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Final Report

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

VOLUME I - SUMMARY

March 1971

Contract NAS8-25619
DRL No. 187 Rev. A
Line Item No. 3

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

Prepared by

MARTIN MARIETTA
DENVER DIVISION

MCR-71-62

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Approved by

R. W. VandeKoppel
Program Manager

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MARTIN MARIETTA CORPORATION
Denver, Colorado 80201

FOREWORD

This report was prepared by the Martin Marietta Corporation under Contract NAS8-25619, "Space Shuttle Propulsion Systems On-board Checkout and Monitoring System Development Study," for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The report is comprised of four volumes:

- Volume I - Summary
- Volume II - Propulsion System Definition and Criteria
- Volume III - OCMS Criteria and Concept
- Volume IV - Appendices

CONTENTS

ABSTRACT

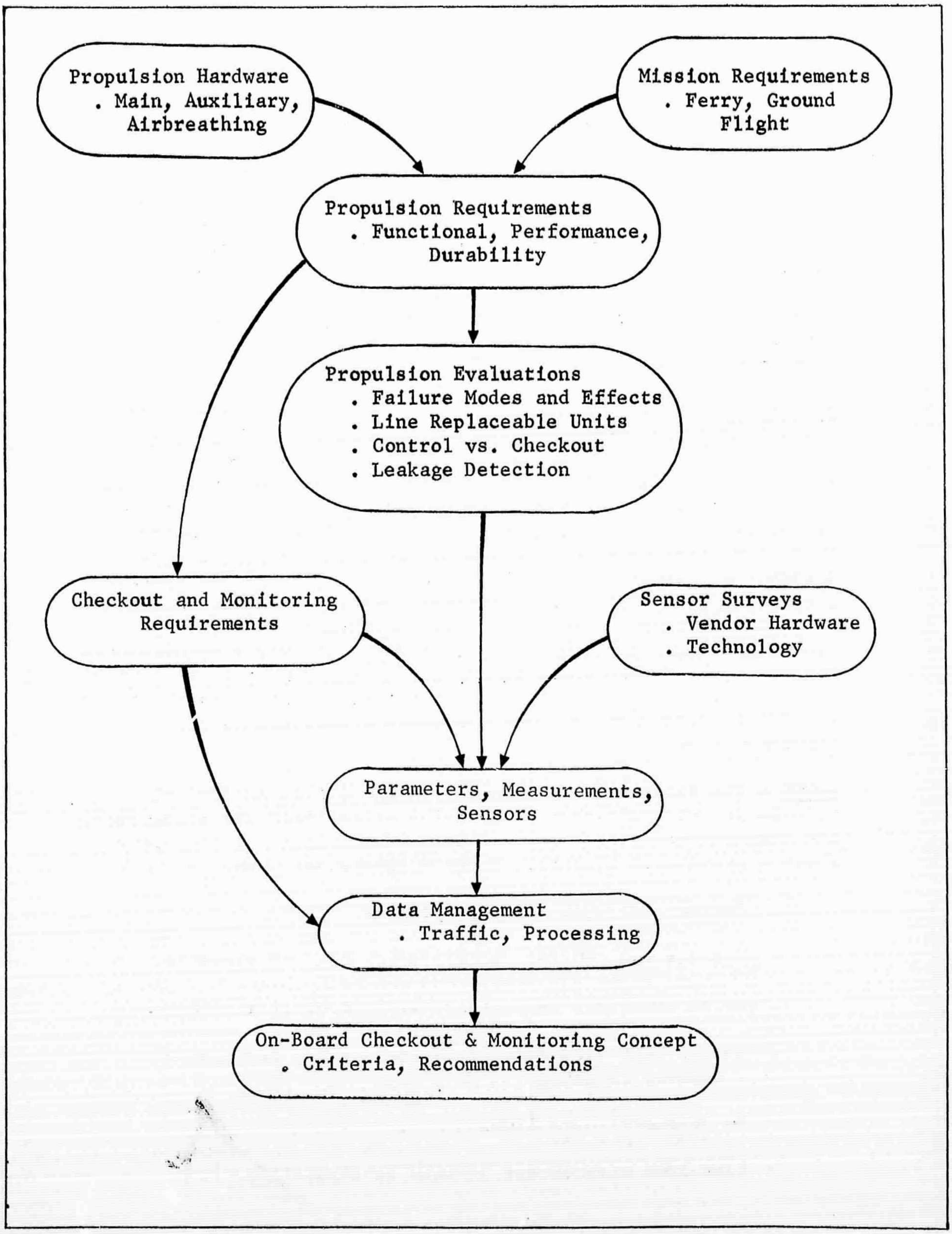
This final report describes the effort completed by the Martin Marietta Corporation under Contract NAS8-25619, "Space Shuttle Propulsion Systems On-Board Checkout and Monitoring System Development Study". The work was comprised of an evaluation of the Space Shuttle main, auxiliary, and airbreathing propulsion systems' functional, performance and durability requirements to define checkout and monitoring criteria, and to evolve an approach for performing the functions of preflight checkout, performance monitoring, fault isolation, emergency detection, display, data storage, post flight evaluation, and maintenance retest.

BACKGROUND - The Space Shuttle program objective of providing an economical space transportation system requires maximum reuse of components as well as minimal time, labor and equipment for servicing and checkout between flights. A requirement for high mission success probability also is inherent in this objective. Recent technology has demonstrated the feasibility of meeting these requirements by incorporating on-board checkout and performance monitoring capability. The propulsion systems (particularly the main engines) are pacing items in the Space Shuttle program; therefore, the checkout and performance monitoring techniques, data management requirements, and sensor requirements must be defined for incorporation in the basic propulsion system designs. This study has been conducted to define an approach and establish procedures, methods and design requirements for implementation.

SCOPE - The intent of the program was to develop analytical techniques and apply them in defining an approach for accomplishing the checkout and performance monitoring functions of the Space Shuttle propulsion systems. Program guidelines were:

- Operational Space Shuttle program.
- Booster and Orbiter, both recoverable and reusable.
- Main, auxiliary and airbreathing propulsion systems.
- No inflight maintenance; 10 working day turnaround between flights.
- No telemetry data link.
- Baselined mission and vehicle configuration.

ABSTRACT (Continued)



STUDY APPROACH

ABSTRACT (Continued)

CONCLUSION - The result of this study indicates that the on-board checkout and monitoring approach is technically feasible, will improve system reliability, and will simplify ground operations. The implementation of the function must be controlled by a requirements standard, to ensure that the necessary approach and methodology are utilized, and so that the required degree of propulsion and electronics systems integration is accomplished. The basic design of the propulsion systems must incorporate the checkout and monitoring functional requirements, including sensors.

METHOD - The technical approach that was developed and used to meet the program objectives is illustrated on the facing page. Key aspects of these study elements are discussed in the remainder of this abstract.

BASELINING - A baseline vehicle configuration with main, auxiliary, and airbreathing propulsion systems on the booster and the orbiter was selected. The propulsion systems, subsystems, assemblies and components were defined on functional schematics. Components were identified by selecting from Space Shuttle Phase B Program definitions and from specific Saturn components. The booster had 14 staged combustion oxygen/hydrogen main engines, 7 hydrogen-fueled turbofan engines, and 38 hydrogen/oxygen separation and attitude control thrusters; a total of 1303 booster propulsion components were defined. The orbiter had 2 main engines, 3 airbreathing engines, 39 thrusters, and a total of 625 propulsion components.

A space station resupply mission was selected. Ferry, ground and flight operations were defined by activity timelines for the 17 sequential phases of the mission.

PROPULSION REQUIREMENTS - The propulsion configuration was related to the mission requirements by defining the propulsion performance, functional, and durability requirements of the mission, including operational interfaces with ground systems.

PROPULSION EVALUATIONS - Failure modes and effects were analyzed at the propulsion component level. This analysis provided visibility to:

- Hazard warning functions;
- Candidate parameters, measurements and sensors;
- Single point failures and excessive redundancy.

ABSTRACT (Continued)

Line replaceable units (propulsion elements which could be fault-isolated inflight and replaced in maintenance operations) were identified, 929 on the booster and 322 on the orbiter. The propulsion control sensors are not included in these quantities.

Diagrams illustrating the sequence and logic involved in propulsion system control functions (start, modulation, shutdown, etc.) were prepared.

Leakage sources and consequences were determined, and a recommended approach was identified for performing the functions of leakage detection and monitoring for hazardous concentration levels of hydrogen gas.

PARAMETERS, MEASUREMENTS, SENSORS - The propulsion evaluations resulted in candidate parameters for the checkout and monitoring function. Recommended measurements were compiled and the associated sensor criteria identified by determining such requirements as accuracy, rate, and environment. Sensor availability was investigated by surveying 93 sensor vendors. In-work sensor technology was also evaluated for potential applications; the following areas were recommended for further sensor technology work:

- Leak detection - ultrasonics.
- Bearing wear detection - acoustic emission and deflection.
- Ignition detection - light detectors, ultrasonics.
- Differential pressure transducers - small ΔP's in high pressure systems.

The measurement definitions (which maximized usage of control functions) resulted in the following measurement quantities:

	Booster	Orbiter
Main Engines (14 booster, 2 orbiter engines)	1274	198
Airbreathing Engines (7 booster, 3 orbiter engines)	287	123
Other Propulsion	1569	1027
TOTAL	3130	1348

ABSTRACT (Continued)

By incorporating checkout and monitoring function requirements in the basic designs of the propulsion components and subsystems, these quantities could be reduced.

DATA MANAGEMENT - The baseline vehicle electronics included the following:

- Central Computer Complex
- Vehicle Data Bus
- Dedicated Peripheral Computers (main and airbreathing engine controllers)
- Displays and Controls
- Recorders.

The vehicle data bus was configured to provide maximum flexibility and minimum remote hardware, at the expense of relatively high data bus rates. Propulsion system vehicle data bus traffic and central computer processing loads were as follows for peak periods:

	Booster	Orbiter
Data Rate, Bits/Second	430,000	64,000
Processing, Seconds/Second	0.76	0.11

Also, during main engine start the data rate across the engine controller/vehicle data bus peaked at 10,600 Bits/second.

ONBOARD CHECKOUT AND MONITORING CONCEPT - Criteria for functional capability and usage in the following areas were developed to establish the degree of on-board checkout, monitoring and evaluation functions:

- Preflight checkout and monitoring
- Inflight monitoring
  - Ready-to-start condition verification
  - Emergency detection
  - Fault detection
  - Fault isolation
  - Real time trend analysis
  - Operating histories
  - Performance data

ABSTRACT (Continued)

- Post flight evaluation
- Maintenance retest
- Control and checkout processing integration

Key elements of these criteria include:

- Preflight checkout of mechanical elements is limited to verification of correct initial conditions for start.
- Inflight functions incorporate maintenance and performance parameters as well as flight safety and mission success parameters.
- Evaluation of flight-recorded data will be accomplished by the on-board computer complex after landing to generate maintenance printouts, trend analysis results, and performance data records.
- The on-board checkout capabilities will be utilized in maintenance operations for verification retest of replaced propulsion elements.
- Control, checkout and monitoring will be treated as a single function for purposes of computer processing.
- Only that information necessary for crew evaluation or action will be displayed.

RECOMMENDATIONS - General recommendations pertaining to the implementation of the propulsion checkout and monitoring function include:

- Incorporate the function into the basic propulsion subsystem and component design.
- Ensure thorough technical coordination between the propulsion and avionics disciplines.
- Minimize number of measurements and complexity of sensors by analyzing requirements of and alternate techniques for each candidate parameter.
- Integrate the propulsion control function with the checkout and monitoring function.
- Conduct further sensor technology work in the areas of leak detection, bearing wear detection, ignition detection, and accurate measurement of small differential pressures in high pressure systems.

A primary objective of the Space Shuttle program is to provide an economical space transportation system. To meet this objective, the program definition studies have evolved a concept which approaches an airliner configuration and mode of operations - a vehicle that can safely and reliably perform a mission, return to the base, and be readied quickly for the next flight.

Implementing this concept requires a departure from many of the ground equipment and flight hardware design approaches and operational procedures which are used on existing launch vehicles. For example, contemporary launch vehicles require many months of preflight checkout and testing operations to ensure flight readiness. A significant amount of test equipment and labor is required to perform these operations; much of the time is spent in attaching the ground equipment to the vehicle, performing tests, and then removing the test hardware. A significant step toward accomplishing the Space Shuttle program objective could therefore be realized by reducing the time, labor and equipment required to service and check out the operational Space Shuttle vehicles between flights.

Recent technology has demonstrated the feasibility of approaching this goal by incorporating on-board checkout and performance monitoring capability. For example, experience is being gained from advanced aircraft operational performance data gathering and analysis systems, such as the Airborne Integrated Data Systems (AIDS) for commercial aircraft and the Malfunction Detection Analysis and Recording (MADAR) system for the C-5A. These systems characteristically monitor from twenty to four hundred aircraft parameters, and process the data to extract maintenance action requirements and establish flight profile analyses. As another example, five years of on-board checkout technology work at the Martin Marietta Corporation culminated in 1970 with the delivery to NASA of a general purpose, flight packaged on-board checkout system. This hardware is currently being used by NASA to develop further on-board checkout concept technology.

This on-board checkout technology background together with the Space Shuttle requirements and characteristics have lead into Contract NAS8-25619, "Space Shuttle Propulsion Systems On-board Checkout and Monitoring System Development Study." Since the propulsion systems (particularly the main engines) are pacing items in the Space Shuttle program and require early development, the establishment of checkout and performance monitoring techniques, data management requirements, and sensor technology requirements must be accomplished early enough to allow the criteria to be incorporated in the basic design. This study has been conducted to define an approach and to establish the candidate procedures, methods and design requirements by which the approach could be implemented.

This final report presents the work accomplished under the subject contract. The report is comprised of four volumes. Volume I, Summary, includes an abstract which presents the highlights of the approach and findings; an elaboration of the technical approach; and the conclusions and recommendations. Volume II, Propulsion System Definition and Criteria, defines the baseline model used in the study and presents the propulsion systems criteria for checkout and monitoring. Volume III, OCMS Criteria and Concept, defines the propulsion systems' on-board checkout and monitoring requirements, measurement and sensor requirements, and presents the on-board checkout and monitoring concept. Volume IV, Appendices, contains significant supporting data produced in the study.

A. OBJECTIVE AND SCOPE

The objective of Contract NAS8-25619, "Space Shuttle Propulsion Systems On-board Checkout and Monitoring System Development Study," was stated in the Contract Scope of Work as follows:

> "Objective: To define an onboard, checkout, inflight monitoring, emergency detection and post flight evaluation system for the Space Shuttle Propulsion systems. This system should be consistent with an overall vehicle approach and optimize for a minimum of operating personnel required for the various phases of Launch and Support Operations. The defined approach should accomplish the goal of assuring an acceptable probability of mission success with requisite probability of safe return. Additionally, the approach should be consistent with the constraints of minimum onboard weight and system complexity.
> A study should establish the checkout, monitoring and evaluation approach which defines the degree to which the function of preflight checkout, subsystem and/or components ready to start condition, inflight performance monitoring, fault isolation, diagnosis, emergency detection, display, data storage, post flight evaluation and maintenance will be performed. This study will include the main, auxiliary and air breathing propulsion systems."

Certain guidelines were used in the study to ensure applicability of the results to the Space Shuttle program, and to provide a set of constraints to bound the study. These constraints and guidelines included the following:

1. Pertinent Space Shuttle Phase B program definitions and requirements were to be incorporated.

2. The study was directed specifically at the operational Space Shuttle program, rather than the development test phase.

3. Inflight maintenance of the Space Shuttle vehicle was excluded; all maintenance was to be performed in ground operations, with a total time allowed for turnaround between flights of 14 calendar days (10 working days).

4. A telemetry data link (for checkout and monitoring) between the Space Shuttle vehicle and ground stations or a space station was excluded.

5. The study was to be conducted on a selected vehicle configuration (including the booster and orbiter propulsion system configurations) and a defined mission.

6. In-flight fault isolation to the line replaceable unit (LRU) level was considered a requirement, where an LRU is a propulsion element that can be removed, replaced and verified during maintenance without deleteriously impacting the Space Shuttle turnaround time.

The conduct of this study was in compliance with the Contract Statement of Work, and the subtasks presented therein were accomplished. The general item in the Statement of Work which read, "In performing this task proper recognition must be given to the demands and requirements of other space shuttle systems such as simultaneous demands for on-board capability" was not expressly met by providing numerical data on the vehicle data bus traffic and processing loads imposed by other subsystems during periods of peak propulsion data traffic. Such numerical data were not available for the baseline data management system used in this study. Also, mathematical models for processing of the propulsion data were deleted as a required product of the study.

B. APPROACH

The technical approach used in conducting the study is illustrated in Figure I-1. The work was organized in two categories. Task I consisted of a definition of the propulsion systems, their functional, performance, and durability requirements, and analyses to establish the propulsion checkout and monitoring criteria. Task 2 was comprised of evaluations to establish the checkout and monitoring requirements for the propulsion systems, definition of measurements and sensors, and evolution of the approach for on-board checkout and monitoring.

As indicated in Figure II-1, the study used a Design Reference Model (DRM) approach. The DRM was comprised of a vehicle configuration (booster and orbiter) with main, auxiliary and airbreathing propulsion systems, baseline vehicle electronics including a data bus and central computer complex, and a reference mission. It was necessary, in forming an adequate base for the study, to define the propulsion systems and the reference mission in detail. The propulsion systems were defined to the components level (there are a total of 1928 components in the booster and orbiter propulsion systems) and the mission in activity timelines for each of the 17 mission phases. Schematic illustrations of the reference mission, booster and orbiter propulsion systems, main engine, and vehicle data management system are presented in Figure II-2 through Figure II-6. The Design Reference Model is described in detail in Volume II.

The functional requirements of each propulsion subsystem were then established. This effort provided visibility to the operational status and interfacing functions of the propulsion subsystems during each mission phase. This information is presented in Volume II, Chapter III.

A key analytical tool used in the study was the Failure Modes and Effects Analyses (FMEAs). The failure modes for each propulsion component were established, and the effect of these failures on the propulsion system, vehicle, mission and crew safety were identified. The failure modes were evaluated to determine candidate failure detection methods. The FMEA results were used in subsequent elements of the study to aid in establishing propulsion checkout and monitoring requirements, to define candidate parameters, measurements and sensors, to define hazard warning functions, to identify areas of excessive or inadequate redundancy in the propulsion systems, and also

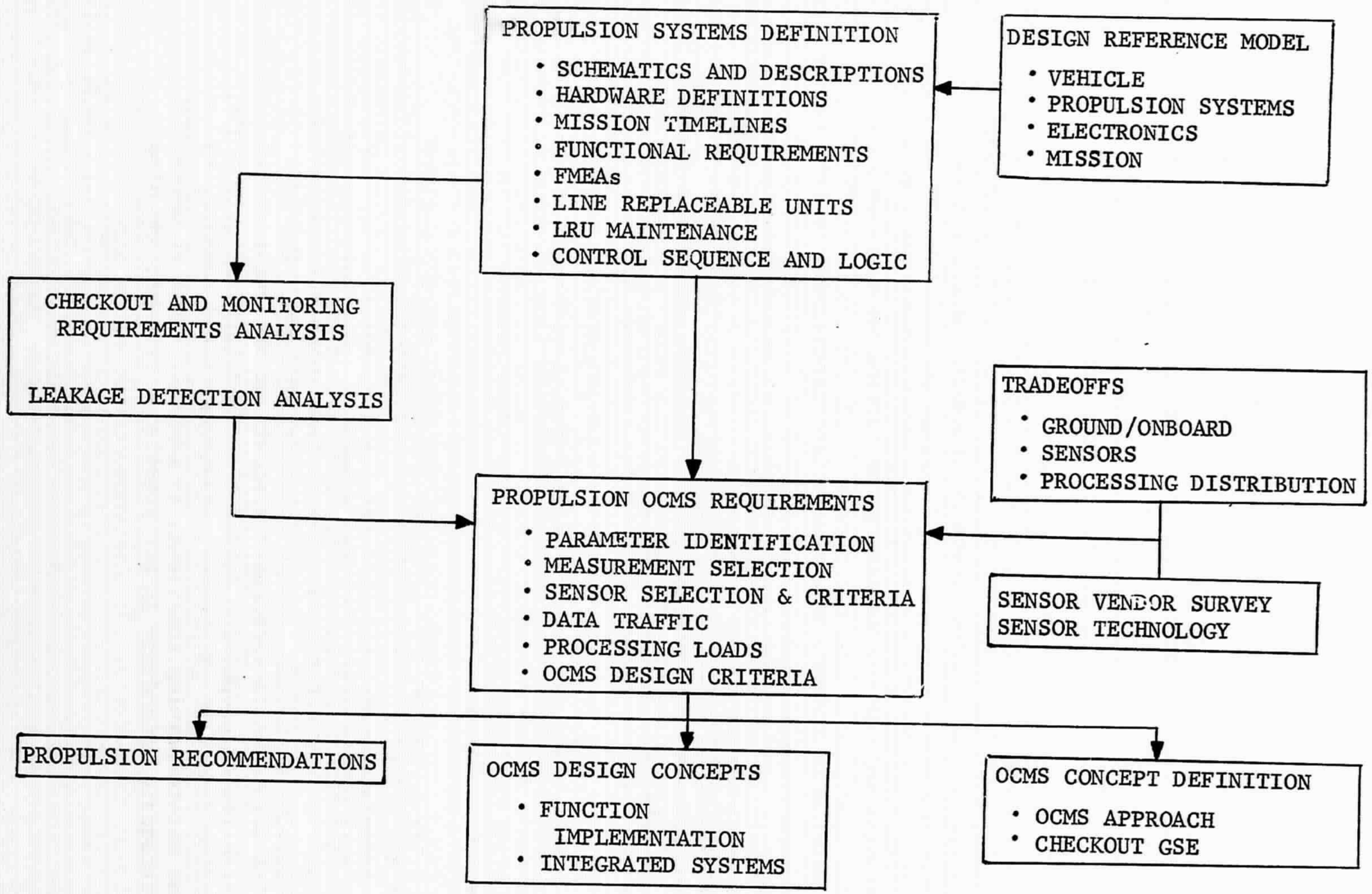


FIGURE II-1 TECHNICAL APPROACH

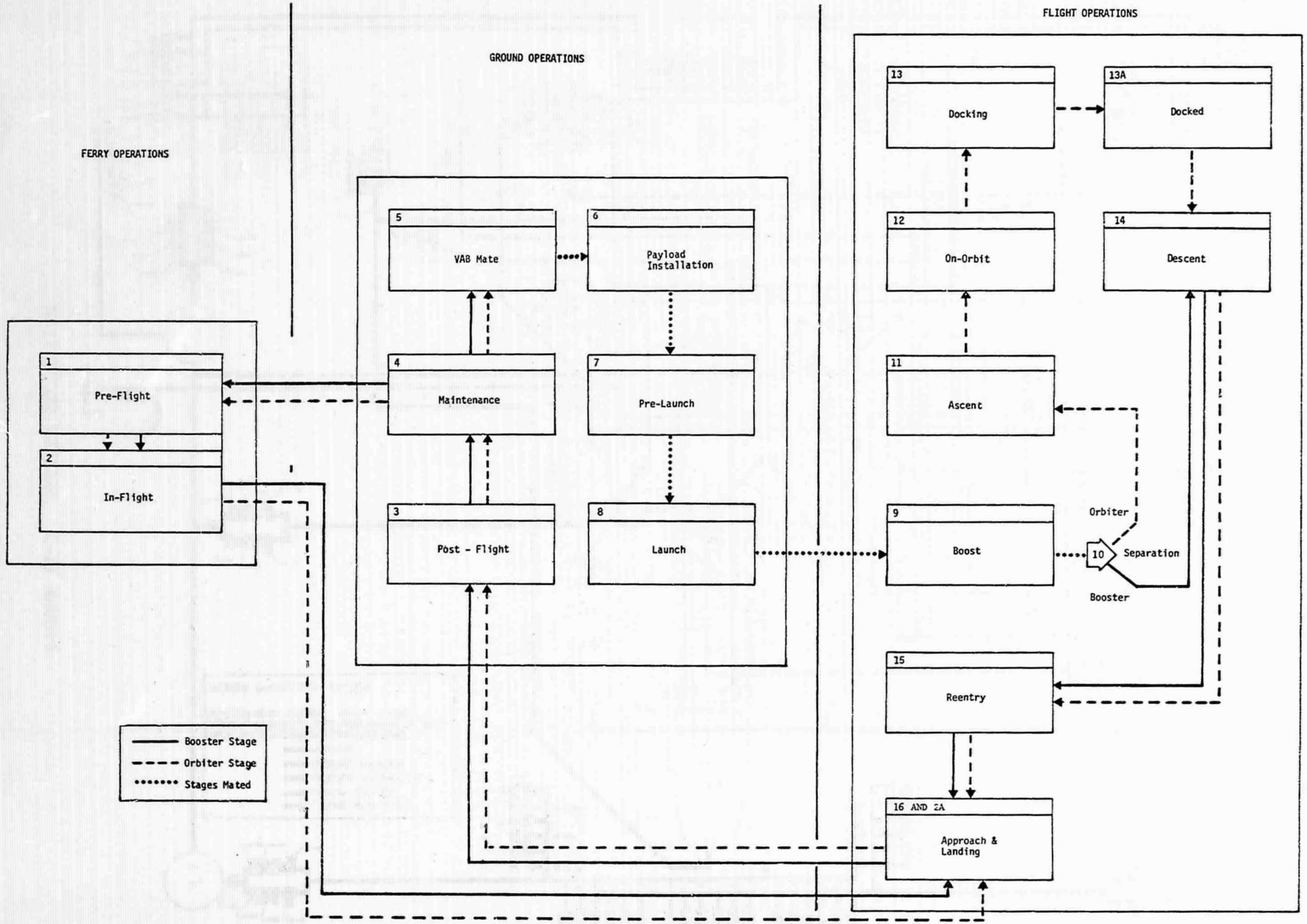


FIGURE II-2 MISSION PHASES

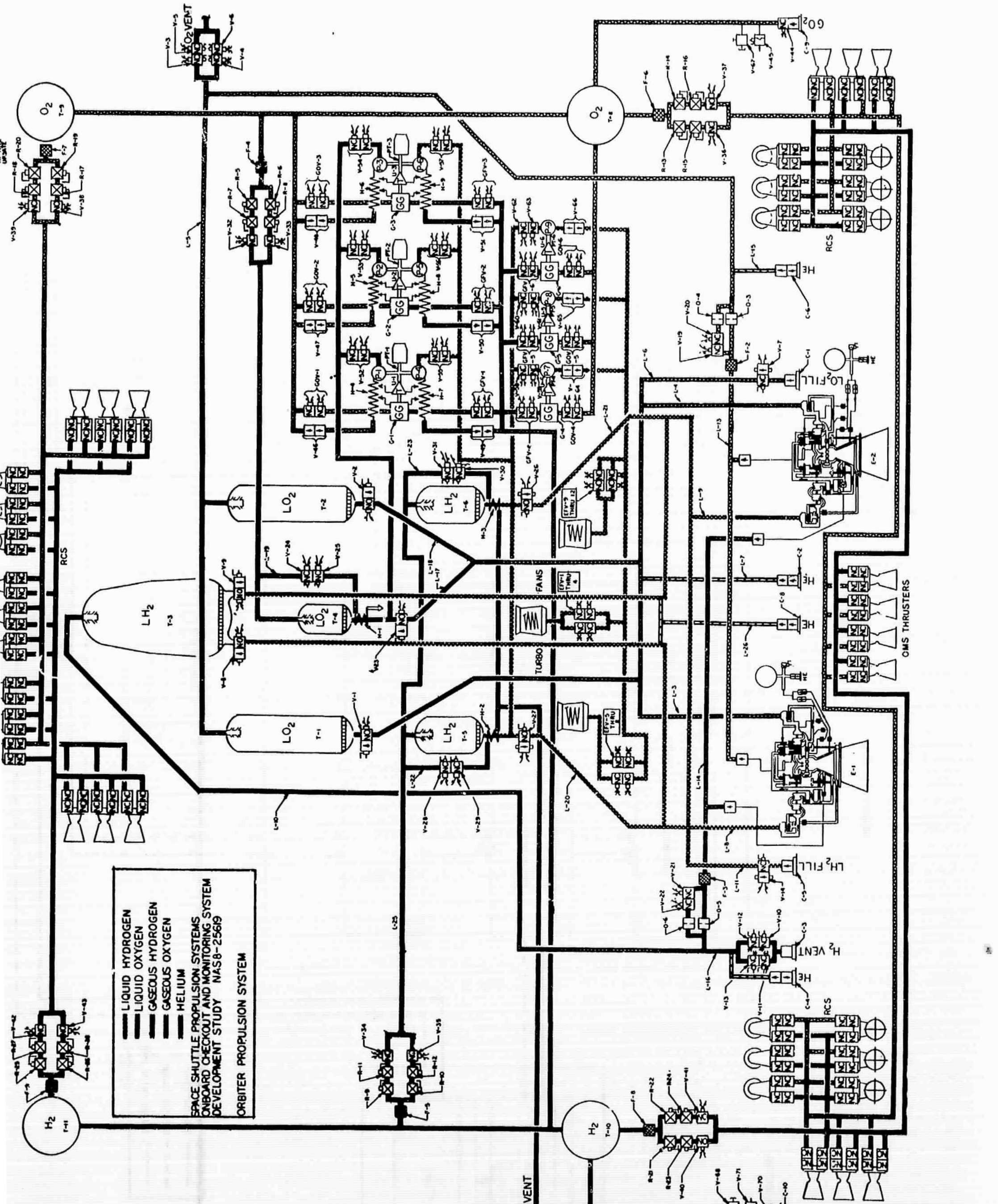
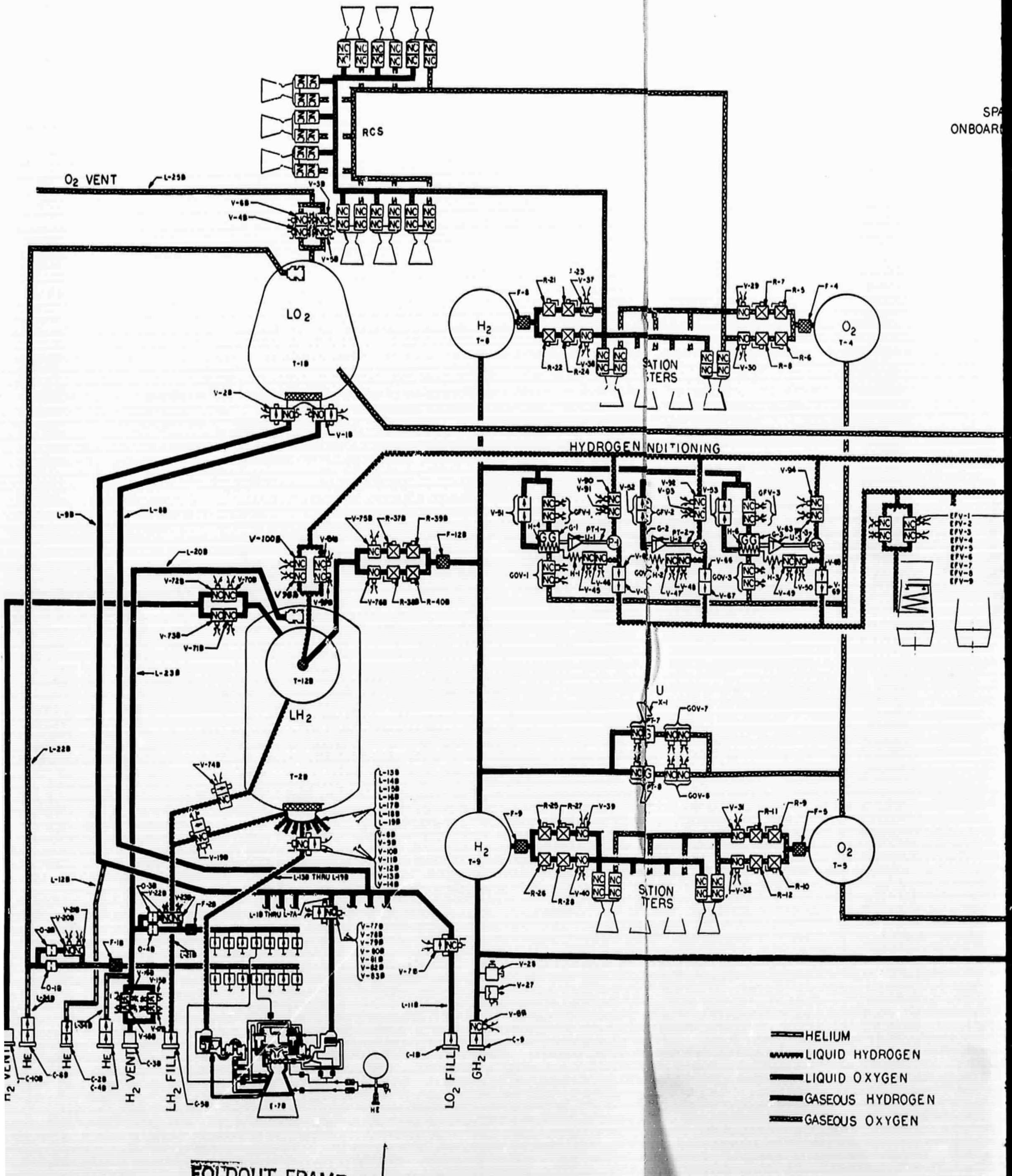


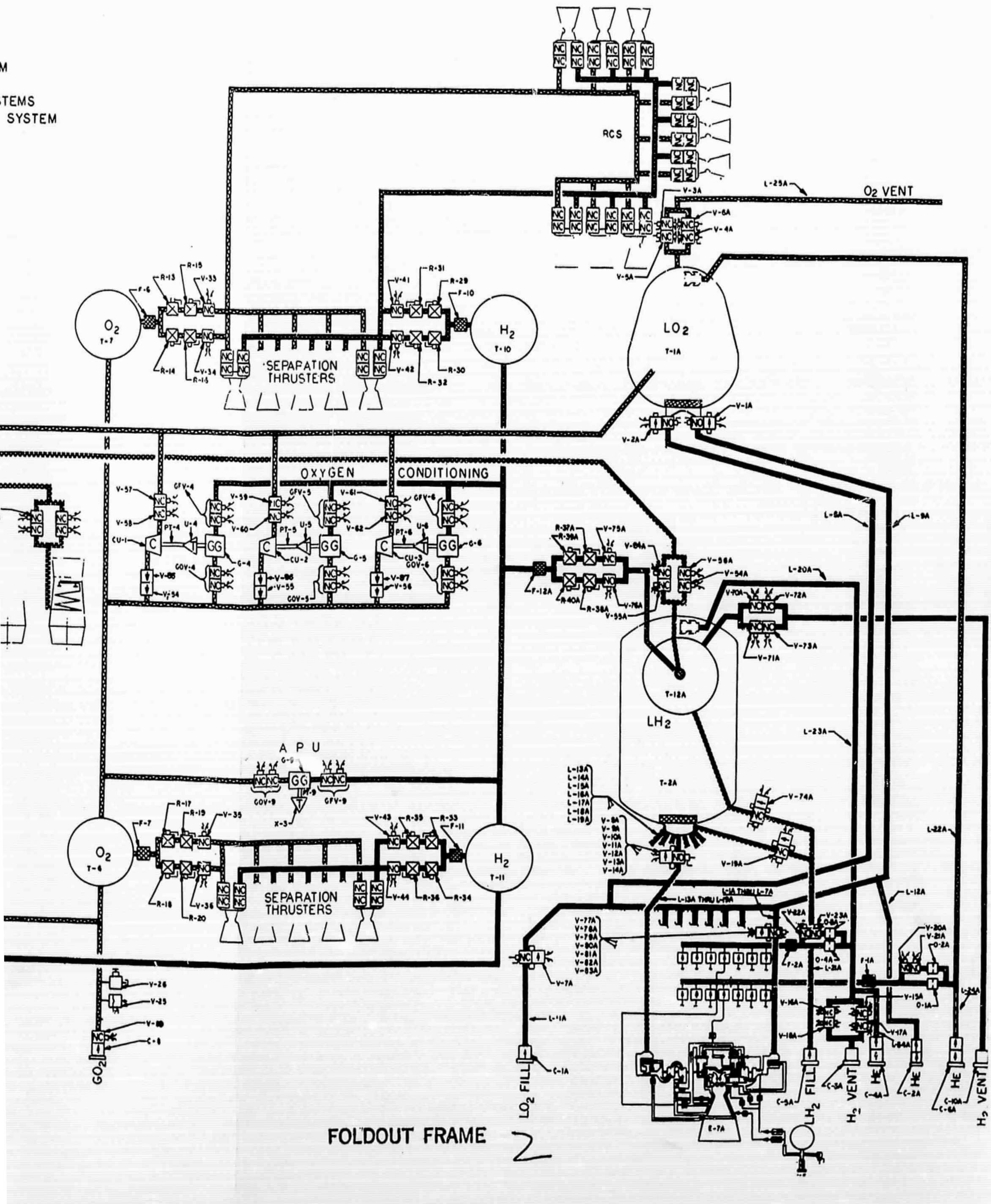
FIGURE II-3 ORBITER PROPULSION



FOLDOUT FRAME

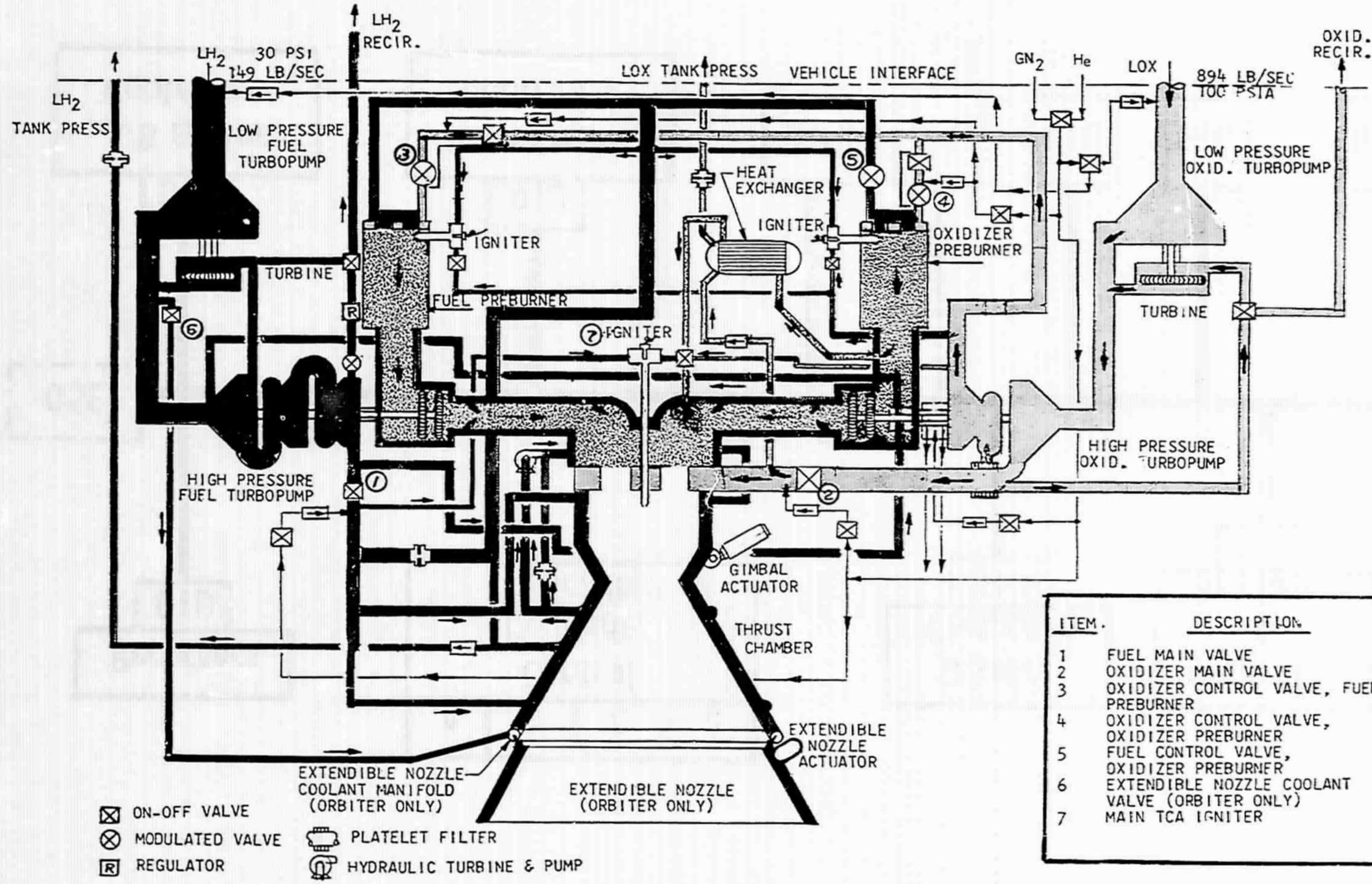
M

STEMS
SYSTEM



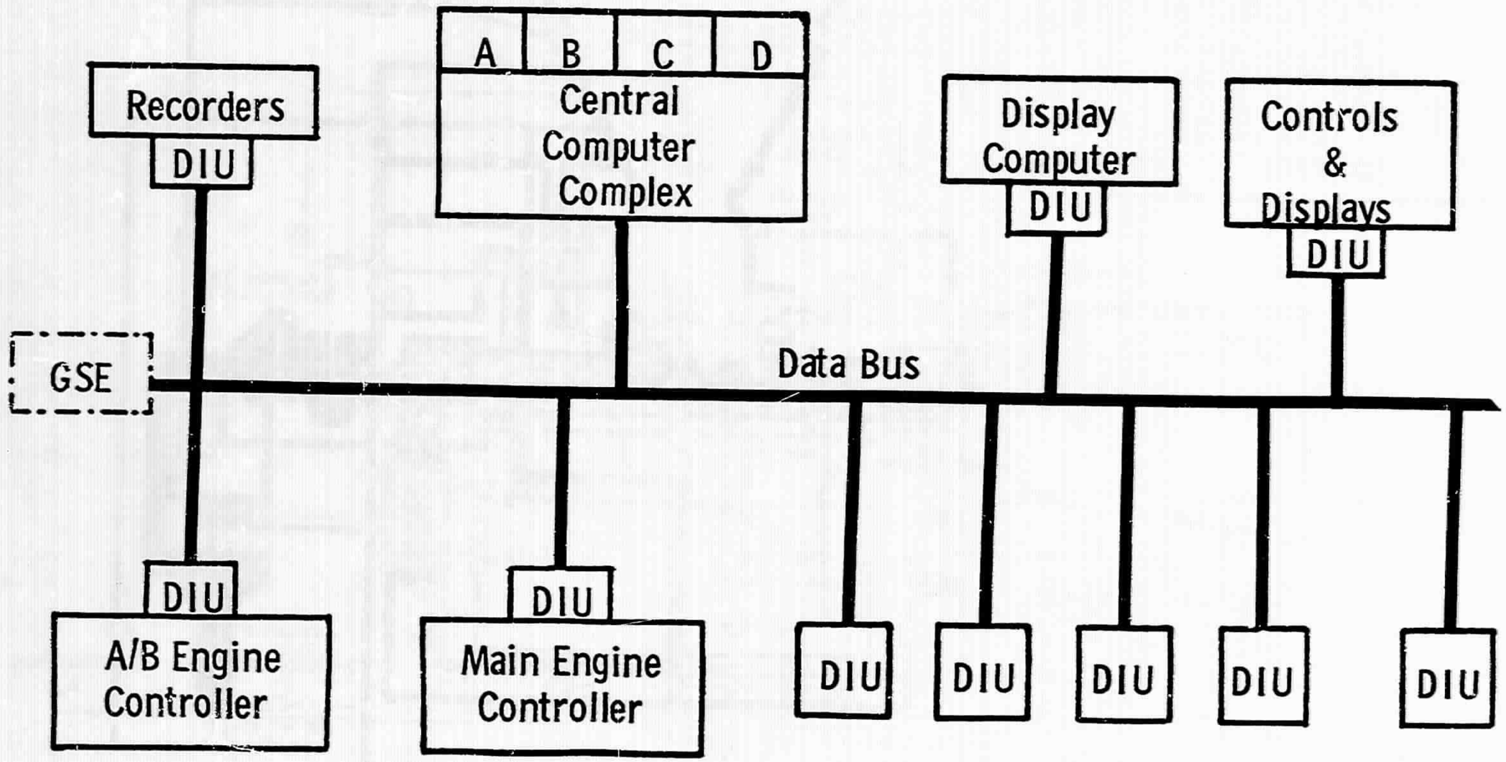
FOLDOUT FRAME 2

FIGURE II-4 BOOSTER PROPULSION



ITEM.	DESCRIPTION
1	FUEL MAIN VALVE
2	OXIDIZER MAIN VALVE
3	OXIDIZER CONTROL VALVE, FUEL PREBURNER
4	OXIDIZER CONTROL VALVE, OXIDIZER PREBURNER
5	FUEL CONTROL VALVE, OXIDIZER PREBURNER
6	EXTENDIBLE NOZZLE COOLANT VALVE (ORBITER ONLY)
7	MAIN TCA IGNITER

FIGURE II-5 MAIN ENGINE



DIU = Digital Interface Unit

FIGURE II-6 VEHICLE DATA MANAGEMENT SYSTEM to define potential ground support equipment requirements. The approach and groundrules used in conducting the FMEAs are described in Volume II, Chapter III, and the FMEA data are contained in Volume IV, Appendix B.

Propulsion line replaceable units (LRUs) were defined, and the maintenance activities and times required for removal, replacement and retest of the LRUs were established. This definition was necessary because of the requirement for inflight fault isolation to the LRU level. A total of 929 booster propulsion LRUs and 322 orbiter LRUs were identified. The LRU selection procedure and listings are in Volume II, Chapter III, and the LRU maintenance procedures are summarized in Volume IV, Appendix C.

The final step in the detailed definition of the propulsion systems was the construction of diagrams which illustrated the sequences and logic for control of the propulsion subsystems during significant activity periods. The generation of these control sequence and logic diagrams was necessary because of the large degree of interaction between control functions and checkout and monitoring functions.

The work summarized in the preceding paragraphs comprised the propulsion system definition and the establishing of propulsion systems checkout and monitoring criteria, i.e., Task 1. These criteria were then analyzed as follows:

A comprehensive analysis of the checkout and monitoring requirements was made. This effort identified, by sequential mission phase, each checkout and monitoring step, including the values expected for each measurement. The results are presented in Volume IV, Appendix D.

Preflight and inflight leak detection is a checkout and monitoring function, and therefore was included in this study as a special area of investigation. Sources and types of leaks were defined, and their effects were evaluated. An onboard approach toward leak detection and hazardous gas concentration monitoring was recommended; this topic is discussed in Volume III, Chapter II.

The propulsion criteria and the results of the checkout and monitoring analysis and the leak detection analysis were evaluated to identify the candidate parameters for propulsion system checkout and monitoring, as well as to identify techniques for implementing the checkout and monitoring functions. To assist in defining measurements and sensors, this program included a survey of sensor vendors. Information was acquired on the availability, characteristics and applications of sensors to match the potential requirements. Additionally, a sensor technology study was made by literature reviews and contacts with appropriate government agencies and industry to identify new work with potential applications. The candidate propulsion system parameters were refined into a definition of required measurements and corresponding sensors. Criteria were prepared for many of the sensors to illustrate the approach necessary for adequate sensor definition (a total of 3130 measurements were stipulated for the booster propulsion checkout and monitoring function, and 1348 measurements for the orbiter function). The measurement and sensor analyses and definitions are described in Volume III, Chapter III and Appendix A.

The vehicle data bus traffic and the processing loads on central computer complex (imposed by the propulsion checkout and monitoring function) were determined for periods of peak data traffic and processing. The definition of the measurement and sensor requirements included analyses of the corresponding sample rates. (The engine controllers incorporated sample averaging to permit a reduced data rate across the engine/vehicle data bus interface as compared with the engine internal sample rate.) The techniques used in establishing sample rates and converting to vehicle data bus traffic are discussed in Volume III, together with a presentation of the peak period traffic and processing loads.

The study was completed by defining the propulsion systems onboard checkout and monitoring function concept. This is described in Volume III, Chapter IV, in terms of the OCMS approach, and implementation concepts. The few items of ground support equipment recommended for the checkout function are also identified in this chapter.

A. OCMS APPROACH

The previous chapter described the technical approach that was derived and used in the study to determine the propulsion checkout and monitoring requirements, and to derive from those requirements the implementation criteria. This chapter presents a summary of the study results. Section A summarizes the implementation criteria; Section B outlines recommendations for further technology work in sensors; and Section C presents further recommendations for implementation.

The basic conclusions of the study are:

- The on-board checkout and monitoring function is technically feasible, will improve system reliability, and will simplify ground operations.
- The implementation requires a substantial degree of coordination between propulsion and electronics. The implementation should be in accordance with a requirements standard to ensure that the necessary approach and methodology are utilized and so that the requisite degree of interdiscipline integration is accomplished.
- The basic design of the propulsion systems, subassemblies and components must incorporate the necessary provisions for checkout and monitoring.

Criteria were developed which establish the degree of performance of on-board checkout, monitoring, and evaluation functions. The derivation of these criteria is discussed in volume III, Chapter IV. The criteria are summarized below.

Preflight Checkout

- Preflight checkout of mechanical elements of the propulsion systems will be limited to verification of correct initial conditions for start, and to monitoring of the start-up and operation of those subsystems which are started prior to flight.

- Preflight self-checks of electronic subsystems and elements will be performed, including verification of sensor electrical elements.

- Applicable system parameters will be monitored and evaluated by onboard equipment during ground operations for purposes of fault detection, fault isolation, and operating history recording.

In-Flight Ready-to-Start Condition Verification

- Appropriate onboard monitoring and evaluation will be provided to verify, just prior to inflight start, that all applicable equipment and associated system parameters are in the correct conditions for start.

Emergency Detection

- Emergency detection provisions must be redundant.

- Redundant caution and warning display capability will be provided for the following conditions:

  Loss or impending loss of major functions
  Flight Safety parameters exceeding safe limits
  Redundancy reduced to "safe" level
  Hazardous leakage.

Fault Detection

- Provisions will be made for inflight detection of failures (including out of specification performance, incipient failures, and transient or intermittant faults) for all identifiable failure modes for which suitable onboard detection techniques and equipment are practical.

Fault Isolation

- Data for fault isolation will be acquired in flight, by onboard equipment.

- Diagnosis for fault isolation will be accomplished with onboard equipment. This diagnosis will isolate any faults to the line replaceable unit, and record the data necessary to provide postflight identification of maintenance requirements.

- Fault isolation will be accomplished as soon after detection as is necessary to identify lost redundancy and to initiate corrective or safing action when applicable. In cases when no LRU-level redundancy exists and where corrective or safing action is taken in response to failure detection only, as in the case of ACPS engine emergency shutdown, diagnosis for fault isolation may be performed on stored data at a later time. Preferably, this type of diagnosis will be accomplished prior to landing, but may be delayed until after landing if necessary.

Real Time Trend Analysis

- Real time trend analysis will be performed only for those failure mode cases where it would result in avoidance of significant damage or in early initiation of precautionary action to cope with an impending emergency condition.

Operating Histories

- Where correlation exists, or is likely, between an LRU's performance and its operating time, stresses, number of on/off cycles, number of revolutions or strokes, or combinations of these, a history of operation of the LRU will be maintained in computer storage so that when an LRU's operating history exceeds the limit for that LRU, a post-flight printout will provide notification of required replacement. These operating histories will not be continuous, but will be periodic or on-condition updated total of accumulated time, cycles, etc., at discrete states (on, standby, NPL, MPL, etc.) or discrete stress levels (20% overtemperature for example).

Performance Data

- Propulsion systems flight performance data will be acquired and recorded on the vehicle maintenance recorder to enable postflight evaluation for verification of inflight diagnosis, identification of incipient failures, and identification and analysis of trends.

Post Flight Evaluation

- In-flight type monitoring and evaluation will be continued until completion of shutdown operations. Servicing programs then will be loaded into the onboard computers, replacing the flight programs. Flight-recorded data will be sorted, edited, and evaluated by the onboard computer complex to produce maintenance printouts, trend analysis results and performance data records.
- Ground connections to the vehicle data bus will be utilized to provide for transmitting commands and data between ground remote control and display provisions and the vehicle control computer complex.

Maintenance Retest

- Maintenance retest of replaced LRU's will employ the onboard checkout function.

Control and Checkout Processing Integration

- Control and checkout will be treated as a single function for purposes of computer processing.

B. SENSOR TECHNOLOGY RECOMMENDATIONS

The majority of the measurement requirements identified for the propulsion on-board checkout and monitoring function can be accomodated through use of conventional sensor concepts. However, it is recommended that additional technology work be conducted in the following categories, because of probable benefit to the OCMS function.

1. Acoustic/Ultrasonic techniques appear to hold the most promise for resolving many fault detection/isolation/prediction requirements not amenable to conventional sensing techniques. Work by Boeing has shown acoustic emission to be a good indicator of bearing incipient failures. Deflection measurement is a possible alternative or suplementary technique. Further work should be done to establish the feasibility of applying both acoustic emission and deflection measurement approaches in application to Space Shuttle propulsion system rotating machinery, and to establish feasibility of applying accoustic emmission sensor approaches to ignition detection and igniter spark location discrimination.

2. Ultrasonic Leak Detection for both internal and external leaks has been shown to be feasible, using combinations of ultrasonic contact probes and ultrasonic microphones. There is insufficient data, however, to show that state-of-the-art devices will work satisfactorily and maintain integrity with cryogenic temperature cycling and at Space Shuttle vibration and acoustic environment levels.

3. Accurate Measurement of Small Differential Pressures in high pressure systems cannot be accomplished with today's technology except in the laboratory. A study to identify and assess approaches for measurement of small differential pressures in high system pressure is recommended. A primary application would be for derivation of flow rate, as an alternate to use of a flow meter.

4. Igniter spark presence and location are not readily detectable with any known suitable technique. In addition to the evaluation of acoustic techniques (as recommended above), it is recommended that other approaches be identified and assessed. One approach that should be investigated is the use of excitation current signatures to determine whether sparking is occuring at the spark plug gap or at some point between the exciter and the plug gap.

C. PROPULSION RECOMMENDATIONS

The study performed under this contract developed a technical approach for incorporating the function of onboard checkout and performance monitoring in the Space Shuttle propulsion systems. Design criteria which define the degree of incorporation of the function were summarized in Section A of this chapter. Additional recommendations for implementation (as extracted from the bulk of the study results) are summarized in the subsequent paragraphs of this section.

1. A substantial degree of coordination between the propulsion and avionics disciplines should be conducted to ensure an optimum implementation of the propulsion systems onboard checkout and performance monitoring function. Both the development of the propulsion systems' checkout and monitoring criteria (measurement requirements and sampling rates, sequences of functional operations, etc.) and the design of the data management system to accomodate the propulsion functions require an integrated systems approach.

2. The basic design of the propulsion system should incorporate the checkout and monitoring functional requirements. Component configuration designs should enable readiness assessment, fault detection and performance monitoring, and should incorporate the requisite sensing elements. Subsystem designs should allow redundancy assessment and fault isolation, and should enable usage of the onboard system for post-maintenance (LRU replacement) verification testing.

3. Emphasis must be placed on minimizing the number of measurements and the complexity of the sensors. The measurements required for propulsion control functions should also be used for checkout and monitoring functions; alternative measurement and sensor techniques (including application of new technology) should be investigated for each candidate parameter; and the sensor criteria (accuracy, sample rate, response, etc.) should be determined by analyzing the requirements of each individual measurement with emphasis on imposing the least stringent criteria.

4. The propulsion control functions should be completely integrated with the onboard checkout function. Since the checkout function must be cognizant of responses to control commands, and the control function must provide data management for cataloging and utilizing redundant hardware, a minimization of total data management complexity can result from combining these two functions.

This study was conducted under Contract NAS8-25619 by the Martin Marietta Corporation, Denver Division. Technical direction was provided by the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, with Mr. Werner Voss as Technical Monitor.

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R. J. Drew	R. F. McConnell
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H. E. Meyer	

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The study was monitored by the following members of the NASA review team:

Werner E. Voss (COR)	Don Woodruff (COR, ALT)
Joe Fries (MSC)	Harlan Harman
Loren Gross	Buford Gallaher
Edward Mintz	Hoyle Yearwood
Don Thompson	

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<u>BIT</u>: A single binary digit. The smallest informational element of a digital system.

<u>BUILT-IN-TEST EQUIPMENT (BITE)</u>: An integral part of a functional unit which serves to test and/or provide status on that functional unit, but does not participate in performing the unit's principle function.

<u>BYTE</u>: A specified number of BITS.

<u>CHECKOUT</u>: The process of determining whether or not specified physical quantities or operations meet their prescribed criteria. The process can include such functions as data acquisition, processing, storage, display, stimulus generation, etc.

<u>CONTROL</u>: The act or process of initiating, regulating and/or terminating the operation and performance of a functional element in a prescribed manner.

<u>CONTROLLER</u>: A device which governs the state or performance of a particular functional element in a prescribed manner, e.g. engine controller.

<u>DATA BUS</u>: The transmission line(s) along which the system computer(s) communicate with the various Digital Interface Units, controllers, peripheral equipment, and other computers.

<u>DATA COMPRESSION</u>: The process of screening and selecting data such that only desired information is retained for further processing and/or storage.

<u>DESIGN REFERENCE MODEL</u>: The baseline configuration.

<u>DIAGNOSIS</u>: The determination of the state or condition of an element or parameter through evaluation of available data.

<u>DIGITAL INTERFACE UNIT</u>: An intermediary unit between the computer(s) and another device which formats that device's output for communication to a computer, and accepts and translates a computer's transmissions to the device.

<u>FAULT ISOLATION</u>: The processing of analyzing a malfunction or abnormality to the extent of determining which functional element is defective, where the functional element is ordinarily a Line Replaceable Unit.

<u>FUNCTIONAL ELEMENT</u>: A unit which performs a characteristic action. Parts, components, assemblies, and subsystems are functional elements of increasing complexity.

<u>GAS PATH ANALYSIS</u>: An assessment of engine performance that is made through evaluation of a set of measured values of pressures, temperatures and/or flow rates.

<u>GROUND SUPPORT EQUIPMENT</u>: (for checkout and monitoring) that equipment in addition to the onboard equipment, which is needed to accomplish the functions of checkout and monitoring.

<u>LINE REPLACEABLE UNIT</u>: A component or group of components that can, as a unit, be removed and replaced in the normal vehicle maintenance area. Such criteria as allowable replacement time spans and degree of complexity of post-replacement calibration form a basis for Line Replaceable Unit selection.

<u>MAINTENANCE</u>: Those functions and activities associated with restoring the vehicle to an operational condition between flights.

<u>MEASUREMENT</u>: A physical quantity or event whose magnitude or time of occurence is of significance.

<u>MONITORING</u>: Repetitive acquisition and evaluation of needed data.

<u>POGO</u>: An oscillatory instability resulting from a dynamic coupling between the fluid and structural elements of the vehicle.

<u>PROCESSING</u>: The manipulations and operations performed on data from the time and place it is acquired to the time and place it is used in its final form.

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

<u>SENSOR</u>: A functional element which 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 occurence of the event.

<u>SINGLE POINT FAILURE</u>: A functional element whose inability to operate within prescribed limits would cause loss of vehicle, crew, and/or mission objectives.

<u>STIMULUS</u>: An excitation or forcing function which is applied from an external source at a prescribed place and time.

<u>TIMELINE</u>: A representation of a sequential series of events which depicts the time of occurence and duration of each event.

<u>TRANSDUCER</u>: Same as sensor.

<u>TREND ANALYSIS</u>: The process of evaluating successive samples of the same data to forecast end of useful life and/or incipient failure as an aid to maintenance operations and to mission or vehicle configuration decisions.