exhaust flame, thus activating the TVC system. Provision is also made for bleeding the TVC system should it be necessary to depressurize or empty the TVC tank. The subsystem configuration is shown in Figure IV-10. The TVC assemblies and components are as follows:

<u>THRUST VECTOR CONTROL SUBSYSTEM</u>

2.2.1 TVC Tank Assembly

- 2.2.1.1 Injectant Tank
- 2.2.1.2 Nitrogen Pressurization Valve
- 2.2.1.3 Injectant Fill and Drain Valve
- 2.2.1.4 Injectant Transfer Tube

2.2.2 Injectant Valve Housing Assembly

- 2.2.2.1 Injectant Valve (24)
- 2.2.2.2 Pyroseal (24)

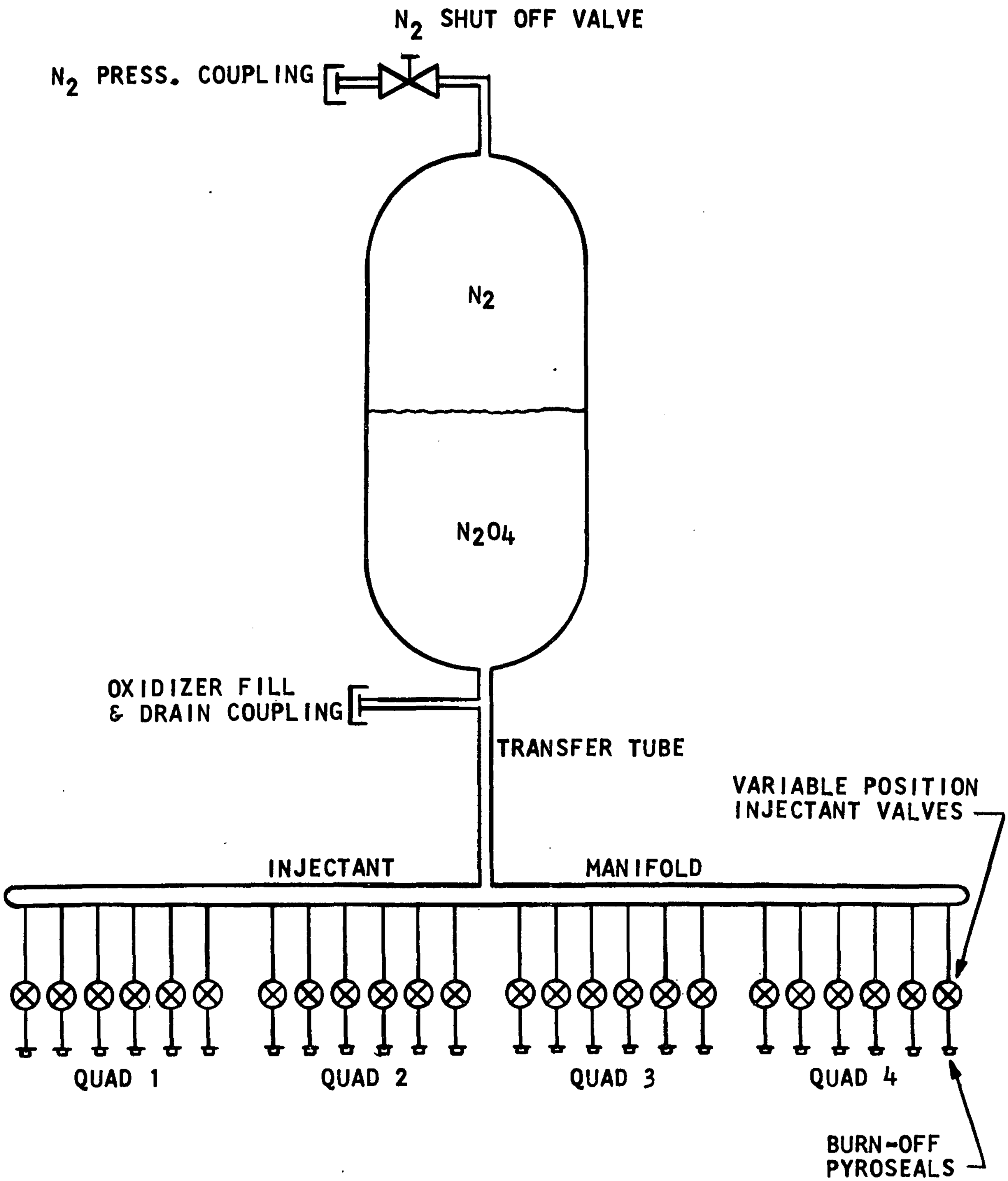

Figure IV-10 Thrust Vector Control Subsystem

OPERATIONS

Figure IV-11 depicts the operational timeline for the Titan III-L and the drop tank orbiter. The booster vehicle checkout and assembly is similar to the operation presently performed on the Titan III-B vehicle. A checkout matrix is shown in Table IV-2 and the vehicle assembly flow is shown in Figure IV-12. A new fuel loading system is supplied to load the booster stage with liquid propellants. The loading system is functionally the same as that used for the Titan III-D, except that removable sight glasses are used for load verification. The main propulsion tanks are loaded with 800,600 lb. oxidizer and 419,000 lb. fuel. The TVC tank is loaded with 12,000 lb. of nitrogen tetroxide. At T-60 hours, the main propellant management subsystem is pre-pressurized to 28 psia and the TVC subsystem is pressurized to a flight pressure of 1,100 psia. At T-2 hours, after arming and ready status verification, the final countdown is initiated.

At T-35 seconds, an automatic sequence signal is supplied to the launch vehicle. This signal accomplishes the following: (1) the storage valves are opened permitting fuel and oxidizer to fill the engine, and (2) the engine starting electrical circuits are readied for receipt of the firing signal.

Opening of the prevalves places the engine in the fill and bleed condition. Both fuel and oxidizer fill the engine above the thrust chamber valves due to the static pressure of the propellants in the tanks above the engine. Air entrapped in the oxidizer lines travels through 3/8 inch flex lines, connected on each subassembly from the discharge line near the pump outlet flange (high point) to the suction line, up into the oxidizer tank. Air removal from the fuel lines is accomplished as fuel hydraulic pressure actuates the thrust chamber valves at engine start.

The fuel-operated valve actuation system consists of a rod and piston mechanically linked to the thrust chamber valves (TCV's), held closed by springs and opened by fuel pressure. A pressure sequencing valve (PSV), also held closed by a spring and opened by fuel pressure, acts as a pilot valve to the TCV actuator. Fuel bleed is accomplished by allowing fuel to flow through a 1/2 inch flex line from the high point on the discharge line at the TCV and discharge line connecting flanges to the PSV inlet port. While in the bleed position, the PSV diverts the fuel into and through the closing side of the TCV actuator, through a 1/4 inch stainless steel vent line to an overboard manifold mounted on the PSV, and out an overboard drain line through a check valve which serves only to protect the PSV from contamination. A bleed orifice, located in the drain line and PSV manifold connection, controls the bleed rate to approximately 1200 cc per minute per engine. As

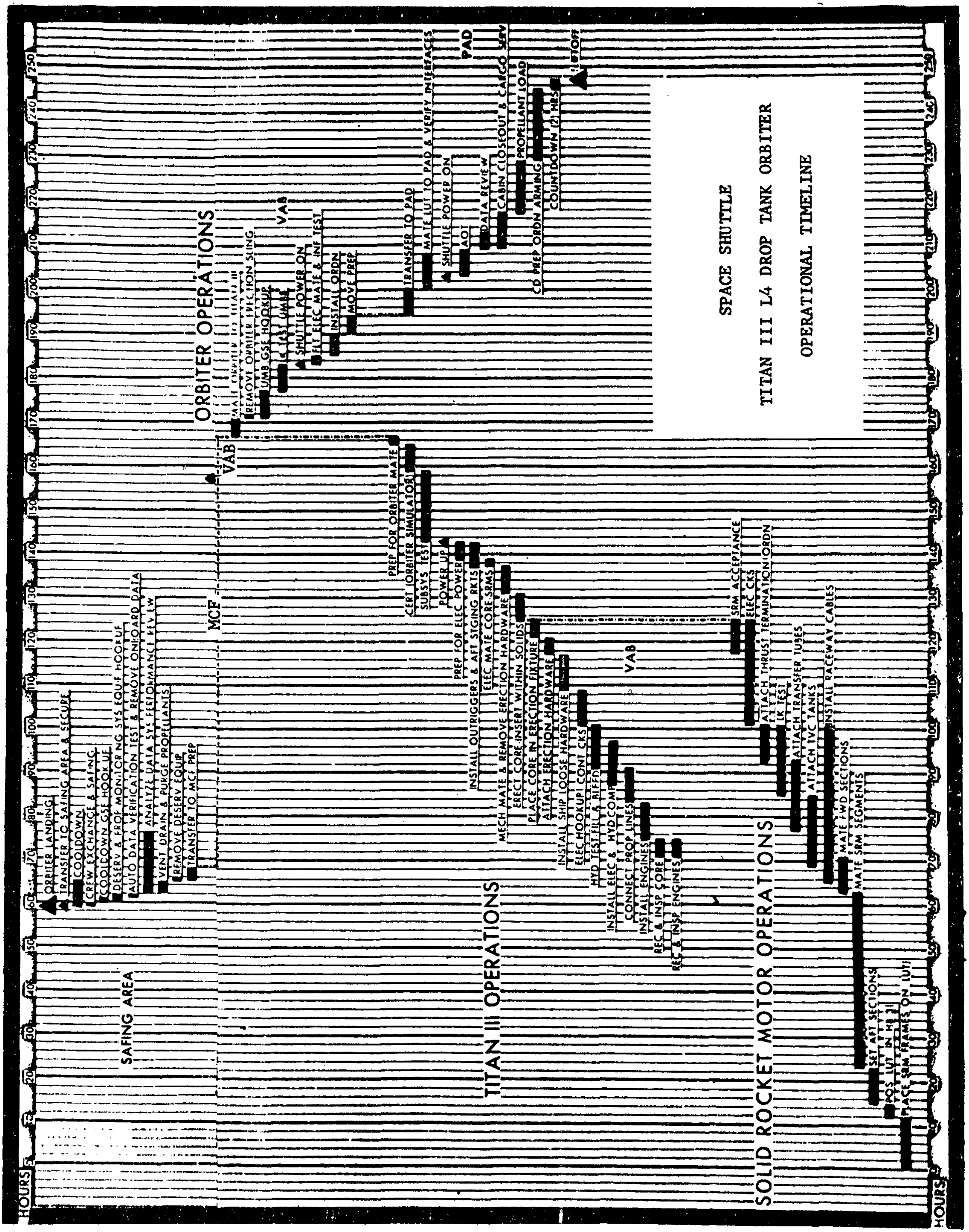
SPACE SHUTTLE
TITAN III L4 DROP TANK ORBITER
OPERATIONAL TIMELINE
ORBITER OPERATIONS
TITAN III OPERATIONS
SOLID ROCKET MOTOR OPERATIONS
SAFING AREA
MCF
VAB
PAD
HOURS
ORBITER LANDING
TRANSFER TO SAFING AREA & SECURE
COOLDOWN
CREW EXCHANGE & SAFING
TRANSFER TO MCF PREP
PREP FOR ORBITER MATE
TRANSFER TO PAD
MATE LUT TO PAD & VERIFY INTERFACES
SHUTTLE POWER ON
DATA REVIEW
CABIN CLOSEOUT & CARGO SERV
PROPELLANT LOAD
CD PREP ORDN ARMING
COUNTDOWN (2) HRS
SRM ACCEPTANCE
INSTALL RACEWAY CABLES
MATE FWD SECTIONS
MATE SRM SEGMENTS
SET AFT SECTIONS
PLACE SRM FRAMES ON LUT

Figure IV-11

TABLE IV-2

BOOSTER PROPULSION CHECKOUT

Test Nomenclature	Supplier Facility	Prep Area	Launch Pad
1. Booster Main Propulsion System			
Instrumentation Check	X	X	X
Electrical Harness Check	X	X	
TCPS Check	X	X	
TPA Torque Check	X	X	
Thrust Chamber Valve Functional	X	X	
PSVOR Position Verification	X	X	
Torque Verification Test	X	X	
Engine Leak Checks	X	X	
Ordnance Test	X	X	
Propellant Tank Hydrostat	X		
Propellant Tank Leak Check	X	X	X
Prevalve Switch Test	X		
Propellant Tank Calibration	X		
Prevalve Borescope Inspection	X	X	
Accumulator Compliance Test	X		
2. Solid Rocket Motor System			
Instrumentation Check	X	X	
Alignment Checks	X	X	
TVC Subsystem Leak Check	X	X	
Injectant Valve Functional	X	X	
Ordnance Test	X	X	
Composite System Test	X	X	
SRM Leak Check		X	
3. Combined Propulsion System			
Flight Instrumentation Check		X	X
Ordnance Check		X	X
Combined System Leak Check		X	
Combined System Test		X	X

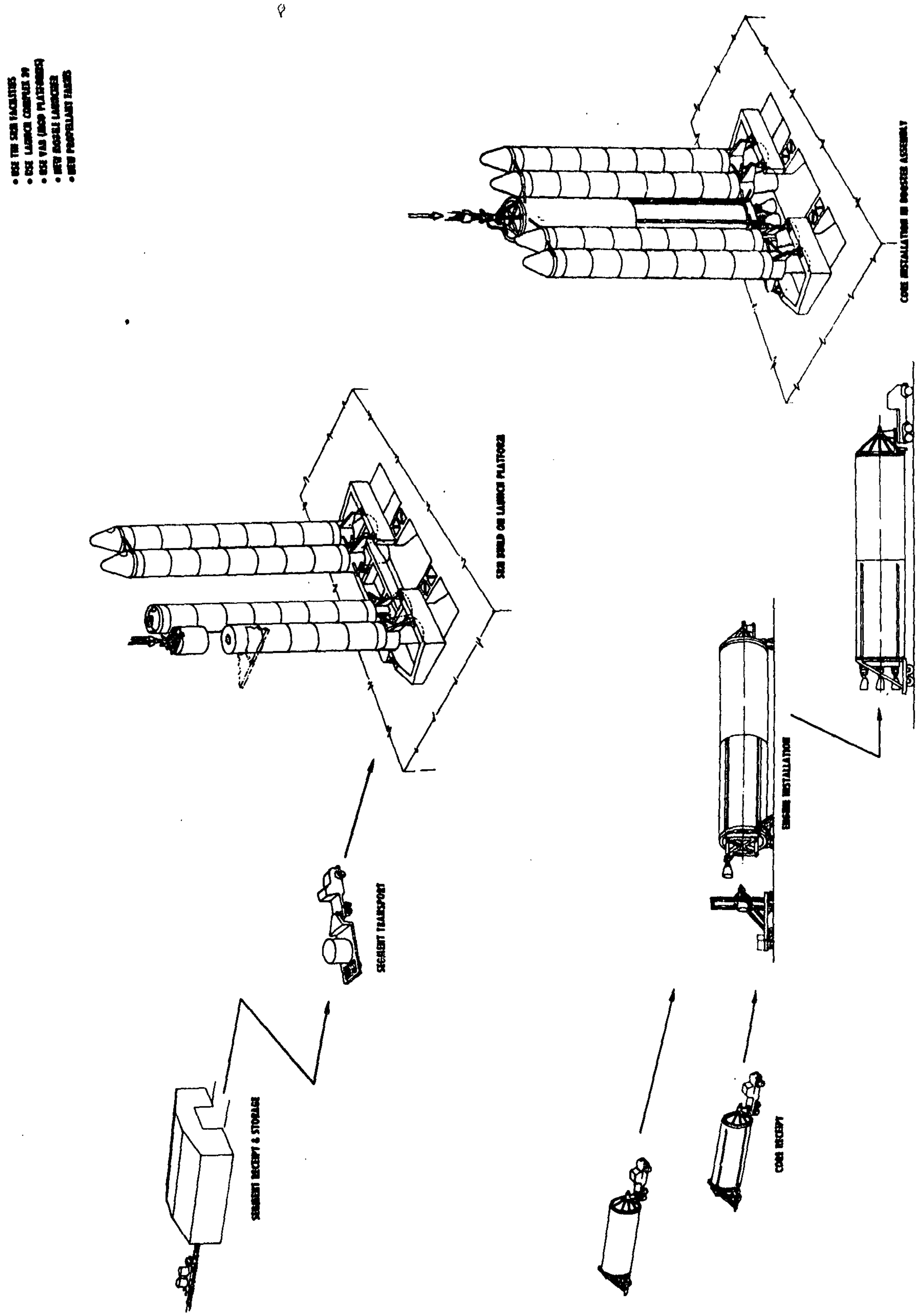

Figure IV-12 Vehicle Assembly Flow

long as the engine remains in the fill and bleed condition, fuel is bled overboard in the manner and at the rate described.

After completing the bleed cycle, the start signal applies 28 vdc to the initiator charges of a solid propellant start cartridge mounted on the turbine inlet manifold of each engine. Two diametrically opposite engines are started sequentially at 0.1 second intervals. The center engine is started at 0.1 second after start command to the last pair. The start cartridge solid propellant ignites and supplies gas to the turbines causing them to accelerate. The turbine shaft of each engine is connected through a gear train to the fuel and oxidizer pump so that pump operation also begins. Since the thrust chamber valves are closed, no propellant flows, and pump acceleration produces only an increasing pressure in the discharge lines and valve actuation system.

When fuel discharge pressure reaches approximately 300 psia, the pressure on the opening end of the PSV spool produces a force which exceeds the spring force on the PSV spool closing end causing the spool to shuttle from the bleed position to the operation position. This occurs approximately 0.25 seconds from FS-1. Relocation of the PSV spool to the operation position halts flow of fuel to the closing side of the TCV actuator, terminating fuel bleed, and allows fuel to enter the actuator opening side. The fuel pressure, increasing beyond the 300 psia PSV actuation pressure, is immediately sufficient to operate the TCV actuator initiating opening of the thrust chamber fuel valves. The fuel and oxidizer valves are mechanically linked so that both move simultaneously. The rate of motion of the TCV actuator piston is controlled by an orifice located in the overboard drain manifold to PSV housing connection nearest the PSV opening end. This opening orifice controls the rate at which bleed fuel can be expelled from the TCV actuator. Valve opening begins approximately 0.3 second after start cartridge initiation. At approximately 1.1 seconds after FS-1 the valves are fully opened.

Propellants begin to flow to the thrust chamber at the time the valves begin to open. Oxidizer flows directly into the injector dome, filling the oxidizer injector manifold, through orifices into the combustion chamber. Fuel is used to regeneratively cool the combustion chamber and must fill a toroidal manifold and flow through stainless steel cooling tubes that make up the chamber walls before reaching the injector fuel orifices and entering the combustion zone. The larger volume the fuel must fill before reaching the injector orifices results in an oxidizer lead into the combustion zone. This slight oxidizer lead (0.25 to 0.30 sec) provides a characteristically smooth start. Initial pressurization of the chamber during oxidizer lead ejects the skirt exit closures.

Opening the thrust chamber valves causes a momentary decrease in discharge pressures as the volume between the TCV's and injector orifices is being filled with propellant. At approximately 0.8 second after FS-1 this filling is completed and hypergolic ignition of the fuel and oxidizer takes place in the combustion chamber. At this point in time pressure in the discharge lines again increases, and fuel and oxidizer are forced through flex lines attached from the main propellant discharge lines, downstream of the TCV's, to the gas generator. Check valves located at the gas generator end of these bootstrap lines prevent the flow of start cartridge gas into the discharge lines. The gas generator ignites at approximately 0.9 second after FS-1 and supplies gas to drive the turbines. At approximately 1.1 seconds after FS-1, the start cartridge burns out, and the engine has reached its operating level, i.e., it has "bootstrapped".

The outputs of the three thrust chamber pressure switches (TCPS's) of each liquid engine are majority voted to provide an engine operation status signal. The TCPS's are calibrated to switch when engine chamber pressure has attained 77% of nominal operating pressure. The receipt of nominal chamber pressure indications from all five liquid engines is a condition to initiate the solid rocket motor ignition sequence. The SRM ignition command fires redundant squibs located in the Safe and Arm device of each SRM. A pyro train provides the required energy to ignite the main propellant grain, providing a nominal thrust build up in 250 msec. The grain is designed to produce an initial thrust of 1.5 million pounds which regresses to approximately 1.1 million pounds in 115 seconds, followed by a 15 second tail-off.

The nozzle operating temperature is more than sufficient to burn off the aluminum "pyro-seal" closures at the outlet of each TVC injectant valve, thereby activating the thrust vector control subsystem. Side forces of up to 100,000 pounds are provided to each SRM by the thrust vector control subsystem on command signals from the core. Pressurized N_2O_4 is injected into the nozzle exit cone through six electromechanical valves in each quadrant which deflect the exhaust gases through the formation of an oblique shock wave in the SRM nozzle.

Shortly after end of web action time, sensed deceleration initiates the SRM staging timer. At a preprogrammed time interval, the forward attach explosive nuts, the aft explosive attach bolts, and the staging rockets are activated. The SRMs are staged simultaneously in pairs such that the resultant direction is down and away from the core vehicle.

At T+130 seconds a core-orbiter overlap burn is initiated by starting two of the three orbiter main engines. Depletion of either or both of the core propellants commands LRE shutdown and orbiter staging at approximately T+277 seconds.

Exhaustion of either or both core propellants is determined by the liquid engine TCPS's which are monitored during an appropriate time interval (TCPS enable). The core engine shutdown sequence is initiated when the first of the five TCPS signals indicates that engine chamber pressure has decreased to 77% or less of nominal operating pressure. As in the engine start sequence, each of the five TCPS signals is a resultant of the indications of three majority voted pressure switches.

At T+282 seconds, the third orbiter main engine is started. The orbiter attains orbit inject velocity at approximately T+444 seconds. The sequence of major events from propellant loading to orbit inject is presented in Table IV-3. The ascent trajectory profile is shown in Figure IV-13.

TABLE IV-3

SEQUENCE OF EVENTS

TIME	EVENT
T-72 Hrs	Complete propellant loading.
T-60 Hrs	Pressurize tankage.
T-12 Hrs	Ordnance arming.
T-8 Hrs	Final pressurization adjust.
T-195 Min	Start final countdown
T-35 Sec	Automatic sequence start. (terminal count)
T-34 Sec	Initiate prevalve opening.
T-3.0 Sec	Start LRE ignition sequence.
T-0.25 Sec	Initiate SRM ignition.
T-0	Liftoff.
T+5.6 Sec	Vehicle clear of pad structure.
T+126 Sec	SRM burnout and staging.
T+130 Sec	Start two orbiter main engines.
T+277 Sec	Booster LRE shutdown and booster staging.
T+282 Sec	Start Orbiter No. 3 engine.
T+444 Sec	Orbit inject.

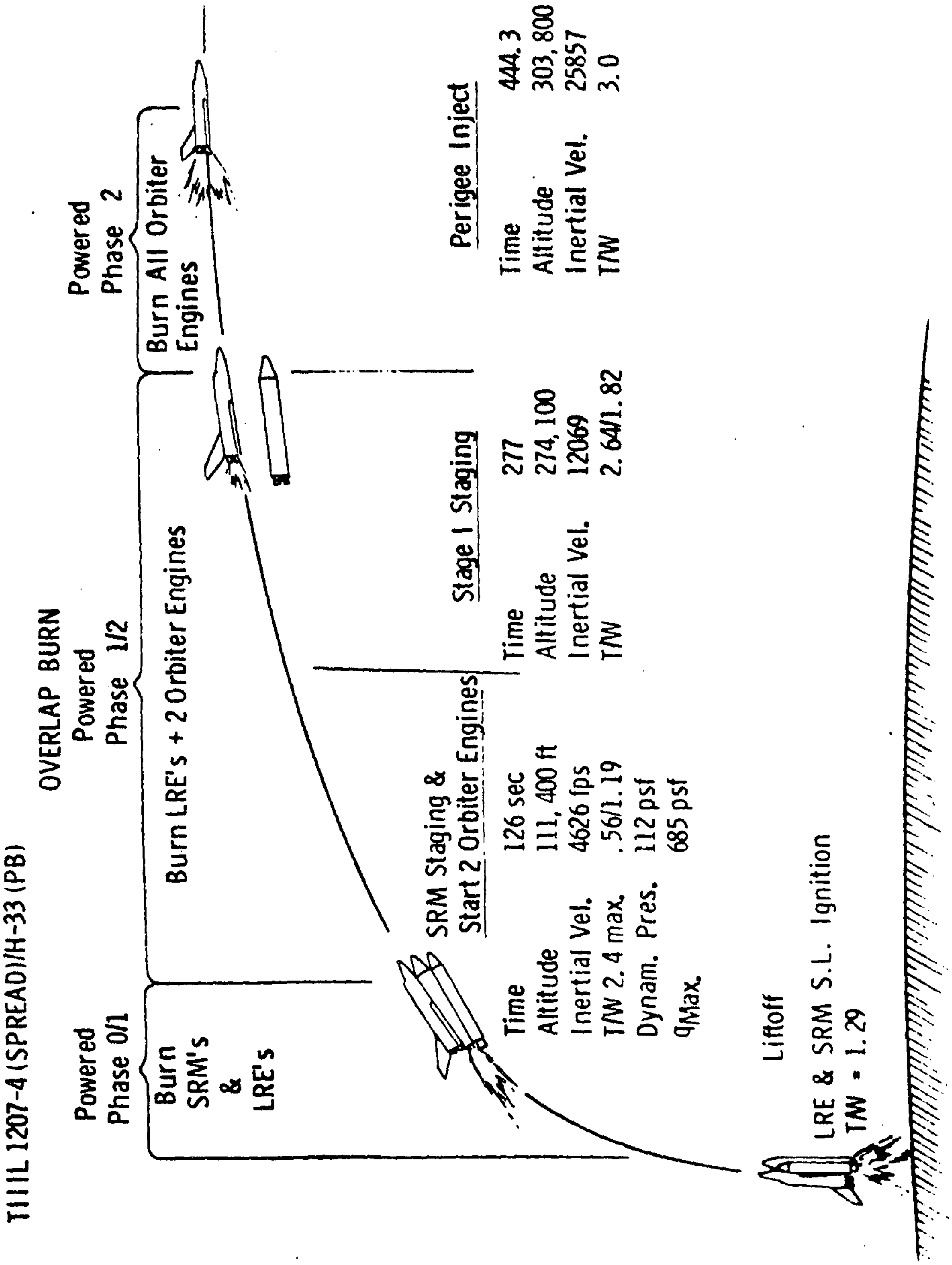

Figure IV-13 Ascent Trajectory Sequencing Profile

SECTION IV-C Propulsion System Analyses

TITAN III L Operational Flow

TEST Equipment List

Control Sequence and Logic Summary

Launch Support Equipment Operation

FMEA Ground Rules

Safety

A T-III L operational flow diagram is presented as Figure IV-14. The flow diagram depicts major operations and time increments associated with the core, liquid rocket engines and the solid rocket motors from the manufacturing facility through launch operations. The test equipment list has been formulated for each applicable time period and is presented in summary form in Figure IV-15.

A control sequence and logic summary is presented in Figure IV-16. The sequence and logic summary deals primarily with the terminal count (T-35 sec.) and the operational phase of the booster. A discussion of the countdown operation and the electrical launch support equipment follows the diagram. Figure IV-17 shows the relative location of the electrical launch support equipment.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

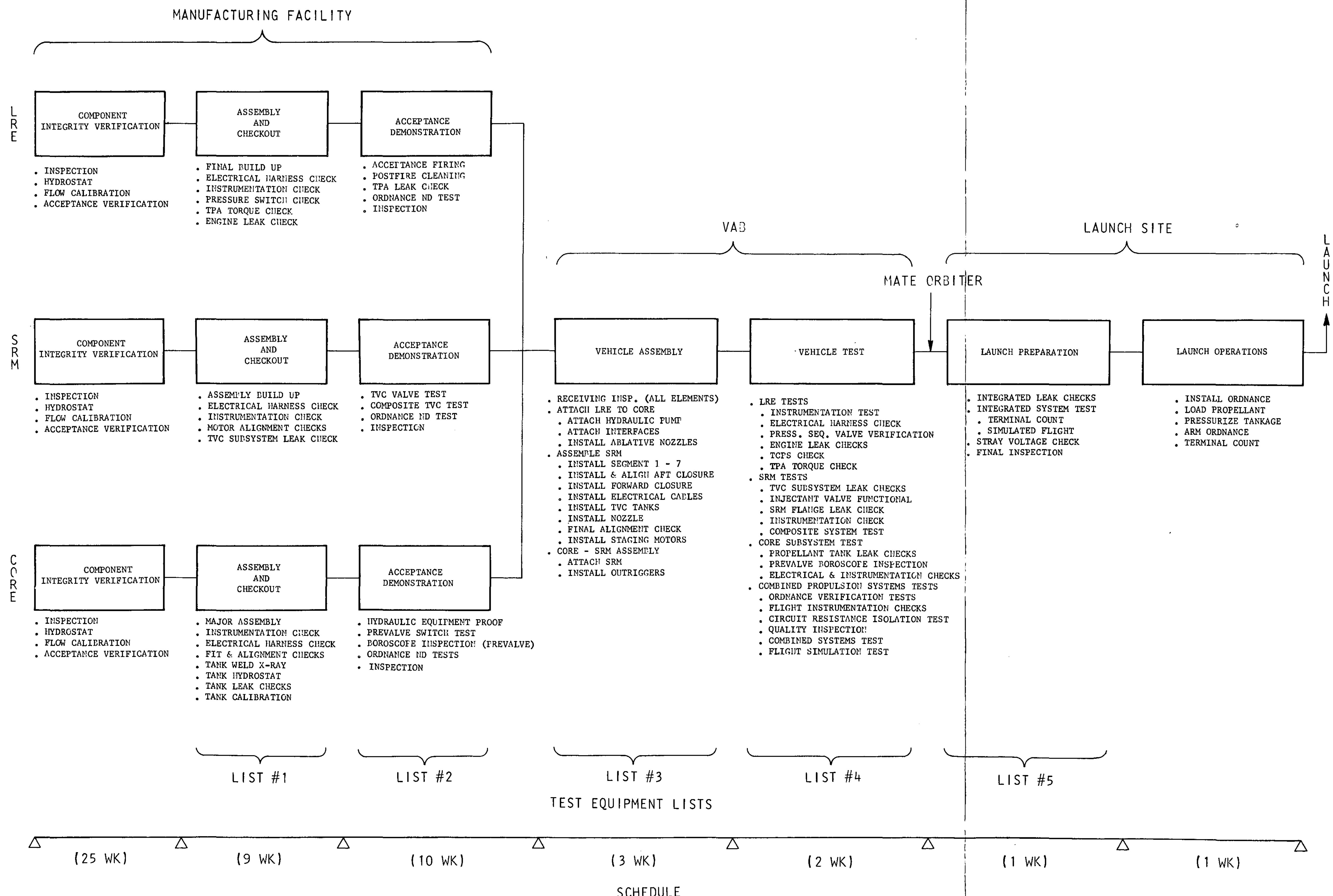

Figure IV-14 TITAN IIIL OPERATIONAL FLOW DIAGRAM

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TEST EQUIPMENT	USE	EQUIPMENT LIST
LRE		
1. Rocket Engine Test Set	1. The Rocket Engine Test Set is used to accomplish the following: A. Leak Tests a. Propellant Systems b. Turbopump Seals c. Hot Gas Systems B. Functional Tests a. Thrust Chamber Pressure Switches (TCPS) b. Thrust Chamber Valves (TCV) C. Electrical Continuity Tests a. Start Cartridge Squib Wiring b. TCV Pressure Sequencing Valve (PSV) Override Solenoids c. Thrust Chamber Pressure Switches D. Electrical Resistance Tests a. Start Cartridge Squibs Circuit Wires to Engine Frame Ground b. TCPS to Engine Frame Ground c. TCVPSV Solenoid to Engine Frame Ground	1, 2, 4
2. Instrumentation Test Set	2. The test set is used to test temperature transmitters, pressure transmitters, thermocouples, frequency-to-dc converters, thrust chamber valve potentiometers, and position indicators. The test set performs two insulation resistance checks, continuity/resistance check, zero stimulus check, 50% or 75% stimulus checks and a frequency check.	1, 4
3. Ordnance Test Set	3. This portable test set is comprised of ordnance test equipment and an adapter cable, and is used to checkout ordnance devices, ordnance wiring and to check for stray voltages prior to installation of live devices.	2, 4, 5

Figure IV-15 Propulsion Test Equipment List

TEST EQUIPMENT	USE	EQUIPMENT LIST
4. Turbopump Pressure Leak Test Kit	4. Verify integrity of turbopump seals.	2
SRM		
1. Electromechanical Valve Test Set	1. Verify TVC EMVs are functioning properly, and do not leak.	1
2. TVC Test Kit	2. Verify TVC EMVs are functioning after being installed in the manifold, and/or to the SRM.	2, 4
3. Critical Circuit Verification Test Set	3. Verify the integrity of SRM electrical circuits.	1, 4, 5
4. TVC System Pressure Leak Test Kit	4. Establish the integrity of all components and connections in the TVC system.	4, 5
5. SRM Pressure Leak Test Kit	5. Check for leaks at segment, head end, and aft end closure flanges of the assembled SRM.	4
6. Instrumentation Test Set	6. Check operation and calibration of SRM instrumentation	1, 4
7. Ordnance Test Set	7. Nondestructive testing of SRM ordnance and ordnance circuits.	2, 4
CORE		
1. Electrical Wiring Test Kit	1. Verify continuity and resistance of all wiring.	1, 4, 5
2. Prevalve Test Kit, Including Boroscope	2. Verify prevalve functions open/close, verify position before prop. loading, and check for foreign material on top of prevalve.	2, 4

Figure IV-15 Propulsion Test Equipment List (Continued)

TEST EQUIPMENT	USE	EQUIPMENT LIST
3. Hydraulic Control Unit	3. This item of portable ground equipment is used to perform fill, flush and bleed operations on the core hydraulic system. The HCU provides the means for stroking the core actuators, for commanding the VPDC to operate the core electrically driven hydraulic pumps, and for monitoring hydraulic pressure, hydraulic system reservoir level, and hydraulic accumulator precharge pressure.	4, 5
COMBINED SYSTEMS TEST EQUIPMENT		
1. Electrical Test Set	1. Verify the integrity of all SRM to core and core to engine interfaces and the complete booster electrical system.	4, 5
2. Ordnance Test Set	2. This portable test set is composed of ordnance test equipment and an adapter cable, and is used to checkout ordnance devices, ordnance wiring, and to check for stray voltages prior to installation of live devices.	4, 5
3. Instrumentation Test Set	3. Used to test temperature and pressure transmitters, thermocouples, frequency converters, thrust chamber valve potentiometers and position indicators. The test set also checks insulation resistance, and continuity/resistance. It can also be used to step calibrate.	4, 5

Figure IV-15 Propulsion Test Equipment List (Continued)

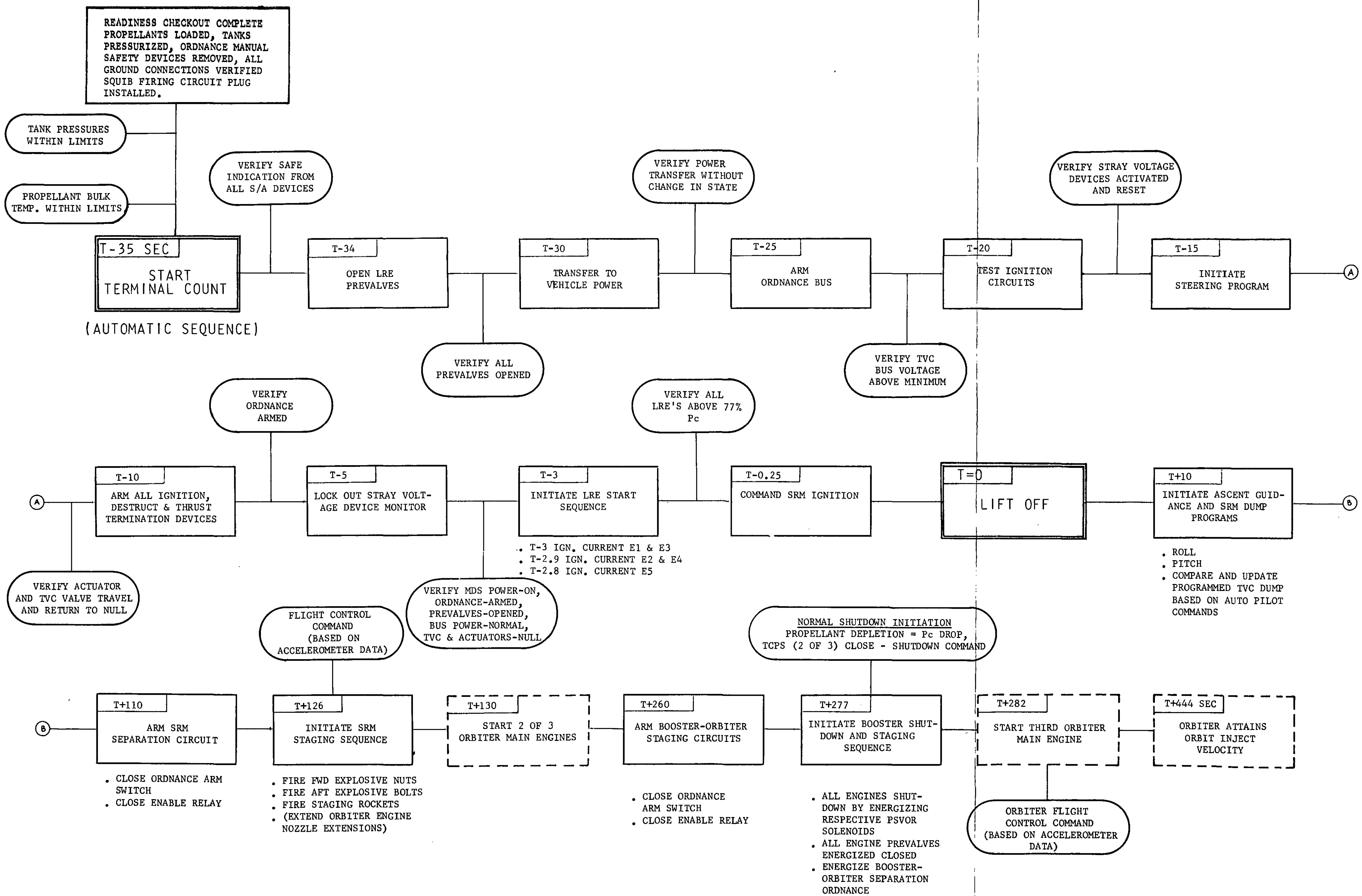


Figure IV-16 T-111 L CONTROL SEQUENCE AND LOGIC SUMMARY

An overview of the countdown operations and the electrical launch support and checkout equipment is presented here to show the relationship of that equipment to the propulsion systems during launch operations. The launch control system is divided between the Launch Umbilical Tower (LUT) equipment room and the Firing Control Room at the VAB. The launch sequence consists of an R-Count which starts at approximately T-28 hours and a T-Count which starts at T-195 minutes and terminates at T-0. The vehicle is brought to a state of readiness during the R-Count via manual checks and operations under the direction of the pad test conductor. During the R-Count, the propellant tanks are loaded and pressurized under the control of the Propellant Transfer and Pressurization Control Set (PTPCS), and the ordnance is installed. The propellant tank vents are removed near the beginning of the T-Count, T-195 minutes. During the T-Count, at approximately T-45 minutes, the final flight controls check is conducted utilizing the vehicle checkout set (VECOS). This equipment verifies the proper operation of the flight controls system and the propulsion system gimbal actuators and thrust vector control valves by applying discrete input commands and monitoring for the proper response. The VECOS automatically controls the test by means of a tape programmer. The T-Count is semi-automatic consisting of a number of manual functions under clock control until T-35 seconds at which time the sequence is completely automatic.

The Control Monitor Group (CMG) controls the time and event based countdown for the T-III L booster, see Figure IV-4. The CMG is under direct control of the Launch Control Console (LCC) via the Data Transmission System (DTS). The CMG receives command signals from the LCC for commencing, resetting, holding, and resuming the countdown. The CMG sends signals to the LCC indicating that signals have been received and certain actions have been taken, and to identify holds. The CMG has the capability to issue control functions, monitor launch functions, provide hold, kill and shutdown capability during the launch sequence, reset the system, patch input and output signals, provide simulation signals during combined systems test, and drive the countdown readout indicators at the pad and in the Firing Control Room.

During the T-Count, power is applied to the SRM squib firing circuits when the pad safety officer installs red arming plugs in the Van Power Distribution Control (VPDC) rack.

The Data Recording Set (DRS) is initialized during the T-Count. The DRS records the time and change of state of discrete signals and events during the launch sequence. It receives timing information from the CMG. The DRS is used for troubleshooting and fault isolation of countdown sequence malfunctions. A remote DRS is provided in the Firing Control Room.

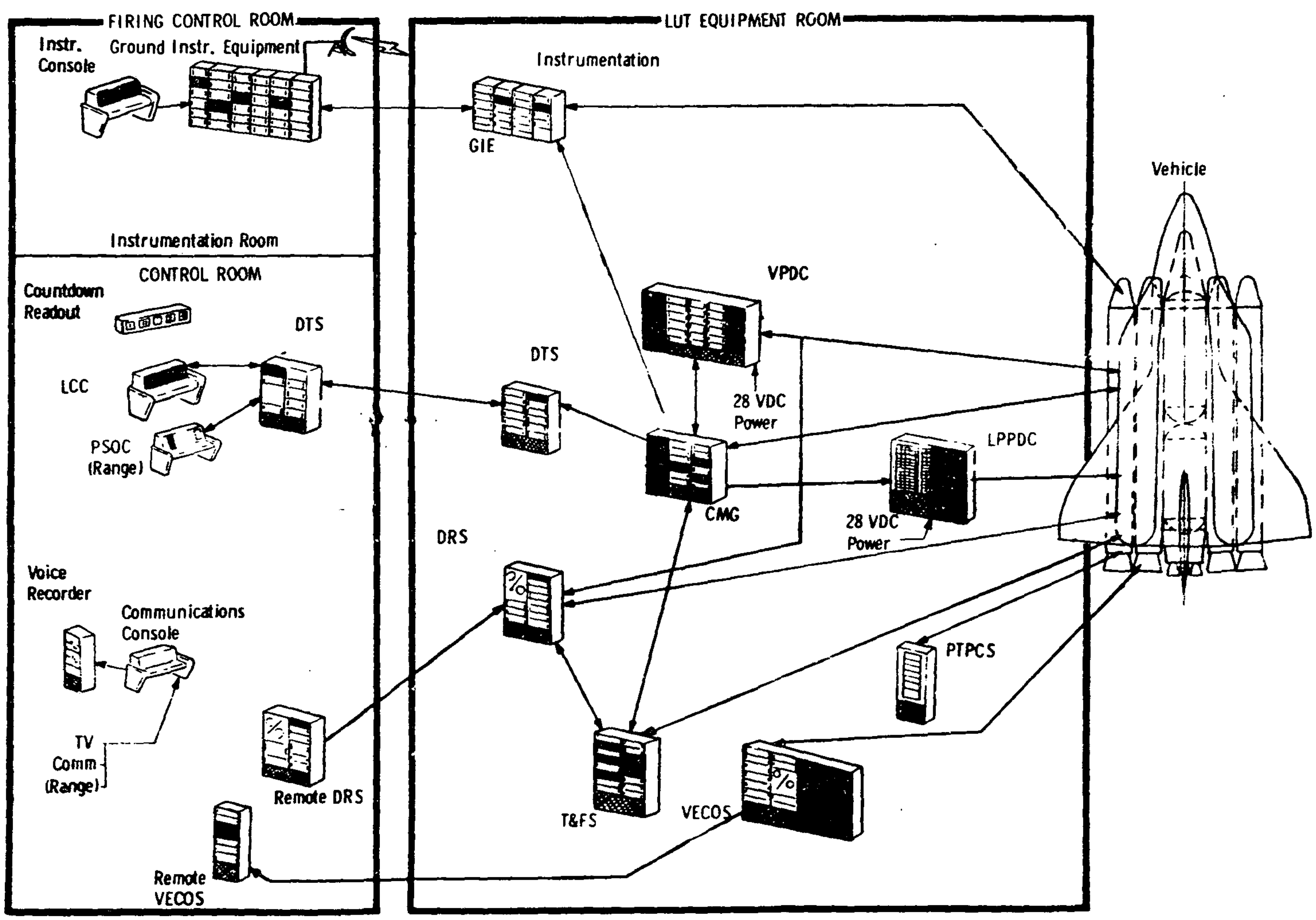


Figure IV-17 **Electrical Ground Support Equipment**

At approximately T-2 minutes in the count, all instrumentation recorders are started. Data from these recorders is subsequently used for postflight data evaluation of the booster telemetry and landline instrumentation measurements. The recorders are part of the Ground Instrumentation Equipment (GIE) which is located in the Instrumentation Room adjacent to the Firing Control Room in the VIB. In addition to recorders, the instrumentation in the VIB consists of a Control Console, receiving antenna, receivers, decoding equipment and patching capability. The GIE in the instrumentation room interfaces with GIE located in the LUT. The GIE in the LUT consists of signal conditioners, patching and encoding for landline measurements, and voltage controlled oscillators to modulate signals for transmission to the instrumentation room.

At T-35 seconds, the automatic terminal count is initiated. From this point through ignition of the SRMs, sequencing of events is controlled by the CMG which issues the required commands at preprogrammed times and assesses feedback signals to be considered as prerequisites for subsequent commands.

At approximately T-20 seconds the CMG commands that the SRM ignition circuits be tested. This command causes a test current of low amperage to be sent through the ignition circuits to verify proper installation of the live ordnance device. Stray voltage detectors (SVDs) in the SRM igniters trip as a result of the test and light SVD monitor lights on the flight safety rack. The SVD monitors are then reset via the CMG.

At approximately T-15 seconds the CMG initiates the countdown steering test which is the final prelaunch test of the Guidance and Control Equipment. The CMG verifies that the LRE actuators and TVC valves move off null during this test.

At approximately T-10 seconds the CMG commands and verifies the arming of all ordnance.

At T-3 seconds the CMG initiates the Liquid Rocket Engine (LRE) start sequence. The closure of all thrust chamber pressure switches (TCPS) on the LREs provides the CMG with the indication that LRE chamber pressure is sufficient to permit ignition of the SRMs at approximately T-0.25 seconds.

FMEA GROUND RULES

1. The FMEA shall be conducted for the operational mode only.

2. The FMEA shall be conducted on all components identified in the Titan III L propulsion system definition. (Structural members which perform no function other than providing structural integrity are excluded.)

3. Electrical cables, wiring harnesses and instrumentation shall be excluded from the FMEA, except where such equipment (such as sensors) is required for control functions within the propulsion subsystem.

4. It is assumed that the proper electrical signal is always transmitted from the control source to the propulsion component requiring such a signal.

5. Human errors are not to be considered in the failure modes and effects analysis.

6. Failure modes and effects of active and passive thermal protection devices shall be excluded.

7. Leakages considered in this analysis shall be to the degree most probable; taking into account the leak path, sealing method, pressure and medium involved in the area under consideration. Leakage requiring a structural failure of the component shall not be analyzed.

8. Redundant components shall be identified.

9. The following criticality categories shall be utilized for potential effect of component failures:

Category	Potential Effect of Failure
1	Loss of life or vehicle
2	Loss of mission
3	All others

a) Launch delays shall be classified as criticality 3.

b) The transition point from launch delay, criticality 3 above, to loss of mission, criticality 2, is considered to occur at the ignition of the solid rocket motors.

c) For this analysis, the loss of one engine shall be considered as loss of mission (criticality 2) since the mission requirements and vehicle capability with one engine out are not fully defined at this time.

CHECKOUT AND MONITORING SAFETY REQUIREMENTS

Evaluations of safety requirements having a direct impact on the OCMF have been primarily directed toward ordnance devices. It has been determined that the existing devices, their handling, checkout, and monitoring are in accord with the T III L requirements.

The ordnance installation and checkout is accomplished during the 28 hours prior to lift off. During this time period and up to 195 minutes before launch the vehicle is under the manual control of the test conductor. The test conductor oversees the installation of ordnance. These operations are accomplished by following approved operating and safety procedures.

The handling of ordnance devices is controlled by procedures which meet accepted safety regulations. The ordnance devices are transported to and around the launch vehicle with an ordnance carrying case which provides shock proof storage for those devices.

Prior to all ordnance installations a Standard Ordnance Circuit Verification Unit (SOCVU) is used during simulation tests to verify all ordnance circuits. During installation, an Ordnance Item Test Set (OITS) is used by the installer to verify that the circuits are safe for ordnance connection.

One of the major tasks of the ordnance system is to start the Solid Rocket Motors. This task is accomplish by the SRM igniter assembly which is composed of three major components(Figure IV-20): The safe and arm device, initiator and the main igniter charge. The main igniter charge provides sufficient hot gases to ignite the SRM propellant. The initiator provides the necessary ignition step between the safe and arm device and the larger igniter. The safe and arm device is the control and firing unit for the initiator/ignitor assembly. The safe and arm device is mounted in the igniter top boss and contains dual ignition squibs. The squibs are fired by a 28 VDC charge and ignite at 4.5 amps. The 28 volt charge to the squibs originates at the Transient Power Supply (TPS) bus in the core and is switched to the squibs via a Squib Firing Circuit (SFC) in the core vehicle.

The safe and arm device used in the SRM ignition train is of particular interest. The major components of this device are shown in Figures IV-18 and IV-19. Figure IV-21 is an electrical schematic of the unit and the connecting circuitry. This device incorporates the following safety features: A housing which interferes with easy access of the squibs wheather the device is in the safe or arm position (Figure IV-19). This housing also prevents the output from the squibs to reach the SRM igniter unless the squibs are directed at this window only when the device is in the arm position (Figure IV-18); if the squibs inadvertently fire while in the safe position, the

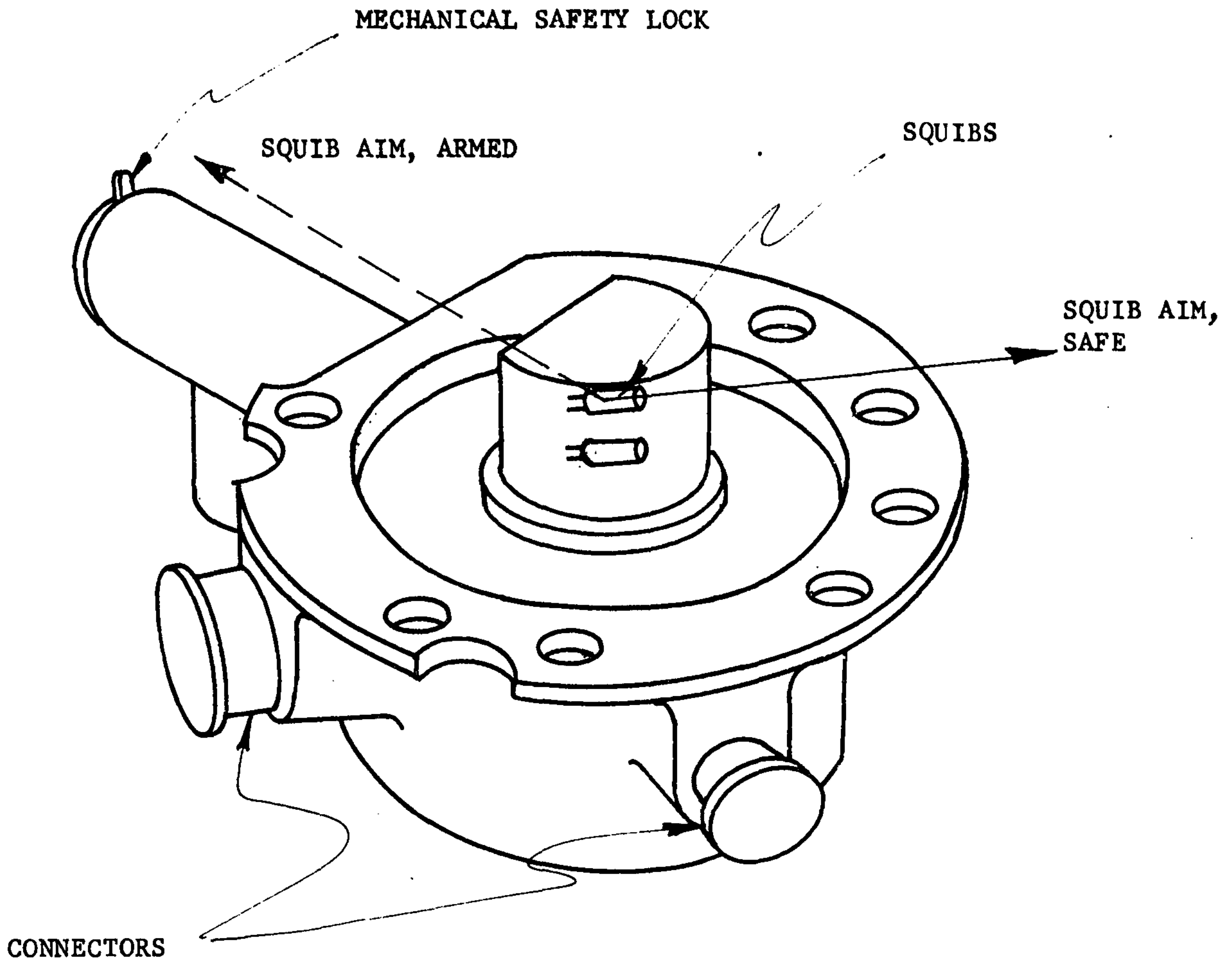


FIGURE IV-18 SAFE AND ARM DEVICE SQUIB LOCATION AND AIM

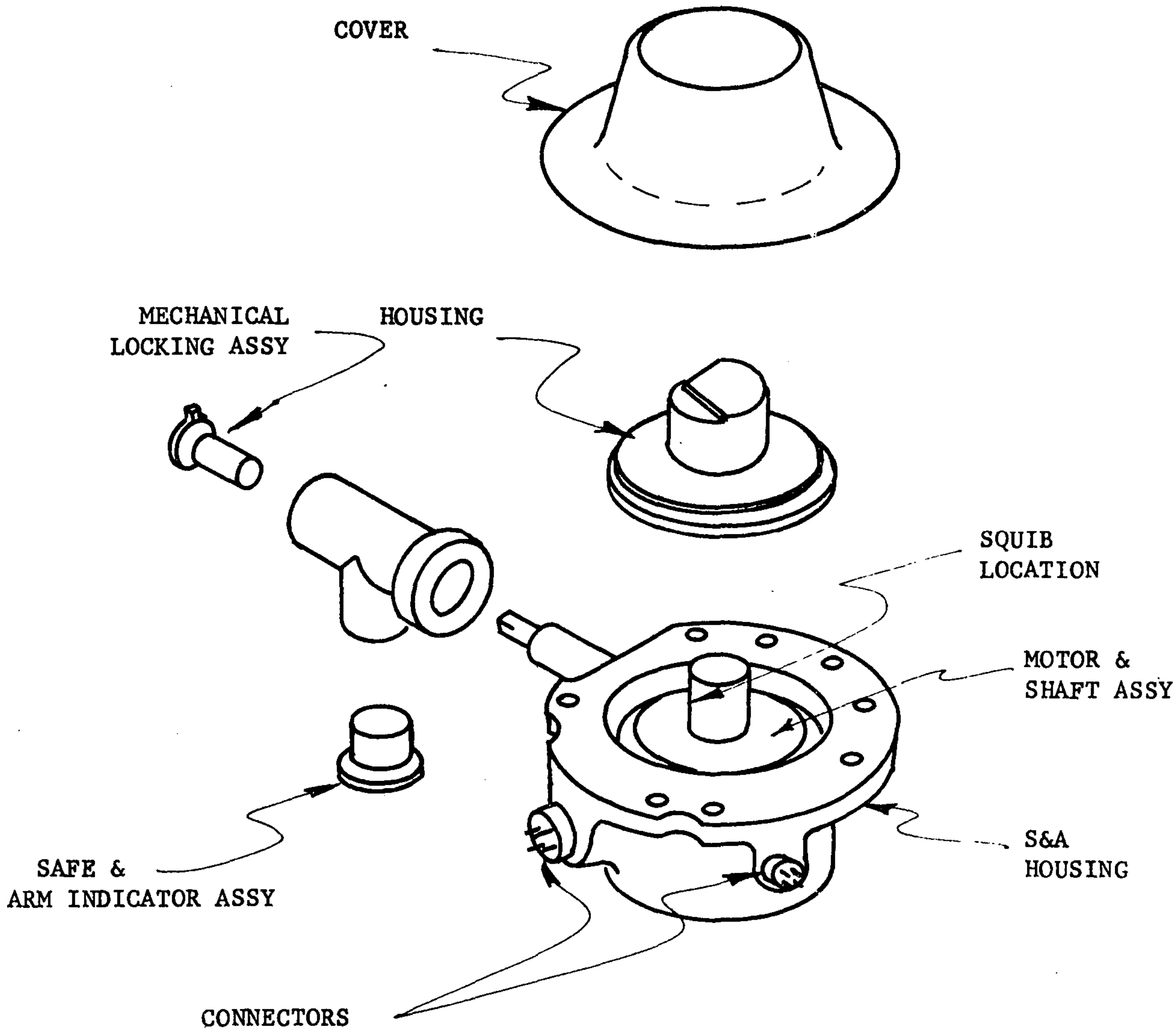


FIGURE IV-19 DISMANTLED SAFE AND ARM DEVICE

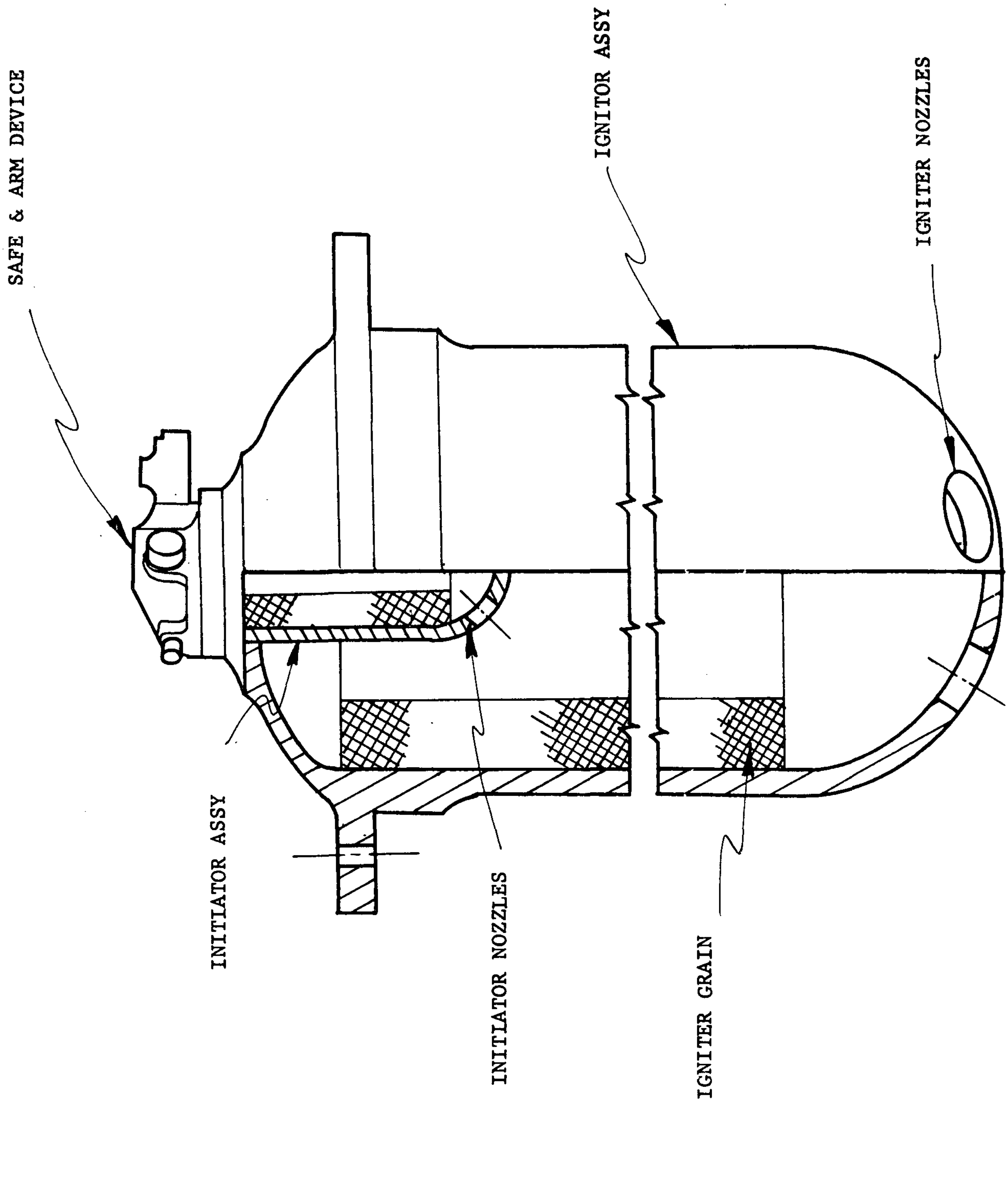
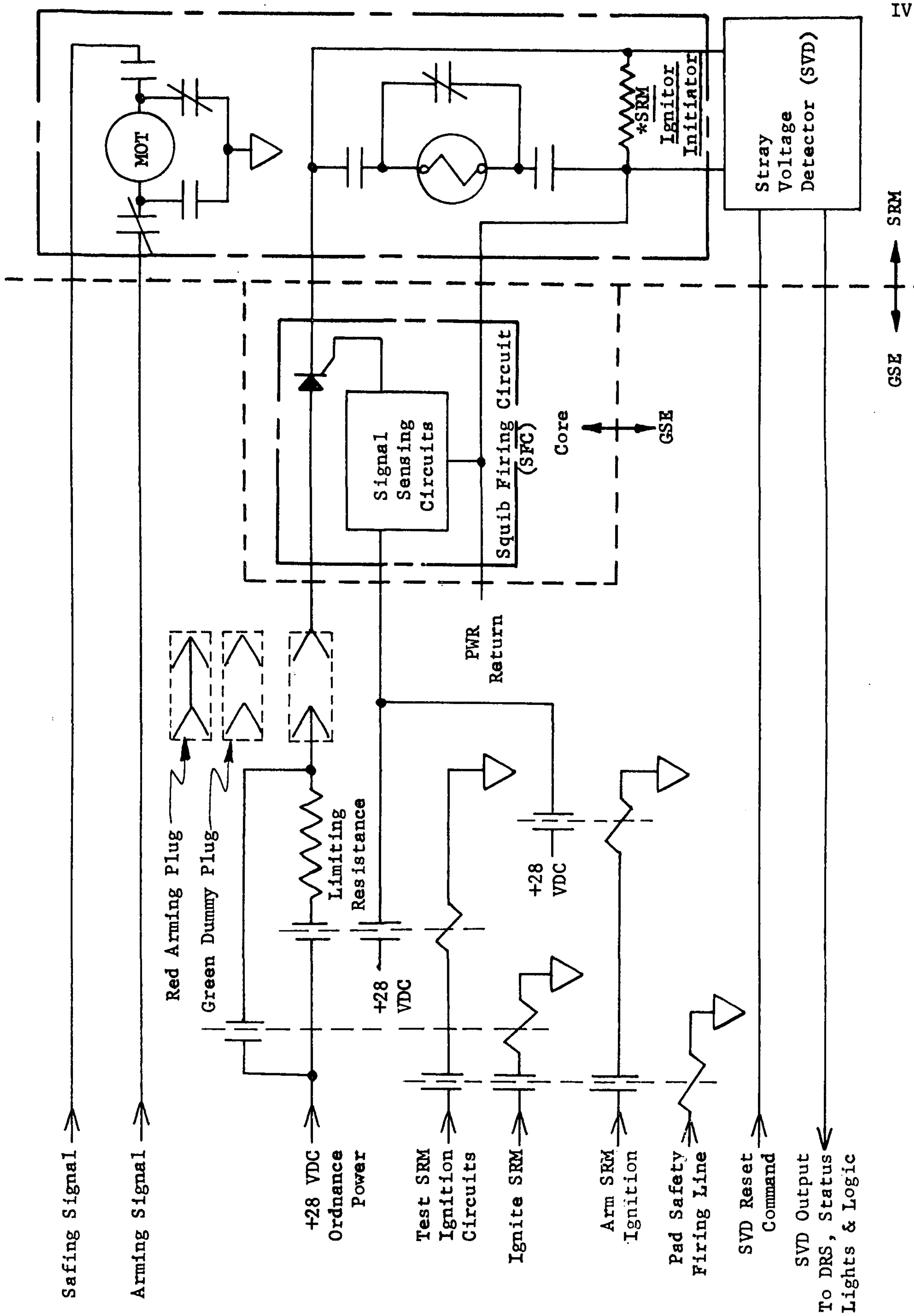


FIGURE IV-20 SRM IGNITER ASSEMBLY



* NOTE: SRM Ignitor Initiator is Replaced with Standard Ordnance Circuit Verification Unit (SOCVU), and Inert Initiator Until Live Ordnance Installation.

Figure IV-21 SRM Ignition Circuitry

output will be dissipated within a free space of sufficient volume to prevent rupture of the window. To check electrical continuity a squib simulator (resistor-switch) is connected to the firing circuit when the device is in the safe position. To fire the squibs, the squib retainer must be rotated 120 degrees so that the squibs face the blowout window (Figure IV-18). The arming signal rotates the squibs to the firing position. After approximately 105 degrees of rotation the circuit is complete; rotation ceases when the shaft has turned 120 degrees. When the squibs are in the safe position they are disconnected from the firing circuit and are short circuited. An externally visible letter, A for armed and S for safe, are aligned with the safe-arm mechanism to indicate device status (Figure IV-19). Also, internal shaft operated switches permit remote indication of device status. A manually engaged lock prevents actuation of the device (Figure IV-19). Once this lock is removed the unit can only be armed electrically, however, the device can be either electrically or manually actuated to the safe position. A temperature control switch prevents the overheating of the squib simulator resistors and prevents inadvertant firing. The device and its housing retains the SRM ignitor pressures.

In order to check out or operate the safe and arm device, manually installed arming plugs located in the GSE must be in place. The sequence of tests performed on the safe and arm circuitry and their purpose is shown in Table IV-4.

TABLE IV-4 Pyrotechnics Checkout Sequence

PERFORMED TIME	DESCRIPTION OF TEST OR TASK	PURPOSE OF TEST OR TASK
1. Pre-CST	Prior to the Combined Systems Test (CST) the SOCVUs and inert initiators are installed in the SRM.	Preparation for ordnance circuit verification.
2. During CST		
a) T-19	During the CST countdown a CMG signal is sent to test SRM ignition circuits. At this time a low current (< 1 amp) is sent via the SFC to the inert initiator in the SRM.	To verify operation of the SVD and the SOCVU under-current sensor
b) T-14.5 - T-13.5	SVD reset applied	SVD & SOCVU operation is monitored by DRS
c) T-3	Following the low current (>500, < 900 ma) test the inert initiator is cycled from the safe to the arm position.	To prepare for check of full ignition current
d) T-0	The full ignition current (>5 amps) is sent via the core SFCs* to the inert initiator. This current trips the SOCVU.	To verify sufficient current vs time is supplied to "fire" the igniter.
3. Following CST	SOCVU is removed and the inert initiator is replaced with the live S/A. SVDs & SOCVUs are calibrated to verify operation levels. SVDs are reset. DRS data is checked to verify proper operation of SVDs during CST.	Preparations for launch as indicated in task description.
4. During launch C/D		
a) T-30 min	When all other personnel have left pad area, "RED" arm plug is installed on TPS control power distribution rack by pad safety personnel.	To allow test and fire signals to be applied during C/D.
b) T-19 sec	The low test current (<1 amp) is applied to the S/A.	To verify continuity of firing circuit and operation of SVDs prior to arming the igniter.

TABLE IV-4 con't

PERFORMED TIME	DESCRIPTION OF TEST OR TASK	PURPOSE OF TEST OR TASK
c) T-14.5 to -13.5	SVD reset applied.	
d) T-3	Igniter is armed	
e) T=0	Igniter is fired if firing lines are not inhibited by pad safety.	
	* Redundant SFCs are used in the core to ignite redundant bridge wires in the S/A device.	

SECTION IV-D Checkout and Monitoring Requirements Analyses

Checkout and Monitoring Function Applicability

Trade Studies

Data Acquisition Requirements

Measurement List/Designated Usage

Measurement Selection Criteria

Identification of the onboard checkout and monitoring functions which are applicable to the T-III L has been conducted on work sheets. The matrix evaluated the functions against propulsion hardware and the measurement parameters identified by the FMEAs. The following identifies the evaluation of the functions considered and their use or applicability to T-III L expendable Shuttle booster.

GROUND CHECKOUT - Ground checkout of the T-III L propulsion system is required to assure system flight readiness and verify the propulsion interfaces.

FAULT DETECTION - This function is required for emergency detection purposes, fault isolation, performance monitoring and postflight evaluation.

FAULT ISOLATION - Fault isolation is limited to redundant hardware on the T-III L booster - specifically to the liquid rocket engines and redundant SRM thrust vector control valves.

REDUNDANCY MANAGEMENT - This function is limited to propulsion items discussed under fault isolation. Redundant sensors, however, are employed for critical parameters. Their redundancy management is handled by electronic majority voting techniques.

EMERGENCY DETECTION - Emergency detection is directly applicable for identification of impending or actual failures which could result in loss of life, vehicle or mission.

CAUTION AND WARNING - C&W will be utilized to inform the orbiter crew of an impending or actual emergency.

PERFORMANCE MONITORING - This function is primarily utilized for postflight evaluation and emergency detection.

DATA STORAGE - Onboard data storage is not directly applicable to the T-III L concept. Selected data will be relayed to the ground for evaluation and storage.

DISPLAY - Selected booster information will be displayed to the orbiter crew.

POSTFLIGHT EVALUATION - A complete postflight analysis will be conducted after each launch. This analysis will use the data sent via T.M. Such things as engine performance, steady state and transient, specification compliance and trends that begin to develop will be noted and recorded. Finally, if any malfunction occurred that could not be fault isolated during the flight, the postflight analysis will attempt to do so.

Trade Studies directed toward Control, Monitoring, and Checkout are presented on pages (IV-58 through IV-62). The results of these are incorporated within the study and discussed in Section IV-E. A Data Acquisition Requirements listing follows the trade studies. The measurement list/designated usage is shown in Table IV-8. The measurement selection criteria is presented in Table IV-9.

TABLE IV-5

VEHICLE GROUND CHECK, SYSTEMS TRADE STUDY

	ADVANTAGES	DISADVANTAGES
OPTION 1 - CONVENTIONAL TITAN III GSE	. Operational capability established. . Crew familiarity established. . Credible cost evaluation to a 97% factor. . Minimum software. . Technically fulfills requirements. . Factory established processes and launch procedures. . Support Titan as a stand above booster. . Will support Battleship & ISMU testing. . Proven design and build. . Low cost for modified design new build. . Proven reliability and adaptability. . Would minimize orbiter weight and costs.	. Some parts called out in the Engineering are obsolete. . 10% design change to replace obsolete parts. . Must be rated for manned vehicle support. . Not inherently flexible to other systems. . Offers no advance in present technology.
OPTION 2 - ORBITER ONBOARD GSE	. Minimum Titan hardware cost. . Would minimize Titan crew. . GSE and qualification test cost charged to orbiter. . Maximum system flexibility with new evolutions. . Minimum ground equipment concept. . Maximum integration of orbiter/booster systems.	. Maximum software concept for Titan. . Orbiter system is presently a paper configuration, thus minimum cost credibility. . Maximum interface between booster and orbiter system. . Two contractors involved to accomplish booster task. . Orbiter equipment would be needed for Battleship and ISMU. . Orbiter GSE must interface or provide flight safety C/O equipment.

TABLE IV-5

VEHICLE GROUND CHECK, SYSTEMS TRADE STUDY

OPTION 2 - ORBITER ONBOARD GSE (CONTINUED)

ADVANTAGES	DISADVANTAGES
	. Requires rewiring of booster vehicle to bring interface to DIU or run data bus through booster. . Maximum orbiter hardware and software impact. . All new procedure and crew training. . Impacts orbiter time line usage. . Decreases credible cost to 70% factor because of new system. . Must provide tracking and flight safety equipment.

OPTION 3 - NEW FACILITY OR GSE

ADVANTAGES	DISADVANTAGES
. Advanced technology possible. . Has evolution possibilities for all up booster. . Development and qualification charged to orbiter. . Design is state-of-the-art and parts are available.	. New procedures and crew training. . Larger crew than conventional GSE. . Increased software problems. . Decrease of cost credibility of 80 to 90% factor depending on approach. . Must provide tracking and flight safety equipment. . Needs additional builds for Battleship and ISMU.

CONCLUSION - Based on its advantages of operational capability, crew considerations, costs, and technical capability, the Conventional Titan III GSE can meet the requirements of vehicle ground checkout for the Titan III L Booster, and therefore it is recommended. Both the Orbiter Onboard GSE and New Facilities or GSE fall behind the Conventional Titan III GSE in meeting the above mentioned criteria.

This can be seen when reviewing the three options.

MONITORING OPTIONS TRADE STUDY

The monitoring options considered for use during flight and ground checkout, before and after the booster and orbiter are mated, are:

a. Inflight monitoring by orbiter onboard equipment.

b. Inflight monitoring by telemetry.

c. Monitoring during mated phases with orbiter onboard equipment.

d. Monitoring during mated phases with GSE.

e. Monitoring during premated phases with existing GSE.

f. Monitoring during premated phases with new GSE.

The inflight monitoring of the booster propulsion system and the SRMs can be accomplished with either the onboard equipment (a) or with telemetry (b). The telemetry method is currently used for Titan III launches and can be adapted to the Titan III L configuration. This modification would basically consist of an expansion of the current design to handle the additional information from the larger core and additional SRMs. Using this method, existing technology, operations and proven equipment can provide a cost effective way of monitoring flight propulsion data.

Providing monitoring through the use of orbiter onboard equipment would provide the crew with the direct performance data and allow the use of new technology; however, the increased interface and equipment development costs, which could not be readily transferred to a recoverable booster does not justify developing new equipment. A minimum of orbiter monitoring is expected to be performed for caution and warning purposes but the bulk of the data could be handled by existing techniques. This would provide the most reliable and cost effective method for inflight monitoring.

Ground preflight mated monitoring can be performed by the orbiter (c) or with conventional GSE (d). The same arguments as presented for the flight monitoring are applicable here. The most cost effective way that will satisfy the monitoring requirements would be to modify the existing equipment to handle the additional data.

The use of the orbiter for preflight mated and flight monitoring would also require that new GSE be developed for the unmated checkout or use an interface unit that would be able to connect with the orbiter interfaces.

The choice of one monitoring method in one phase, i.e., onboard monitoring during flight, dictates which method is most compatible in the other phases. The use of the onboard orbiter monitoring during flight would allow the use of this same equipment for ground monitoring. Also new GSE would be needed to mate with the booster outputs. The telemetry method allows the use of modified existing Titan equipment throughout the three phases.

Therefore, it appears that the most cost effective method of monitoring the large core booster and the 4 SRMs would be to modify the existing designs to benefit directly from the many years of Titan experience. The development of a new system to monitor an interim booster when existing equipment can be utilized does not seem practical.

TABLE IV-6 CONTROL TRADE STUDY

TIME PHASE AND OPERATION	CONTROL CONSIDERATIONS	CHOICE
A. Prior to Orbiter Mate		
1. System test and operation	Ground, Booster	Ground
B. Post Mate		
1. CST	Ground, Orbiter	Ground
2. Propellant loading & pressurization	Ground, Orbiter	Ground
3. Terminal count and launch execution	Ground, Orbiter	Ground
a. TVC, engine & SRM start		
C. Inflight		
1. TVC - program	Orbiter, Booster	Orbiter
2. Normal booster LRE shutdown (5)	Orbiter, Booster	Orbiter
3. Individual engine shutdown (MFD)	Orbiter, Booster	Booster
4. Inadvertant separation SRM	Orbiter, Booster	Booster (SRM)
5. Inadvertant separation Core	Orbiter, Booster	Booster
6. Destruct command Core - SRM	Ground, Orbiter	Ground
7. SRM separation ordnance	Orbiter, Booster	Orbiter
8. Abort	Orbiter, Booster	Orbiter

Discussion: Evaluation of control associated with Titan III L propulsion functions has identified that the control origin is dependent on the time phase of the operations.

A. Prior to mating the orbiter to the booster, control of propulsion functions, system tests and operations is best accomplished by ground equipment. Booster self-test capabilities are not warrented as the booster is of an expendable nature and the ground equipment required is available.

B. Control requirements after orbiter mating and prior to flight are also best satisfied by ground equipment. Utilization of orbiter GSE or orbiter bilt in equipment is also not warrented from an operations and cost effectiveness standpoints.

C. Operational or inflight control function are of a shared nature as depicted above.

TABLE IV-7 DATA ACQUISITION REQUIREMENTS

PARAMETER	PROPULSION ELEMENT	PARAMETER RANGE AND UNITS	ALLOWABLE ERROR	RESPONSE RATE	SAMPLE RATE	DATA USAGE	TIME OF DATA ACTIVITY
Pressure, Oxidizer Suction, PoS	Inlet to main engine oxidizer pump (1.1.3.1)	0-200 psia 90 psia, nominal	± 6.8 psia	80 Hz	400 sps	Post flight analysis; verification of engine, oxidizor inlet pressure level and stability.	T-35 sec thru entire engine operation.
Pressure, Fuel Suction, PfS	Inlet to main engine fuel pump (1.1.3.2)	0-150 psia 40 psia, nominal	± 5.1 psia	80 Hz	400 sps	Post flight analysis; verification of engine, fuel inlet pressure level and stability.	T-35 sec thru entire engine operation.
Pressure, Thrust Chamber, P_C	Side of main engine injector (1.1.1.1)	0-1000 psia 825 psia, nominal	± 34 psia	80 Hz	400 sps	Post flight analysis; evaluation of engine performance and chamber pressure characteristics.	Total engine operating period.
Pressure, Oxidizer Discharge, PoD	Discharge side of main engine oxidizer pump (1.1.3.1)	0-1500 psia 1150 psia, nominal	± 51 psia	80 Hz	400 sps	Post flight analysis; TPA performance evaluation.	Total engine operating period.
Pressure, Fuel Discharge, PfD	Discharge of main engine fuel pump (1.1.3.2)	0-1500 psia 1350 psia, nominal	± 51 psia	80 Hz	400 sps	Post flight analysis; TPA performance evaluation.	Total engine operating period.
Pressure, Oxidizer Bootstrap Venturi Inlet, PoBTVI	Inlet to main engine, gas generator, oxidizer cavitating venturi (1.1.4.4)	0-1500 psia 1000 psia, nominal	± 51 psia	20 Hz	100 sps	Post flight analysis; gas generator performance.	Total engine operating period.
Pressure, Fuel Bootstrap Venturi Inlet, PfBTVI	Inlet to main engine, gas generator, fuel cavitating venturi (1.1.4.5)	0-1500 psia 1250 psia, nominal	± 51 psia	20 Hz	100 sps	Post flight analysis; gas generator performance.	Total engine operating period.
Pressure, Gas Generator Chamber PcGG	Side of main engine gas generator (1.1.4.1)	0-100 psia 600 psia, nominal	± 34 psia	40 Hz	200 sps	Post flight analysis; gas generator performance.	Total engine operating period.
Pressure, Fuel Pressurant Orifice Inlet, PfPOI	Inlet to main pressurization, fuel pressurization sonic nozzle (1.3.2.2)	0-500 psia 200 psia, nominal	± 17 psia	40 Hz	200 sps	Post flight analysis; performance verification of fuel autogenous pressurization assembly.	Total engine operating time.

TABLE IV-7 DATA ACQUISITION REQUIREMENTS

PARAMETER	PROPULSION ELEMENT	PARAMETER RANGE AND UNITS	ALLOWABLE ERROR	RESPONSE RATE	SAMPLE RATE	DATA USAGE	TIME OF DATA ACTIVITY
Pressure, Oxidizer Pressurant Orifice Inlet, PoPOI	Inlet to main pressurization, oxidizer pressuirzation back pressure orifice (1.3.1.3)	0-1000 psia 275 psia, nominal	± 34 psia	40 Hz	200 sps	Post flight analysis; performance verification of oxidizer autogenous pressuirzation assembly.	Total engine operating time
Pressure, Lube Pump Discharge, PLD	Discharge of main engine lube oil pump (1.1.3.4)	0-100 psia 38 psia, nominal	± 38 psia	40 Hz	200 sps	Post flight analysis; gear box & lubricating hardware evaluation .	Total engine operating time.
Pressure, Hydraulic System, PHS	Discharge of main engine hydraulic pump (1.1.6.3)	0-4500 psia	± 210	20 Hz	100 sps	Terminal count; verification of proper operating pressure. Post flight analysis; operational integrity of TVC assembly.	T-35 sec thru total engine operating period.
Differential Pressure Pitch Actuator, PPA-D	Both sides of main engine gimbal actuator (1.1.6.2)P	-7000/+7000 psid	± 300 psid	40 Hz	200 sps	Post flight analysis; evaluation of TVC operation and contingency torques.	T-35 sec thru LRE operation.
Differential Pressure YAW Actuator PYA-D	Both sides of main engine gimbal actuator (1.1.6.2)Y	-7000/+7000 psid	± 300 psid	40 Hz	200 sps	Post flight analysis; evaluation of TVC operation and contingency torques.	T-35 sec thru LRE operation.
Temperature, Oxidizer Suction, ToS	Inlet to main engine oxidizer pump (1.1.3.1)	0-100°F 70°F, nominal	± 5.5°F	4 Hz	20 sps	Post flight analysis; engine performance calculations.	T-35 sec thru LRE operation.
Temperature, Fuel Suction, TfS	Inlet to main engine fuel pump (1.1.3.2)	0-100°F 70°F, nominal	± 5.5°F	4 Hz	2 sps	Post flight analysis; engine performance calculations.	T-35 sec thru LRE operation.
Temperature, Fuel Pressurant Orifice Inlet, TFPOI	Inlet to main engine fuel pressurization sonic nozzle (1.3.2.2)	0-500°F 240°F, nominal	± 17°F	4 Hz	20 sps	Post flight analysis; performance of fuel autogenous pressurization.	Total engine operation.
Temperature, Oxidizer Pressurant Orifice Inlet, TOPOI	Inlet to main engine oxidizer pressurization back pressure orifice (1.3.1.3)	0-500°F 250°F, nominal	± 17°F	4 Hz	20 sps	Post flight analysis; performance of oxidizer autogenous pressurization.	Total engine operation.

TABLE IV-7 DATA ACQUISITION REQUIREMENTS

PARAMETER	PROPULSION ELEMENT	PARAMETER RANGE AND UNITS	ALLOWABLE ERROR	RESPONSE RATE	SAMPLE RATE	DATA USAGE	TIME OF DATA ACTIVITY
Temperature, Nozzle Extension Skin, TNES-1, 3, 5	Main engine ablative nozzle (1.1.1.3)	0-1000^oF 190^oF, nominal	$\pm$ 34^oF	4 Hz	20 sps	Post flight analysis; integrity verification of ablative nozzle and refrasil insulation.	Total engine operation.
Temperature, Gear Box Bearing, No. 6A, 6B TGB-6A, B	Main engine turbopump assembly gear box (1.1.3.3)	0-500^oF 200^oF, nominal	$\pm$ 17^oF	40 Hz	200 sps	Post flight analysis; caution and warning display to crew.	Total engine operating period.
Thrust Chamber Pressure Switch, TCPS-A, B, C	Main engine injector dome (1.1.1.1)	Increasing pressure (620 $\pm$ 40 psia) Decreasing pressure (600 $\pm$ 60 psia)	$\pm$ 40 psia $\pm$ 60 psia	$<.\overline{01}$ sec $<.\overline{01}$ sec	Discrete (100 sps) Discrete (100 sps)	Used for engine start and shutdown logic, liftoff and staging logic and for C&W and fault isolation logic.	Total LRE operating period.
Speed, Turbine, NT	Main engine turbopump assembly gear box (1.1.3.3)	0-31000 RPM (23,000 RPM, nominal)	$\pm$ 1054 RPM	8 Hz	40 sps	Post flight analysis; turbo pump assembly performance evaluation	Total LRE operating period.
Level, Hydraulic Reservoir, LHS	Main engine hydraulic reservoir above hydraulic pump (1.1.6.3)	0-100%	3.4%	4 Hz	20 sps	Preflight and flight verification of hydraulic system.	T-35 sec through LRE operation.
Position, Oxidizer Prevalve, LOPV	Main propellant management oxidizer prevalve (1.2.1.3)	Open/Closed	-	-	Discrete	Indication to crew and ground personnel of valve position.	Propellant loading; T-35 sec to core separation.
Position, Fuel Prevalve, LFPV	Main propellant management fuel prevalve (1.2.2.3)	Open/Closed	-	-	Discrete	Indication to crew and ground personnel of valve position.	T-35 sec to core separation.
Position, Pitch Actuator, LPA	Main engine gimbal actuator (1.1.6.2)P	$\pm$ 5 degrees	0.2 degrees	20 Hz	100 sps	Verify engine in proper position for start and compare position to commands.	T-35 sec to LRE shutdown.
Position, YAW Actuator, LYA	Main engine gimbal actuator (1.1.6.2)Y	$\pm$ 5 degrees	0.2 degrees	20 Hz	100 sps	Verify engine in proper position for start and for comparing position to commands.	T-35 sec to LRE shutdown.
Detector, Engine Compartment Fire/ Leakage DECF/DgEC	Engine compartment at each main engine (1.1)	On/Off	-	-	Discrete	Alert crew hazardous condition within the LRE compartment. NOTE: This detector is identified as Research & Technology item requiring further eval.	T-35 sec to core separation.

TABLE IV-7 DATA ACQUISITION REQUIREMENTS

PARAMETER	PROPULSION ELEMENT	PARAMETER RANGE AND UNITS	ALLOWABLE ERROR	RESPONSE RATE	SAMPLE RATE	DATA USAGE	TIME OF DATA ACTIVITY
Pressure, Oxidizer Tank, Gas, PgOT-1, 2	Main propellant management oxidizer tank (1.2.1.1), Top.	0-50 psia 35 psia, nominal	$\pm$ 1.7 psia	8 Hz	40 sps	Verify tank pressure is sufficient for structural integrity and LRE operation. Caution and warning indication to crew.	From tank pre-pressurization to LRE shutdown.
Pressure, Fuel Tank, Gas, PgFT-1, 2	Main propellant management fuel tank (1.2.2.1), Top.	0-50 psia 27 psia, nominal	$\pm$ 1.7 psia	8 Hz	40 sps	Verify tank pressure is sufficient for structural integrity and LRE operation. Caution and warning indication to crew.	From tank pre-pressurization to LRE shutdown.
Temperature, Oxidizer Tank, Liquid, ToT	Main propellant management oxidizer tank (1.2.1.1)	0-150°F 110°F, nominal	$\pm$ 1.7°F	4 Hz	20 sps	Post flight analysis; check of total system performance.	T-10 sec to core separation.
Temperature, Fuel Tank, Liquid, TfT	Main propellant management fuel tank (1.2.2.1)	0-150°F 70°F, nominal	$\pm$ 1.7°F	-	Land line analog	Propellant bulk temperature evaluation required for launch committment.	Propellant loading to liftoff.
Pressure, Motor Head End, $PgMHE_{A, B}$	SRM assmembly forward closure (2.1.1.1)	0-1000 psia	$\pm$ 34 psia	80 Hz	400 sps	Post flight analysis; for SRM performance verification. Caution and warning indication to crew.	SRM ignition to SRM staging.
Pressure, Injectant Manifold, PoIM	SRM TVC tank assembly in manifold downstream of injectant transfer tube (2.2.1.4)	0-1500 psia	$\pm$ 51 psia	80 Hz	400 sps	Post flight analysis; for TVC performance verification.	SRM ignition to SRM staging.
Pressure, Injectant Tank, Gas, PgIT	SRM TVC tank assembly injectant tank (2.2.1.1)	0-1500 psia	51 psia	-	Land line	Used for tank pressure integrity verification.	From tank pressurization to liftoff.
Position, Injectant Valve, Average, Quad 1 thru 4, A & B	SRM TVC injectant valve, (2.2.2.1)	0-9.5 VDC	$\pm$ 0.32 VDC	20 Hz	100 sps	Verify valve positions corresponds to steering commands; post flight analysis.	SRM burn.
Position, SRM S/A Device, L-S/A	SRM assembly rocket motor igniter (2.1.1.5) safe and arm device.	Safe/Armed	-	-	Discrete Land line	Indicates igniter safe or arm status.	T-35 sec to liftoff.

TABLE IV-7 DATA ACQUISITION REQUIREMENTS

PARAMETER	PROPULSION ELEMENT	PARAMETER RANGE AND UNITS	ALLOWABLE ERROR	RESPONSE RATE	SAMPLE RATE	DATA USAGE	TIME OF DATA ACTIVITY
Detector, SRM Brunthrough, DBT	Rocket motor subsystem SRM assembly (2.1.1)	On/Off	-	-	Discrete	Caution and warning indication - possible abort initiate. NOTE: This detector is identified as a supporting research and technology item requiring further evaluation.	Total SRM burn.

TABLE IV-8

TITAN III L PROPULSION
MEASUREMENT LIST/DESIGNATED USAGE

CORE LRE MEASUREMENTS	SYMBOL	Telemetry Inputs	GSE INPUTS		ORBITER INPUTS			Booster Malfunction Detection Logic
			Sequence/ Control Logic	Landline In-strumentation	Malfunction Detection Logic	Display	Sequence Logic	
Pressure, Oxidizer Suction	PoS	X						
Pressure, Fuel Suction	PfS	X						
Pressure, Thrust Chamber	Pc	X						
Pressure, Oxidizer Discharge	PoD	X						
Pressure, Fuel Discharge	PfD	X						
Pressure, Oxidizer Bootstrap Venturi Inlet	PoBTVI	X						
Pressure, Fuel Bootstrap Venturi Inlet	Pf BTVI	X						
Pressure, Gas Generator Chamber	Pc GG	X						
Pressure, Fuel Pressurant Orifice Inlet	PFPOI	X						
Pressure, Oxidizer Pressurant Orifice Inlet	POPOI	X						
Pressure, Lube Pump Discharge	PLD	X						
Pressure, Hydraulic System	PHS	X						
Differential Pressure, Pitch Actuator	P PA-D	X						
Differential Pressure, Yaw Actuator	PYA-D	X						
Temperature, Oxidizer Suction	ToS	X						
Temperature, Fuel Suction	Tfs	X						
Temperature, Fuel Pressurant Orifice Inlet	TFPOI	X						
Temperature, Oxidizer Pressurant Orifice Inlet	TOPOI	X						
Temperature, Nozzle Extension Skin-1	TNES-1	X						
Temperature, Nozzle Extension Skin-3	TNES-3	X						
Temperature, Nozzle Extension Skin-5	TNES-5	X						
Temperature, Gear Box Bearing No. 6A	TGB-6A	X			X	X		

TABLE IV-8

TITAN III L PROPULSION
MEASUREMENT LIST/DESIGNATED USAGE

CORE LRE MEASUREMENTS (CONTINUED)	SYMBOL	TELEMETRY INPUTS	GSE Inputs: Sequence/ Control Logic	GSE Inputs: Landline In-strumentation	Orbiter Inputs: Malfunction Detection Logic	Orbiter Inputs: Display	Orbiter Inputs: Sequence Logic	Booster Malfunction Detection Logic
Temperature, Gear Box Bearing No. 6B	TGB-6B	X						
Thrust Chamber Pressure Switch A	TCPS-A	X						
Thrust Chamber Pressure Switch B	TCPS-B	X	X		X	X	X	X
Thrust Chamber Pressure Switch C	TCPS-C	X						X
Speed, Turbine	NT	X						
Level, Hydraulic Reservoir	LHS	X						
Position, Oxidizer Prevalve	LOPV	X	X					
Position, Fuel Prevalve	LFPV	X	X					
Position, Pitch Actuator	LPA	X						
Position, Yaw Actuator	LYA	X						
Detector, Engine Compartment Fire/Leakage	DECF/DgEC	X			X	X		
CORE TANK MEASUREMENTS								
Pressure, Oxidizer Tank Gas-1	PgOT-1	X			X	X		
Pressure, Fuel Tank Gas-1	PgFT-1	X			X	X		
Pressure, Oxidizer Tank-2	PgOT-2	X			X	X		
Pressure, Fuel Tank Gas-2	PgFT-2	X			X	X		
Temperature, Oxidizer Tank Liquid	ToT			X				
Temperature, Fuel Tank Liquid	TfT			X				

TABLE IV-8

TITAN III L PROPULSION
MEASUREMENT LIST/DESIGNATED USAGE

SRM MEASUREMENTS	SYMBOL	Telemetry	GSE Inputs		Orbiter Inputs			Booster Malfunction Detection Logic
			Sequence/ Control Logic	Landline In-strumentation	Malfunction Detection Logic	Display	Sequence Logic	
Pressure, Motor Heat End, A	PgMHEA	XX			X	X		
Pressure, Motor Head End, B	$PgMHE_B$	XX						
Pressure, Injectant Manifold	PoIM	X						
Pressure, Injectant Tank Gas	PgIT							
Position, Injectant Valve, Average Quad 1, A	$LIVAL_A$	X					X	X
Position, Injectant Valve, Average Quad 1, B	$LIVA1_B$	X					X	X
Position, Injectant Valve, Average Quad 2, A	$LIVA2_A$	X					X	X
Position, Injectant Valve, Average Quad 2, B	$LIVA2_B$	X					X	X
Position, Injectant Valve, Average Quad 3, A	$LIVA3_A$	X					X	X
Position, Injectant Valve, Average Quad 3, B	$LIVA3_B$	X					X	X
Position, Injectant Valve, Average Quad 4, A	$LIVA4_A$	X					X	X
Position, Injectant Valve, Average Quad 4 B	$LIVA4_B$	X					X	X
Position, SRM S/A Device	L8-S/A	X	X					
Detector, SRM Burnthrough	DBT	X			X	X	X	

TABLE IV-9 Measurement Selection Criteria

MEASUREMENT	REQUIREMENT IDENTIFICATION	USAGE JUSTIFICATION
Pressure, Oxidizer Suction, PoS	FMEA - 1.3.1.7; Checkout and monitoring requirements analysis, parameter optimization study	Pump inlet pressures are required for post flight analysis of system hydraulic oxcillations and propellant depletion determination. The measurement can also be used to verify tank pressures.
Pressure, Fuel Suction, PfS	FMEA - 1.3.1.7; Checkout and monitoring requirements analysis, parameter optimization study.	Same as above
Pressure, Thrust Chamber, P_C	FMEA - 1.1.2.1 (Fuel), 1.1.2.2 (OX), 1.1.2.3, 1.1.3.1, 1.1.3.2, 1.1.3.3, 1.1.4.1, 1.1.4.2, 1.1.4.3, 1.1.4.4, 1.1.4.5, 1.1.4.6, 1.1.4.7, 1.1.5.1, 1.1.5.2; Checkout and monitoring requirements analysis.	Thrust chamber pressure is required for calculating engine performance parameters. This measurement is also used to detect various modes of engine and engine component failures.
Pressure, Oxidizer Discharge	FMEA - 1.1.3.1, 1.1.3.3, 1.1.3.6; Checkout and monitoring requirements analysis.	Measurement is used to determine pump performance, to calculate flowrate and to detect failures in the pump or related hardware such as the gear box.
Pressure, Fuel Discharge, PfD	FMEA - 1.1.3.2, 1.1.3.3, 1.1.3.6; Checkout and monitoring requirements analysis	Same as above.
Pressure, Oxidizer Bootstrap Venturi Inlet, PiBTVI	FMEA - 1.1.4.4; Checkout and monitoring requirements analysis, parameter optimization study.	Measurement is needed to analyze gas generator loop performance.
Pressure, Fuel Bootstrap Venturi Inlet, PfBTVI	FMEA - 1.1.4.4; Checkout and monitoring requirements analysis, parameter optimization study.	Same as above.
Pressure, Gas Generator Chamber PcGG	FMEA - 1.1.4.1, 1.1.4.4, 1.1.4.5, 1.1.4.6, 1.1.4.7; Checkout and monitoring requirements analysis	This pressure measurement is required for establishing the gas generator performance and to analyze associated problem areas.

TABLE IV-9

MEASUREMENT	REQUIREMENT IDENTIFICATION	USAGE JUSTIFICATION
Pressure, Fuel Pressurant Orifice Inlet, PfPOI	FMEA - 1.3.2.1, 1.3.2.2, 1.3.2.4; Checkout and monitoring requirements analysis.	Information from this measurement is required for acceptance and postflight analysis to calculate autogenous flowrate. Data is also used to verify engine burst disc rupture and system integrity after engine shutdown.
Pressure, Oxidizer Pressurant Orifice Inlet, PoPOI	FMEA - 1.3.1.3, 1.3.1.5; Checkout and monitoring requirements analysis.	Same as above.
Pressure, Lube Pump Discharge	FMEA - 1.1.3.5; Checkout and monitoring requirements analysis, paremeter optimization analysis.	This measurement provides corrolating information for condition of the gear box.
Pressure, Hydraulic System, PHS	FMEA - 1.1.6.1, 1.1.6.4; Checkout and monitoring requirements analysis.	Hydraulic pressure data is required to verify subsystem integrity for launch and flight operation.
Differential Pressure Pitch Actuator, PPA-D	FMEA - 1.1.6.1, 1.1.6.2, 1.1.6.4; Checkout and monitoring requirements analysis.	This data is required for postflight analysis to determine actuator loads and non-symmetrical thrust.
Differential Pressure YAW Actuator, PYA-D	FMEA - 1.1.6.1, 1.1.6.2, 1.1.6.4; Checkout and monitoring requirements analysis.	Same as above.
Temperature, Oxidizer Suction, ToS	Parameter optimization analysis.	Required for postflight analysis for propellant density determination.
Temperature, Fuel Suction, TfS	Same as above.	Same as above.
Temperature, Fuel Pressurant Orifice Inlet, TFPOI	FMEA - 1.3.2.1, 1.3.2.2; Checkout and monitoring requirements analysis.	Data is required for postflight analysis to determine autogenous gas temperature and gas cooler performance.
Temperature, Oxidizer Pressurant Orifice Inlet, TOPOI	FMEA - 1.3.1.3; Checkout and monitoring requirements analysis.	Data is required for postflight analysis to determine autogenous gas energy level and superheater performance.

TABLE IV-9

MEASUREMENT	REQUIREMENT IDENTIFICATION	USAGE JUSTIFICATION
Temperature, Nozzle Extension Skin TNES - 1, 3, 5	FMEA - 1.1.1.2; Checkout and monitoring requirements analysis.	This measurement is required for determining the nozzle insulation performance and integrity of the nozzle extension.
Temperature, Gear Box Bearing No. 6A, 6B TGB - 6A, B	FMEA - 1.1.3.5; Checkout and monitoring performance analysis.	This measurement is required for indication of impending gear box failure and bearing trend analysis (used for caution & warning).
Thrust Chamber Pressure Switch TCPS - A, B, C	FMEA - 1.1.1.4, 1.1.2.1 (Fuel), 1.1.2.2 (Ox), 1.1.2.3, 1.1.3.6, 1.1.4.2, 1.1.4.3, 1.1.5.1, 1.1.5.2; Checkout and monitoring requirements analysis, control sequence and logic study.	Switches are required for engine start and shutdown verification, liftoff and staging sequencing, fault detection, caution and warning, and fault isolation.
Speed, Turbine, NT	FMEA - 1.1.3.3, 1.1.3.5, 1.1.3.6, 1.1.4.1; Checkout and monitoring requirements analysis.	Measurement is required for postflight evaluation of the gear box and gas generator loop and TVC analysis.
Level, Hydraulic Reservoir, LHS	Operational flow analysis, parameter optimization study.	This measurement is required to verify flight control system readiness and inflight operation.
Position, Oxidizer Prevalve, LOPV	FMEA - 1.2.1.3, 1.2.2.3; Control sequence and logic analysis.	Required for verification of prevalve position for propellant loading, prior to engine ignition, and engine isolation after shutdown.
Position, Fuel Prevalve, LFPV	FMEA - 1.2.1.3, 1.2.2.3; Control sequence and logic analysis.	Same as above.
Position, Pitch Actuator, LPA	FMEA - 1.1.6.1, 1.1.6.2; Checkout and monitoring requirements analysis, parameter optimization study.	Measurement required for engine position indication for start and evaluation of steering command response.
Position, YAW Actuator, LYA	FMEA - 1.1.6.1, 1.1.6.2; Checkout and monitoring requirements analysis, parameter optimization study.	Same as above.

TABLE IV-9

MEASUREMENT	REQUIREMENT IDENTIFICATION	USAGE JUSTIFICATION
Detector, Engine Compartment Fire/ Leakage, DECF/DgEC	FMEA - 1.1.3.2, 1.1.3.4, 1.1.4.1, 1.1.4.5, 1.1.5.2, 1.2.2.3, 1.3.2.1; Checkout and monitoring requirements analysis.	Required for fire/leakage detection in the engine compartment. Provide input to caution and warning.
Pressure, Oxidizer Tank, Gas, PgOT-1, 2	FMEA - 1.1.4.1, 1.3.2.1, 1.3.2.3, 1.3.2.4, 1.3.2.5, 1.3.2.6, 1.3.1.1, 1.3.1.2, 1.3.2.6, 1.3.1.1, 1.3.1.2, 1.3.1.3, 1.3.1.4, 1.3.1.5, 1.3.1.7; Checkout and monitoring requirements analysis, control sequence and logic analysis.	Needed to verify status of tank gas pressure for structural integrity and engine inlet conditions. Data inputs utilized for crew caution and warning and range safety.
Pressure, Fuel Tank Gas, PgFT - 1, 2	Same as above.	Same as above.
Temperature, Oxidizer Tank, Liquid, ToT	FMEA - 1.3.2.1; Control sequence and logic analysis.	Required for launch committment, i.e., propellant bulk temperature limit verification.
Temperature, Fuel Tank, Liquid, TfT	Control logic and sequence analysis.	Same as above.
Pressure, Motor Head End, $PgMHE_{A, B}$	FMEA - 2.1.1.1, 2.1.1.2, 2.1.1.3, 2.1.1.6; Checkout and monitoring requirements analysis.	Required for SRM performance verification, monitoring and malfunction detection.
Pressure, Injectant Manifold, PoIM	Checkout and monitoring requirements analysis (FMEA - 2.1.1.4, 2.2.1.2).	Required for TVC performance verification and future N_2O_4 dump program adjustments.
Pressure, Injectant Tank, Gas, PgIT	Checkout and monitoring requirements analysis, control sequence and logic analysis.	Required for injectant tank integrity verification and determination of proper tank pressurization prior to launch.
Position, Injectant Valve, Average, Quad 1 thru 4, A & B	FMEA - 2.2.2.1; Control sequence and logic analysis.	Needed to verify response to steering commands and fault isolation of malfunctioning valve.

TABLE IV-9

MEASUREMENT	REQUIREMENT IDENTIFICATION	USAGE JUSTIFICATION
Position, SRM S/A Device, L-S/A	FMEA - 2.1.1.5; Safety requirements study, control sequence and logic analysis.	Required for S/A position determination for safety and operational purposes.
Detector, SRM Burnthrough, DBT	FMEA - 2.1.1.1, 2.1.1.2, 2.1.1.3, 2.1.1.4; Checkout and monitoring requirements analysis.	Needed to detect hazardous condition for caution and warning information.

SECTION IV-E Checkout and Monitoring Requirements Implementation

Avionics Description

TITAN III Propulsion Instrumentation Summary

Instrumentation Location

TITAN III L PROPULSION RELATED AVIONICS

I. GENERAL - The avionics related to the propulsion system consists of portions of the electrical and electronic subsystems. An overall view of the interconnections between propulsion and avionics is shown in Figure IV-22. The purpose of the avionic-to-propulsion interconnections are discussed in the following paragraphs.

II. DIGITAL INTERFACE UNIT (DIU) - The DIU's are extensions of the orbiter Central Computer Complex (CCC). These units provide the interfaces between the booster avionic subsystems and the CCC via the digital data bus. Propulsion related signals which interface with the DIU's, (Reference Figure IV-23) are as follows:

1. Steering and Dump signals are provided from the DIU to the booster TVC driver electronics package. The steering signals are issued in accordance with the desired flight attitude which is controlled by the orbiter. The dump signals are issued from the orbiter in accordance with a nominal preprogrammed dump schedule. The TVC electronics interprets the steering and dump signals and provides the outputs required to drive the actuator valve coils in the LRE's and the injectant valve positioning electronics in the SRM's. The TVC driver electronics integrates the outputs to the SRM valves to determine the total injectant fluid usage

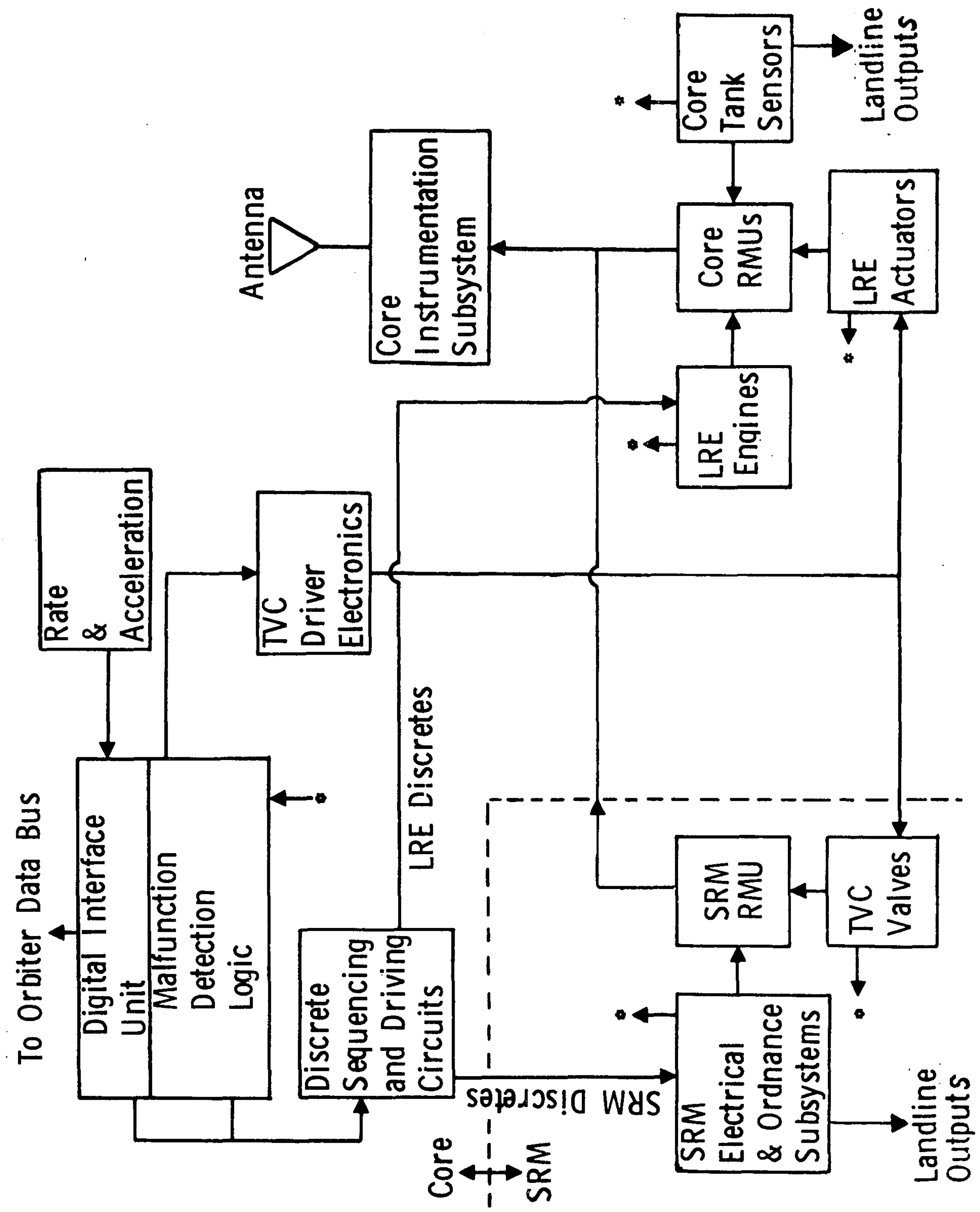


Figure IV-22 Titan III L Propulsion Related Avionics

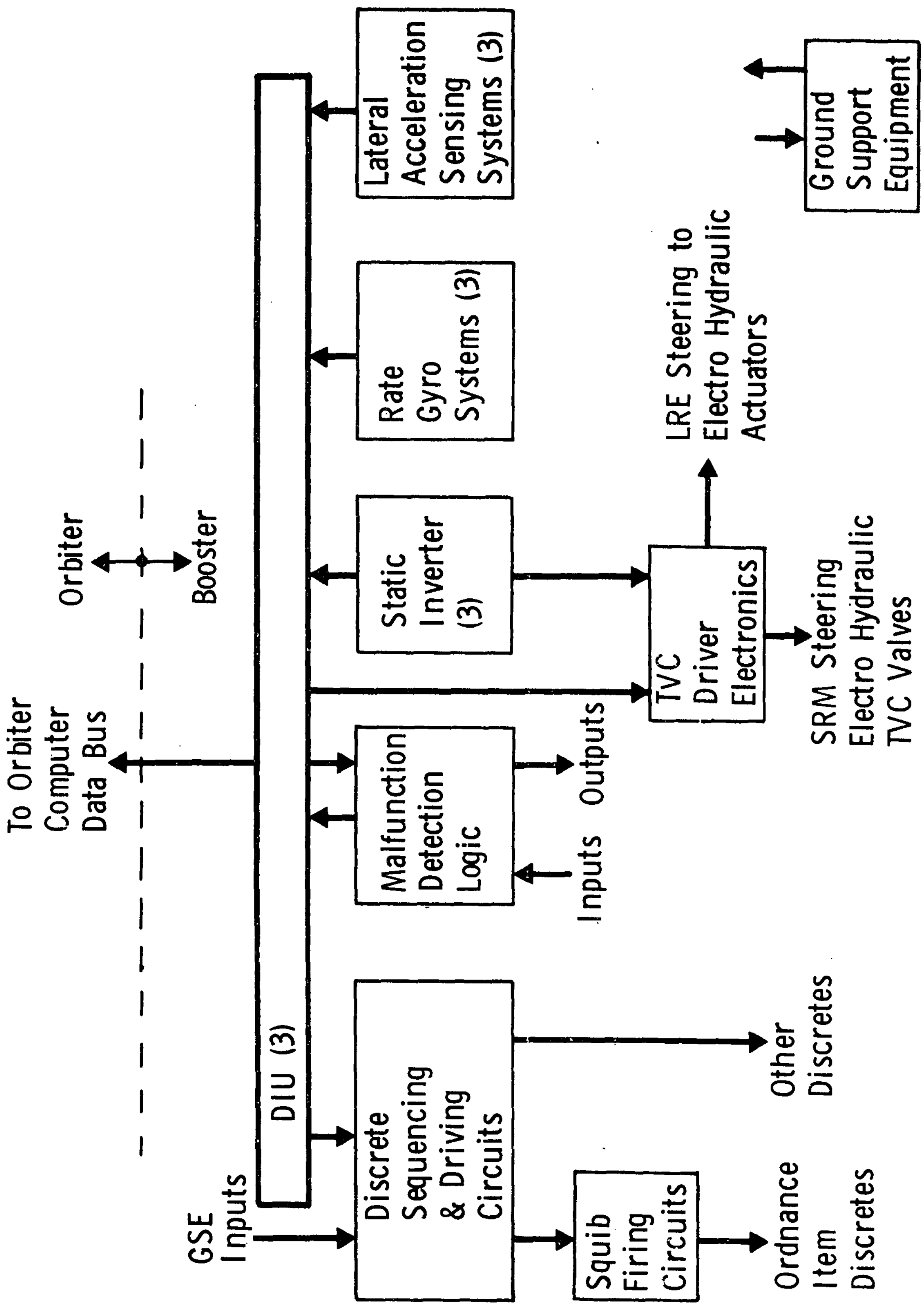


Figure IV-23 DIU/Orbiter/GSE Interfaces

a) Open prevalves

b) Start

c) Shutdown

Discrete signals provided to the SRM's include:

a) Start

b) Thrust Termination

c) Staging

III. <u>TITAN III L INSTRUMENTATION SYSTEM</u> - The instrumentation system proposed for T III L is similar to systems flown on 17 successful Titan III flights to date. The Titan III instrumentation systems evolved as a result of experience gained on earlier missile programs coupled with state-of-the-art hardware advances and requirements changes. The specific system proposed for T III L is based on the system proposed and partially developed for T III M. The Instrumentation Summary (Table IV-10) indicates range, sample rate and other information applicable to T III L propulsion measurements. Figures IV-24 and IV-25 locate measurements/sensors within a LRE subsystem and an SRM subsystem. The operation and interface requirements for the instrumentation system are discussed in the following subparagraphs.

1. The Typical Sequence of Operation for propulsion measurements sensed and transmitted by the T III L instrumentation system are shown in the block diagram (Figure IV-26). The measurement originates as an electrical signal from some source such as a pressure transducer, bus voltage or discrete switch.

versus flight time and adjusts the SRM steering-dump commands to correspond with the preprogrammed dump schedule.

2. Rate and lateral acceleration inputs from booster flight control components are sent to the orbiter via the DIU. The booster rates and accelerations are used in conjunction with orbiter attitudes and rates to determine the steering required.

3. Malfunction Detection Logic outputs from the booster are provided to the orbiter CCC via the DIU. The Malfunction Detection Logic outputs provide the status of booster parameters which can indicate that a hazardous condition exists on the booster. The booster propulsion parameters monitored by the Malfunction Detection Logic include:

   a) Oxidizer tank pressure
   b) Fuel tank pressure
   c) Thrust chamber pressure switches
   d) SRM chamber pressure
   e) Temperature, Gearbox Bearing No. 6
   f) Detector SRM Burnthrough

4. Discrete Sequencing and Driving Circuit inputs from the DIU and Malfunction Detection Logic are provided to control LRE and SRM functions. Discrete signals provided to the LRE's include:

   a) Open prevalves

TABLE IV-10

TITAN III PROPULSION

INSTRUMENTATION SUMMARY

CORE LRE MEASUREMENTS	SYMBOL	RANGE & UNITS	USED ON PREVIOUS TITAN III VEHICLES	TECHNOLOGY EXISTS	NEW TECHNOLOGY REQUIRED	TRANSDUCER TYPE	ACCURACY IN EQUIVALENT ENGINEERING UNITS (±): TRANSDUCER ONLY	ACCURACY IN EQUIVALENT ENGINEERING UNITS (±): TOTAL INSTRUMENTATION SYSTEM	A/B TLM MEAS RESPONSE: SAMPLE RATE IN SAMPLES PER SECOND	A/B TLM MEAS RESPONSE: EQUIVALENT MAXIMUM RESPONSE	APPLICABLE NOTES
Pressure, Oxidizer Suction	PoS	0/200 PSIA	NO	YES	-	Strain Gage Bridge	3.0	4.8	400	80 Hz	1, 3
Pressure, Fuel Suction	PfS	0/150 PSIA	YES	-	-	Strain Gage Bridge	2.24	3.64	400	80 Hz	1, 2
Pressure, Thrust Chamber	Pc	0/1000 PSIA	YES	-	-	Strain Gage Bridge	23.4	31.0	400	80 Hz	1, 2
Pressure, Oxidizer Discharge	PoD	0/1500 PSIA	YES	-	-	Strain Gage Bridge	35.0	43.5	400	80 Hz	1, 2
Pressure, Fuel Discharge	PfD	0/1500 PSIA	YES	-	-	Strain Gage Bridge	35.0	43.5	400	80 Hz	1, 2
Pressure, Oxidizer Bootstrap Venturi Inlet	PoBTVI	0/1500 PSIA	YES	-	-	Strain Gage Bridge	35.0	43.5	200	40 Hz	1, 2
Pressure, Fuel Bootstrap Venturi Inlet	PfBTVI	0/1500 PSIA	YES	-	-	Strain Gage Bridge	35.0	43.5	200	40 Hz	1, 2
Pressure, Gas Generator Chamber	PcGG	0/1000 PSIA	YES	-	-	Strain Gage Bridge	23.4	31.0	200	40 Hz	1, 2
Pressure, Fuel Pressurant Orifice Inlet	PfPOI	0/500 PSIA	YES	-	-	Strain Gage Bridge	12.7	16.5	100	20 Hz	1, 2
Pressure, Oxidizer Pressurant Orifice Inlet	PoPOI	0/1000 PSIA	YES	-	-	Strain Gage Bridge	23.4	31.0	100	20 Hz	1, 2
Pressure, Lube Pump Discharge	PLD	0/100 PSIA	YES	-	-	Strain Gage Bridge	.76	3.7	100	20 Hz	1, 2
Pressure, Hydraulic System	PHS	0/4500 PSIA	YES	-	-	Strain Gage Bridge	108.0	202.0	100	20 Hz	1, 2
Differential Pressure, Pitch Actuator	DPPA	-7000/7000 PSID	YES	-	-	Strain Gage Bridge	197.0	285.0	100	20 Hz	1, 2
Differential Pressure, Yaw Actuator	DPYA	-7000/7000 PSID	YES	-	-	Strain Gage Bridge	197.0	285.0	100	20 Hz	1, 2
Temperature, Oxidizer Suction	ToS	0/100 °F	YES	-	-	Resistance-Bridge	1.75	5.5	20	4 Hz	1, 2
Temperature, Fuel Suction	TfS	0/100 °F	YES	-	-	Resistance-Bridge	1.75	5.5	20	4 Hz	1, 2
Temperature, Fuel Pressurant Orifice Inlet	TfPOI	0/500 °F	YES	-	-	Resistance-Bridge	8.75	12.47	20	4 Hz	1, 2
Temperature, Oxidizer Pressurant Orifice Inlet	ToPOI	0/500 °F	YES	-	-	Resistance-Bridge	8.75	12.47	20	4 Hz	1, 2
Temperature, Nozzle Extension Skin - 1	TNES-1	0/1000 °F	YES	-	-	T/C & Ref. Comp.	22.2	27.0	20	4 Hz	1, 2
Temperature, Nozzle Extension Skin - 3	TNES-3	0/1000 °F	YES	-	-	T/C & Ref. Comp.	22.2	27.0	20	4 Hz	1, 2
Temperature, Nozzle Extension Skin - 5	TNES-5	0/1000 °F	YES	-	-	T/C & Ref. Comp.	22.2	27.0	20	4 Hz	1, 2
Temperature, Gearbox Bearing No. 6A	TGB-6A	0/500 °F	NO	YES	-	Resistance-Bridge	8.75	12.47	200	40 Hz	1, 4
Temperature, Gearbox Bearing No. 6B	TGB-6B	0/500 °F	NO	YES	-	Resistance-Bridge	8.75	12.47	200	40 Hz	1, 4
Detector, Engine Compartment Fire/Leakage	DECF/DgEC	* *	NO	-	YES	*	*	*	*	*	* 9
Thrust Chamber Pressure Switch A	$TCPS_A$	ON/OFF Press.	YES	-	-	Pressure Switch	N/A	N/A	100	0.1 sec	5
Thrust Chamber Pressure Switch B	$TCPS_B$	ON/OFF Press.	YES	-	-	Pressure Switch	N/A	N/A	100	0.1 sec	5
Thrust Chamber Pressure Switch C	$TCPS_C$	ON/OFF Press.	YES	-	-	Pressure Switch	N/A	N/A	100	0.1 sec	5
Speed Turbine	NT	0/31000 RPM	YES	-	-	Magnetic Probe & AC to DC Converter	808	929	200	40 Hz	1, 2
Level, Hydraulic Reservoir	LHS	0/100 %	YES	-	-	Potentiometer	1	2.74	20	4 Hz	1, 2

TABLE IV-10

CORE LRE MEASUREMENTS (CON'T)	SYMBOL	RANGE & UNITS		USED ON PREVIOUS TITAN III VEHICLES	TECHNOLOGY EXISTS	NEW TECHNOLOGY REQUIRED	TRANSDUCER TYPE	ACCURACY IN EQUIVALENT ENGINEERING UNITS (±)		A/B TLM MEAS RESPONSE		APPLICABLE NOTES
								TRANSDUCER ONLY	TOTAL INSTRUMENTATION SYSTEM	SAMPLE RATE IN SAMPLES PER SECOND	EQUIVALENT MAXIMUM RESPONSE	
Position, Oxidizer Prevalve	LoPV	ON/OFF	Open/ Closed	YES	-	-	Microswitch	N/A	N/A	N/A	N/A	5, 6
Position, Fuel Prevalve	LfPV	ON/OFF	Open/ Closed	YES	-	-	Microswitch	N/A	N/A	N/A	N/A	5, 6
Position, Pitch Actuator	LPA	-5/5	DEG	YES	-	-	Potentiometer	.089	.18	100	20 Hz	1, 2
Position, Yaw Actuator	LYA	-5/5	DEG	YES	-	-	Potentiometer	.089	.18	100	20 Hz	1, 2
CORE TANK MEASUREMENTS	SYMBOL											
Pressure, Oxidizer Tank Gas-1	PgOT-1	0/50	PSIA	NO	YES	-	Potentiometer	1.0	1.5	40	8 Hz	1, 3
Pressure, Fuel Tank Gas-1	PgFT-1	0/50	PSIA	NO	YES	-	Potentiometer	1.0	1.5	40	8 Hz	1, 3
Pressure, Oxidizer Tank Gas-2	PgOT-2	0/50	PSIA	NO	YES	-	Potentiometer	1.0	1.5	40	8 Hz	1, 3
Pressure, Fuel Tank Gas-2	PgFT-2	0/50	PSIA	NO	YES	-	Potentiometer	1.0	1.5	40	8 Hz	1, 3
Temperature, Oxidizer Tank Liquid	ToT	20/200	^{o}F	YES	-	-	Resistance-Bridge	2.5	N/A	N/A	N/A	6
Temperature, Fuel Tank Liquid	TfT	20/200	^{o}F	YES	-	-	Resistance-Bridge	2.5	N/A	N/A	N/A	6
SRM MEASUREMENTS	SYMBOL											
Pressure, Motor Head End, A	$PgMHE_A$	0/1000	PSIA	YES	-	-	Strain Gage Bridge	23.4	31.0	400	80 Hz	1, 8
Pressure, Motor Head End, B	$PgMHE_B$	0/1000	PSIA	YES	-	-	Strain Gage Bridge	23.4	31.0	400	80 Hz	1, 8
Pressure, Injectant Manifold, A	$PoIM_A$	0/1500	PSIA	YES	-	-	Strain Gage Bridge	35.0	43.5	400	80 Hz	1, 8
Position, Injectant Valve, Average Quad 1, A	$LIVA1_A$	0/9.5	VDC	YES	-	-	Potentiometer	.1	.2	100	20 Hz	1, 8
Position, Injectant Valve, Average Quad 1, B	$LIVA1_B$	0/9.5	VDC	YES	-	-	Potentiometer	.1	.2	100	20 Hz	1, 8
Position, Injectant Valve, Average Quad 2, A	$LIVA2_A$	0/9.5	VDC	YES	-	-	Potentiometer	.1	.2	100	20 Hz	1, 8
Position, Injectant Valve, Average Quad 2, B	$LIVA2_B$	0/9.5	VDC	YES	-	-	Potentiometer	.1	.2	100	20 Hz	1, 8
Position, Injectant Valve, Average Quad 3, A	$LIVA3_A$	0/9.5	VDC	YES	-	-	Potentiometer	.1	.2	100	20 Hz	1, 8
Position, Injectant Valve, Average Quad 3, B	$LIVA3_B$	0/9.5	VDC	YES	-	-	Potentiometer	.1	.2	100	20 Hz	1, 8
Position, Injectant Valve, Average Quad 4, A	$LIVA4_A$	0/9.5	VDC	YES	-	-	Potentiometer	.1	.2	100	20 Hz	1, 8
Position, Injectant Valve, Average Quad 4, B	$LIVA4_B$	0/9.5	VDC	YES	-	-	Potentiometer	.1	.2	100	20 Hz	1, 8
Detector, SRM Burnthrough	DBT	*	*	NO	-	YES	*	*	*	*	*	* 9
Position, SRM S/A Device	L-S/A	ON/OFF	Safe/ Armed	NO	YES	-	Rotary Switch Con.	N/A	N/A	N/A	N/A	5, 6
Pressure, Injectant Gas	PgIJ	0/1500	PSIA	YES	-	-	Strain Gage Bridge	35.0	N/A	N/A	N/A	6

NOTES:

1. Response time is limited by the physical characteristics of the sensor and/or the rate at which the measurement is sampled. Generally transducer response is much faster than the response allowed by the instrumentation system sample rate. For the purpose of this table it was assumed that the response of telemetered measurements is always limited by the sample rate. Therefore, since 5 samples are required to define 1 cycle of data, the response rate for analog measurements is equal to 1/5 the sample rate.

2. Accuracies given are based on error analysis for identical measurements on previous Titan III vehicles. The accuracies given include some transducer and system errors which can be calibrated out. The "transducer" accuracy column lists the physical equivalent for the sum of the applicable transducer errors. The "total system" accuracy column lists the equivalent engineering units for the root - sum - square of the applicable system errors such as transducer, signal conditioning, airborne encoding, ground decoding, and recorder errors.

3. Accuracies given are new values specifically derived for T III L because of the new measurement range.

4. Measurement was not flown on previous Titan vehicles. The new measurement was evaluated and the required information derived and assigned specifically for T III L.

5. Accuracy is not applicable to this bi-level measurement. The maximum response time for airborne bi-level measurements is equivalent to the time-span between telemetry system samples. The airborne system sample rate and response columns do not apply to bi-level landline outputs as these outputs are continuously monitored by ground control logic and the data recording set.

6. Landline output only.

7. Landline measurement only, therefore, airborne system response and accuracies do not apply.

8. Accuracy information has been approximated for this measurement and is based on error analysis for similar type core measurement. (See Note 2).

9. This measurement is listed under new technology required because further investigation is required to establish sensor type and derive other measurement information.

b) Start

c) Shutdown

Discrete signals provided to the SRM's include:

a) Start

b) Thrust Termination

c) Staging

III. TITAN III L INSTRUMENTATION SYSTEM - The instrumentation system proposed for T III L is similar to systems flown on 16 successful Titan III flights to date. The Titan III instrumentation systems evolved as a result of experience gained on earlier missile programs coupled with state-of-the-art hardware advances and requirement changes. The specific system proposed for T III L is based on the system proposed and partially developed for T III M prior to the cancellation of that program. The instrumentation summary (Table IV-1) indicates range, sample rate and other information applicable to T III L propulsion measurements. Figures IV-12 and IV-13 locate measurements/sensors within a LRE subsystem and an SRM subsystem. The operation and interface requirements for the instrumentation system are discussed in the following subparagraphs.

1. The Typical Sequence of Operation for propulsion measurements sensed and transmitted by the T III L instrumentation system are shown in the block diagram (Figure IV-14). The measurement originates as an electrical signal from some source such as a pressure transducer, bus voltage or discrete switch.

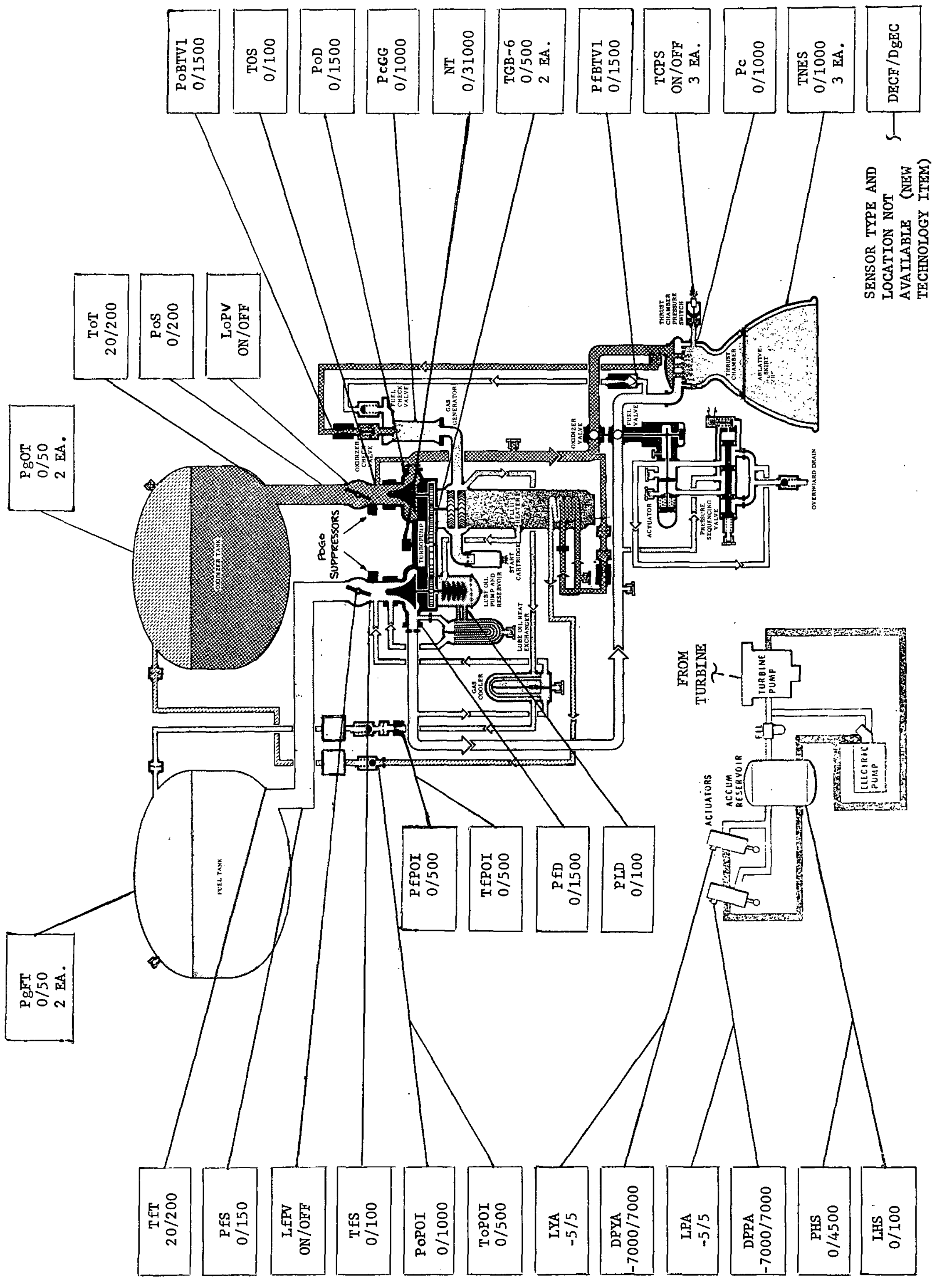
If the electrical signal is not compatible with the required inputs of the Remote Multiplexer Unit (RMU), it is sent to a signal conditioner where it is transformed into a compatible signal. The signal is then sampled and amplified in the RMU and upon command from the RMIS Converter Unit (CU), the signal is sent to the CU in (Pulse Amplitude Modulated) PAM form. The CU transforms the PAM signal into digital form and places the digital information in a serial binary pulse train which modulates the PCM/FM transmitter. The transmitter amplifies, and provides the S-Band RF carrier on which the PCM wave train is transmitted to ground receiving stations for decoding, recording and display of data.

2. Ground interfaces with the airborne instrumentation system are required for test and checkout as follows:

   a. The PCM landline outputs are used to present the RMIS outputs to the ground station without the use of the RF subsystem. This method of monitoring the PCM outputs is used during subsystem testing and when it is expedient not to radiate RF.

   b. Ground Instrumentation Equipment (GIE) must be mated directly with the RMIS converter unit to program the memory of the CU. This operation is performed to obtain the desired sample rate for all applicable measurements.

   c. Certain tank instrumentation such as temperature transducers may also be monitored by propellant GSE during and following liquid propellant loading operations.



ENGINE MODULE TYPICAL OF 5 PLACES

Figure IV-24 Propulsion System Sensor Locations

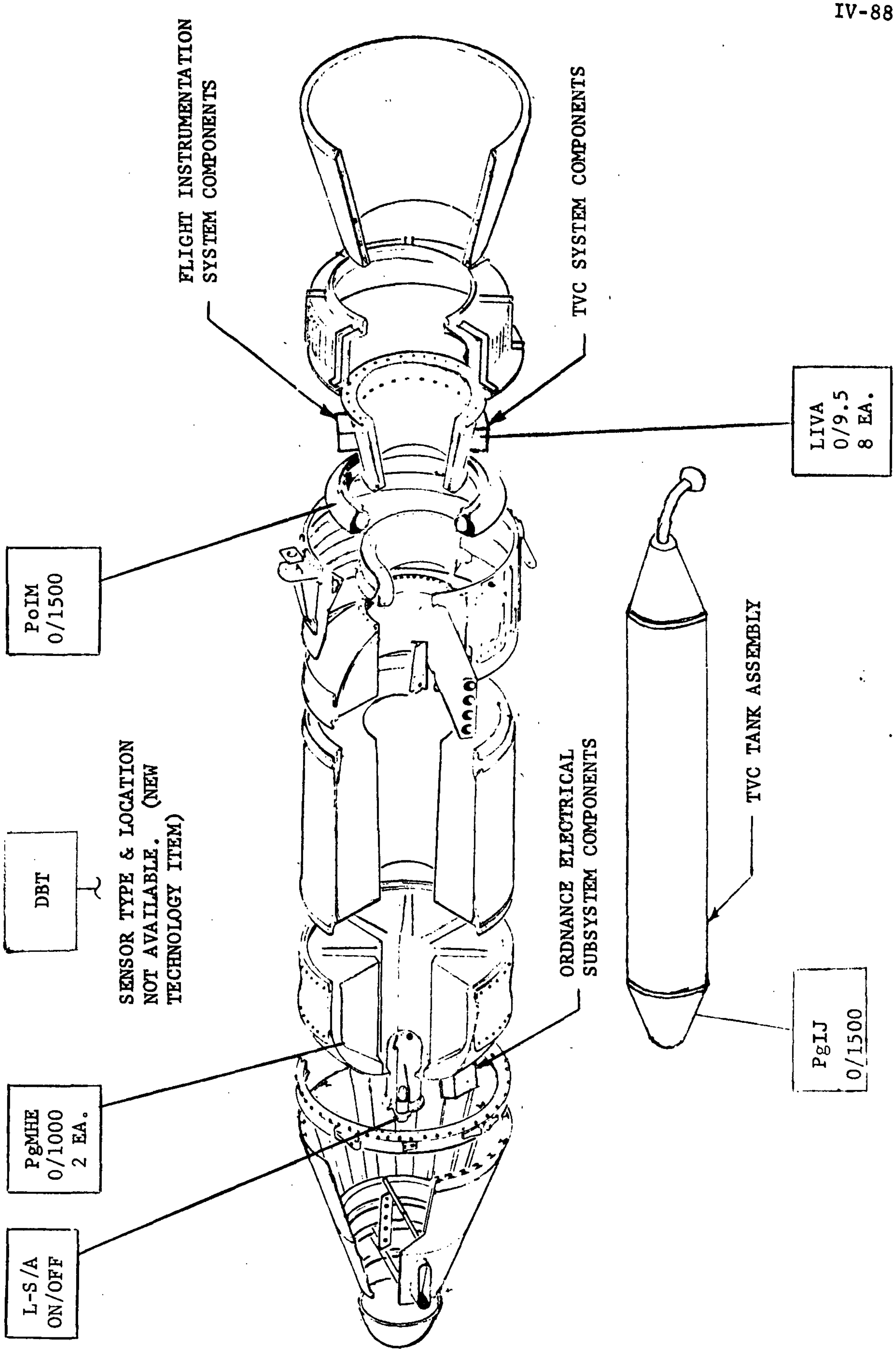


Figure IV-25 Solid Rocket Motor Sensor Locations

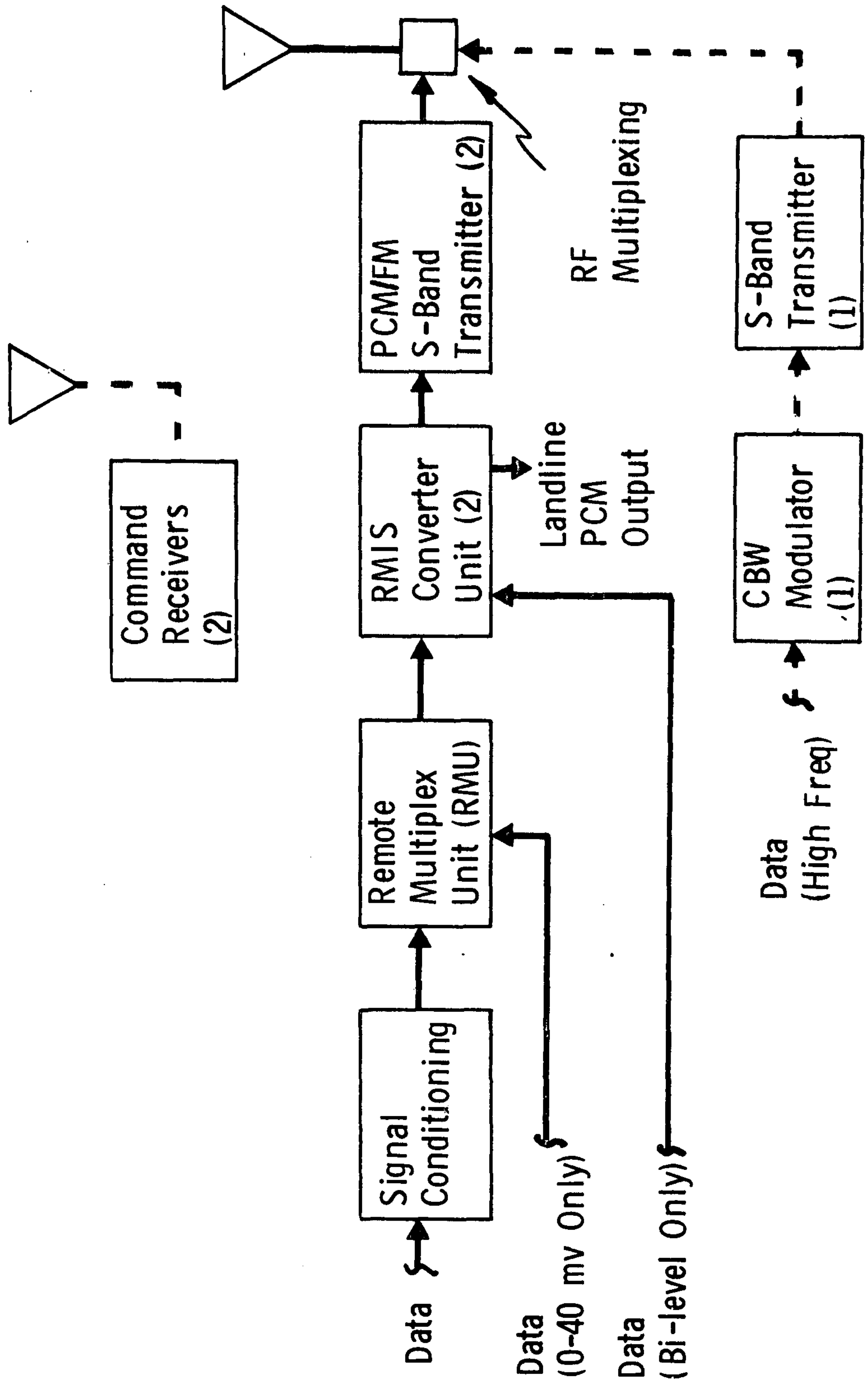


Figure IV-26 Titan III L Instrumentation

IV. <u>TITAN III L SRM ELECTRICAL SUBSYSTEMS</u> - The SRM contains 3 subsystems which involve avionics. The functions performed by the SRM subsystems, in conjunction with the electrical/electronic signals and components involved, are shown in Figure IV-27 and discussed in the following paragraphs.

1. The SRM ordnance electrical subsystem provides for SRM ignition, staging, and thrust termination as well as an Inadvertent Separation Detection System (ISDS). The ignition and staging functions are performed upon receipt of discrete commands from the core vehicle. The thrust termination function is capable of being activated either by the core or by the ISDS.

   The ISDS provides the required logic, power and ordnance for thrust termination of the SRM should it become inadvertently separated from the core. Power for all other ordnance subsystem functions is supplied from the core transient power system (TPS).

2. The SRM Thrust Vector Control (TVC) subsystem is used to provide SRM steering via the injection of liquid nitrogen tetroxide (N_2O_4) into the nozzle exit cone to deflect the exhaust gases. Twenty-four electromechanical injectant valves are arranged in groups of six around the 4 quadrants of the exit cone. The valves control the flow of injectant in accordance with 0 to 10 volt command signals received from the TVC driver electronics in the core vehicle. While steering is accomplished via the injection of Fluid in the individual quadrants, excess injectant fluid is "dumped"

equally in all quadrants. TVC power is derived from the TVC battery during flight. Before launch, ground power is supplied through the ground power umbilical. On command from the ground, a motor actuated switch connects the TVC battery(s) to the power distribution bus.

3. The SRM instrumentation subsystem monitors performance of the SRM system during countdown, launch and flight and provides data for major malfunction analysis. Performance parameters, in the form of analog signals, obtained from transducers and monitors located throughout the SRM, are routed to the aft instrumentation box, and on to a remote multiplex unit. The analog signals are sampled and amplified in the RMU and upon command from the core RMIS converter unit (CU), the signal is sent through the forward staging disconnects to the CU in PAM form.

4. The SRM ground power umbilical is used to provide ground power, vehicle monitor power and commands from ground equipment. Monitors required to determine the status and performance of the ordnance electrical system for ground checkout, combined systems test, and launch countdown and holds are provided to ground facilities via the SRM ground power umbilical.

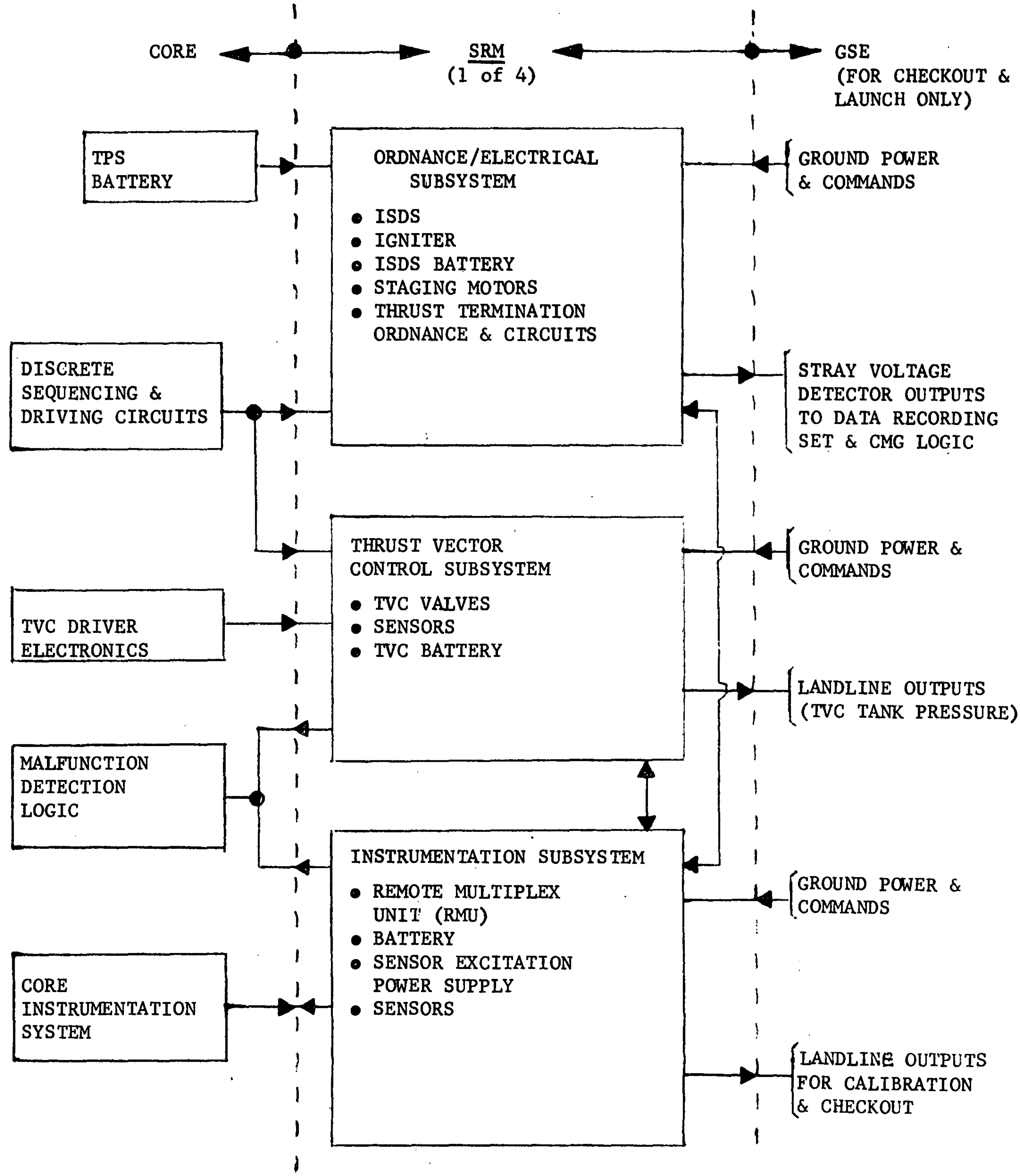


Figure IV-27 TITAN III L SRM AVIONICS

Quarterly Progress Report

October-December 1971

Space Shuttle Propulsion Systems
Onboard Checkout And
Monitoring System Development Study

Appendix A

TITAN III Propulsion
Measurement Usage

TITAN III PROPULSION MEASUREMENT USAGE

LRE MEASUREMENTS - STAGE I		PREVIOUS TITAN III PROGRAMS								RECOMMENDED T-III L USAGE			
		B		C		D		M					
MEASUREMENT NAME	SYMBOL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	PHASE B STUDY PRELIMINARY LIST	TASK III PRELIMINARY LIST	TASK III FINAL LIST	APPLICABLE NOTES
Pressure, Oxidizer Suction	PoS	.5	.5	.5	.5	.5	.5	.5	.5	1	1	1	A
Pressure, Fuel Suction	PfS	1	.5	1	.5	1	.5	1	1	1	1	1	A
Pressure, Fuel Toroidal Accumulator	PfTA	1	.5	1	.5	1	.5	1	1	1	1	0	A
Pressure, Thrust Chamber	Pc	1	1	1	1	1	1	1	1	1	1	1	A
Pressure, Oxidizer Discharge	PoD	1	1	1	1	1	1	1	1	1	1	1	A
Pressure, Fuel Discharge	PfD	1	1	1	1	1	1	1	1	1	1	1	A
Pressure, Oxidizer Bootstrap Venturi Inlet	PoBTVI	1	0	1	0	1	0	1	1	1	1	1	A
Pressure, Fuel Bootstrap Venturi Inlet	PfBTVI	1	0	1	0	1	0	1	1	1	1	1	A
Pressure, Gas Generator Chamber	PcGG	1	1	1	1	1	1	1	1	1	1	1	A
Pressure, Fuel Pressurant Orifice Inlet	PFPOI	.5	0	.5	0	.5	0	.5	0	1	1	1	A
Pressure, Oxidizer Pressurant Orifice Inlet	POPOI	.5	0	.5	0	.5	0	.5	0	1	1	1	A
Pressure, Oxidizer Accumulator Bellows A	$PoAB_A$	0	0	0	0	0	0	1	1	1	1	0	A
Pressure, Oxidizer Accumulator Bellows B	$PoAB_B$	0	0	0	0	0	0	1	1	0	1	0	A
Pressure, Lube Pump Discharge A	PLD_A	1	0	1	0	1	0	1	0	1	1	1	A
Pressure, Lube Pump Discharge B	PLD_B	0	0	0	0	0	0	0	0	0	1	0	A
Pressure, Lube Pump Discharge C	PLD_C	0	0	0	0	0	0	0	0	0	1	0	A
Pressure, Oxidizer Injector	PoJ	1	0	1	0	1	0	1	0	1	0	0	A
Pressure, Fuel Injector	PfJ	1	0	1	0	1	0	1	0	1	0	0	A
Pressure, Gas Gearbox	PgGB	1	0	1	0	1	0	1	0	1	0	0	A
Pressure, Gas Generator Oxidizer Injector	PoJGG	0	0	0	0	0	0	0	0	1	0	0	A

TITAN III PROPULSION MEASUREMENT USAGE

LRE MEASUREMENTS - Stage I		PREVIOUS TITAN III PROGRAMS								RECOMMENDED T-III L USAGE			
		B		C		D		M					
MEASUREMENT NAME	SYMBOL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	PHASE B STUDY PRELIMINARY LIST	TASK III PRELIMINARY LIST	TASK III FINAL LIST	APPLICABLE NOTES
Pressure, Gas Generator Fuel Injector	PfJGG	0	0	0	0	0	0	0	0	1	0	0	A
Pressure, Oxidizer Pressurant Venturi Inlet	PoPVI	.5	0	.5	0	.5	0	.5	0	1	0	0	A
Pressure, Hydraulic System - 1	PHS01	1	1	1	1	1	1	1	1	1	1	1	B
Pressure, Hydraulic System -2	PHS-2	0	0	0	0	0	0	1	1	0	0	0	B
Differential Pressure, Pitch Actuator	PPA-D	1	1	1	1	1	1	1	1	1	1	1	A
Differential Pressure, Yaw Actuator	PYA-D	1	1	1	1	1	1	1	1	1	1	1	A
Temperature, Oxidizer Suction	ToS	.5	.5	.5	.5	.5	.5	.5	.5	1	1	1	A
Temperature, Fuel Suction	TfS	.5	.5	.5	.5	.5	.5	.5	.5	1	1	1	A
Temperature, Fuel Pressurant Orifice Inlet	TfPOI	.5	.5	.5	.5	.5	.5	.5	.5	1	1	1	A
Temperature, Oxidizer Pressurant Orifice Inlet	ToPOI	.5	.5	.5	.5	.5	.5	.5	.5	1	1	1	A
Temperature, Nozzle Exit Liner Backside - 2	TNELB-2	1	0	1	0	1	0	1	0	1	1	0	A
Temperature, Nozzle Exit Liner Backside - 4	TNELB-4	1	0	1	0	1	0	1	0	1	1	0	A
Temperature, Nozzle Exit Liner Backside - 7	TNELB-7	1	0	1	0	1	0	1	0	1	1	0	A
Temperature, Nozzle Extension Skin - 1	TNES-1	1	0	1	0	1	0	1	0	1	1	1	A
Temperature, Nozzle Extension Skin - 3	TNES-3	1	0	1	0	1	0	1	0	1	1	1	A
Temperature, Nozzle Extension Skin - 5	TNES-5	1	0	1	0	1	0	1	0	1	1	1	A
Temperature, Nozzle Extension Skin - 6	TNES-6	1	0	1	0	1	0	1	0	1	1	0	A
Temperature, Gearbox Bearing No. 6	TGB-6	0	0	0	0	0	0	0	0	0	1	1	A
Temperature, Gas Cooler Inlet, Fuel	TfGGI	0	0	0	0	0	0	0	0	0	1	0	A
Temperature Gas Cooler Outlet, Fuel	TfGGO	0	0	0	0	0	0	0	0	0	1	0	A

TITAN III PROPULSION
MEASUREMENT USAGE

LRE MEASUREMENTS - STAGE I		PREVIOUS TITAN III PROGRAMS								RECOMMENDED T-III L USAGE			
		B		C		D		M					
MEASUREMENT NAME	SYMBOL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	PHASE B STUDY PRELIMINARY LIST	TASK III PRELIMINARY LIST	TASK III FINAL LIST	APPLICABLE NOTES
Temperature, Turbine Inlet	TTI	1	0	1	0	1	0	1	0	1	0	0	A
Temperature, Hydraulic System - 1	THS - 1	0	0	0	0	0	0	1	1	1	0	0	B
Temperature, Hydraulic System - 2	THS - 2	0	0	0	0	0	0	1	1	0	0	0	B
Pitch Actuator Extended Limit Switch	PAELS	0	0	0	0	0	0	0	0	0	1	0	A
Pitch Actuator Retracted Limit Switch	PARLS	0	0	0	0	0	0	0	0	0	1	0	A
Yaw Actuator Extended Limit Switch	YAELS	0	0	0	0	0	0	0	0	0	1	0	A
Yaw Actuator Retracted Limit Switch	YARLS	0	0	0	0	0	0	0	0	0	1	0	A
Thrust Chamber Pressure Switch A	$TCPS_A$	1	0	1	0	1	0	0	0	1	1	1	A
Thrust Chamber Pressure Switch B	$TCPS_B$	0	0	0	0	0	0	0	0	1	1	1	A
Thrust Chamber Pressure Switch C	$TCPS_C$	0	0	0	0	0	0	0	0	0	1	1	A
Oxidizer Pressurant Pressure Switch, Delta P	DoPPS	0	0	0	0	0	0	0	0	1	0	0	A
Fuel Pressurant Pressure Switch, Delta P	DfPPS	0	0	0	0	0	0	0	0	1	0	0	A
Speed Turbine	NT	1	0	1	0	1	0	1	1	1	1	1	A
Level, Hydraulic Reservoir	LHS	1	1	1	1	1	1	2	2	0	1	0	A
Displacement, Oxidizer Accumulator Bellows A	$LOAB_A$	0	0	0	0	0	0	1	1	0	1	0	A
Displacement, Oxidizer Accumulator Bellows B	$LOAB_B$	0	0	0	0	0	0	1	1	0	1	0	A
Position, Oxidizer Prevalve	LOPV	1	1	1	1	1	1	1	1	1	1	1	E
Position, Fuel Prevalve	LFPV	1	1	1	1	1	1	1	1	1	1	1	E
Position, Pitch Actuator	LPA	1	1	1	1	1	1	1	1	1	1	1	A
Position, Yaw Actuator	LYA	1	1	1	1	1	1	1	1	1	1	1	A

TITAN III PROPULSION
MEASUREMENT USAGE

LRE MEASUREMENTS - STAGE I		PREVIOUS TITAN III PROGRAMS								RECOMMENDED T-III L USAGE			
		B		C		D		M					
MEASUREMENT NAME	SYMBOL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	PHASE B STUDY PRELIMINARY LIST	TASK III PRELIMINARY LIST	TASK III FINAL LIST	APPLICABLE NOTES
Position, Thrust Chamber Valve	LTCV	1	0	1	0	1	0	1	0	1	0	0	A
Detector, Engine Compartment Fire/Leakage	DECF, DgEC	0	0	0	0	0	0	0	0	0	0	1	F
TANK MEASUREMENTS - STAGE I													
Pressure, Oxidizer Tank Gas-1	PgOT-1	1	1	1	1	1	1	1	1	1	1	1	C
Pressure, Fuel Tank Gas-1	PgFT-1	1	1	1	1	1	1	1	1	1	1	1	C
Pressure, Oxidizer Tank Gas-2	PgOT-2	0	0	0	0	0	0	1	1	1	1	1	C
Pressure, Fuel Tank Gas-2	PgFT-2	0	0	0	0	0	0	1	1	1	1	1	C
Pressure, Oxidizer Tank Gas-3	PgOT-3	0	0	0	0	0	0	0	0	0	1	0	C
Pressure, Fuel Tank Gas-3	PgFT-3	0	0	0	0	0	0	0	0	0	1	0	C
Position, Oxidizer Outage Level	1oOL	1	1	1	1	1	1	1	1	1	1	0	C
Position, Fuel Outage Level	LfOL	1	1	1	1	1	1	1	1	1	1	0	C
Position, Oxidizer High Point	LoHP	1	0	1	0	1	0	1	1	1	0	0	C
Position, Fuel High Point	LfHP	1	0	1	0	1	0	1	1	1	0	0	C
Temperature, Oxidizer Tank Gas	TgOT	0	0	0	0	0	0	0	0	0	1	0	E
Temperature, Fuel Tank Gas	TgFT	0	0	0	0	0	0	0	0	0	1	0	E
Temperature, Oxidizer Tank Liquid	ToT	1	1	1	1	1	1	1	1	0	1	1	E
Temperature, Fuel Tank Liquid	TfT	1	1	1	1	1	1	1	1	0	1	1	E

TITAN III PROPULSION
MEASUREMENT USAGE

SRM MEASUREMENTS		PREVIOUS TITAN III PROGRAMS								RECOMMENDED T-III L USAGE			
		B		C		D		M					
MEASUREMENT NAME	SYMBOL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	INITIAL	OPERATIONAL	PHASE B STUDY PRELIMINARY LIST	TASK III PRELIMINARY LIST	TASK III FINAL LIST	APPLICABLE NOTES
Pressure, Motor Head End, A	$PgMHE_A$	0	0	1	1	1	1	1	1	1	1	1	D
Pressure, Motor Head End, B	$PgMHE_B$	0	0	1	1	1	1	0	0	1	1	1	D
Pressure, Injectant Manifold, A	$PoIM_A$	0	0	1	1	1	1	1	1	1	1	1	D
Pressure, Injectant Manifold, B	$PoIM_B$	0	0	1	1	1	1	1	1	1	1	0	D
Pressure Rate, Head End	PRHE	0	0	0	0	0	0	0	0	0	1	0	F
Pressure, Gas Injectant	PgIT	0	0	1	1	1	1	1	1	0	0	1	E
Pressure Igniter Case		0	0	0	0	0	0	1	1	0	0	0	D
Position, Injectant Valve, Average Quad 1, A	$LIVA1_A$	0	0	1	1	1	1	1	1	1	1	1	D
Position, Injectant Valve, Average Quad 1, B	$LIVA1_B$	0	0	1	1	1	1	1	1	1	1	1	D
Position, Injectant Valve, Average Quad 2, A	$LIVA2_A$	0	0	1	1	1	1	1	1	1	1	1	D
Position, Injectant Valve, Average Quad 2, B	$LIVA2_B$	0	0	1	1	1	1	1	1	1	1	1	D
Position, Injectant Valve, Average Quad 3, A	$LIVA3_A$	0	0	1	1	1	1	1	1	1	1	1	D
Position, Injectant Valve, Average Quad 3, B	$LIVA3_B$	0	0	1	1	1	1	1	1	1	1	1	D
Position, Injectant Valve, Average Quad 4, A	$LIVA4_A$	0	0	1	1	1	1	1	1	1	1	1	D
Position, Injectant Valve, Average Quad 4, B	$LIVA4_B$	0	0	1	1	1	1	1	1	1	1	1	D
Injectant Manifold Pressure Switch A	$IMPS_A$	0	0	0	0	0	0	0	0	0	1	0	D
Injectant Manifold Pressure Switch B	$IMPS_B$	0	0	0	0	0	0	0	0	0	1	0	D
Injectant Manifold Pressure Switch B	$IMPS_B$	0	0	0	0	0	0	0	0	0	1	0	D
Injectant Manifold Pressure Switch C	$IMPS_C$	0	0	0	0	0	0	0	0	0	1	0	D
Position, SRM S/A Device	L-S/A	0	0	1	1	1	1	1	1	1	1	1	D
Detector, SRM Burnthrough	DBT	0	0	0	0	0	0	0	0	0	1	1	F

APPLICABLE NOTES FOR MEASUREMENT USAGE TABLE

A. Measurement usage is listed for each liquid rocket engine (LRE). Previous Titan vehicles (B,C, D & M) had 2 Stage I LREs (subassemblies). Titan III L vehicles have 5 Stage I LREs.

Example: .5 = 1 measurements per 2 LREs
1 = measurements per LRE
0 = no measurement

B. Measurements per hydraulic system are listed. One hydraulic system was used on previous Titan vehicles (B, C, D & M); 5 independant hydraulic systems areatilized on T-III L.

C. Measurements per tank are listed. (equivilant for all Titan III vehicles)

D. SRM measurements are listed per SRM. Only those measurements applicable to SRMs with electro-mechanical TVC values are listed. Earlier SRMs employed hydraulic systems in conjunction with electro-hydraulic TVC values.

E. Indicates landline measurement only.

F. Technology item requiring further evaluation.