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Final Report

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

VOLUME II
PROPULSION SYSTEM DEFINITION AND CRITERIA

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

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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

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NOMENCLATURE

I. Definitions

BIT: A single binary digit. The smallest informational element of a digital system.

BUILT-IN-TEST EQUIPMENT (BITE): 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

BYTE: A specified number of BITS.

CHECKOUT: 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.

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

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

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

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

DESIGN REFERENCE MODEL: The baseline configuration.

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

DIGITAL INTERFACE UNIT: 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.

FAULT ISOLATION: 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.

NOMENCLATURE (Continued)

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

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

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

LINE REPLACEABLE UNIT: 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.

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

MEASUREMENT: A physical quantity or event whose magnitude or time of occurence is of significance.

MONITORING: Repetitive acquisition and evaluation of needed data.

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

PROCESSING: 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.

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

SENSOR: 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.

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

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

NOMENCLATURE (Continued)

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

TRANSDUCER: Same as sensor.

TREND ANALYSIS: 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.

II. Abbreviations and Acronyms

Note: Measurement nomenclature is defined in the measurement section.

A/B	Airbreather or airbreathing
APS	Auxiliary Propulsion System
APU	Auxiliary Power Unit
BITE	Built-In Test Equipment
CC	Combustion Chamber
CCC	Central Computer Complex
CCU	Channel Control Unit
C_f	Thrust Coefficient
C*	Characteristic Exhaust Velocity
DIU	Digital Interface Unit
DRM	Design Reference Model
ΔV	Change in Velocity
EPL	Emergency Power Level
FMEA	Failure Modes and Effects Analysis
FPB	Fuel Preburner
FS_1	Fire Switch #1 (Engine Start Signal)
FS_2	Fire Switch #2 (Engine Shutdown Signal)
GHe	Gaseous Helium
GH_2	Gaseous Hydrogen
GN_2	Gaseous Nitrogen
GOX	Gaseous Oxygen
GSE	Ground Support Equipment
G & N	Guidance and Navigation
HPFTPA	High Pressure Fuel Turbopump Assembly

NOMENCLATURE (Continued)

HPOTPA	High Pressure Oxidizer Turbopump Assembly
Ign	Igniter or Ignition
KSC	Kennedy Space Center
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
LOX	Liquid Oxygen
LPFTPA	Low Pressure Fuel Turbopump Assembly
LPOTPA	Low Pressure Oxidizer Turbopump Assembly
LRU	Line Replaceable Unit
MPL	Minimum Power Level
MR	Mixture Ratio
MSFC	Marshall Space Flight Center
NPL	Normal Power Level
OCMS	Onboard Checkout and Monitoring System
OMS	Orbital Maneuvering System
OPB	Oxidizer Preburner
P/L	Payload
RCS	Reaction Control System
TCA	Thrust Chamber Assembly
TPF	Terminal Phase Finalization
TPI	Terminal Phase Initiation
TVC	Thrust Vector Control
VAB	Vertical Assembly Building
WTR	Western Test Range

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I. INTRODUCTION

The technical approach used in this study to define the Space Shuttle propulsion systems' on-board checkout and monitoring system is described in Volume I and is illustrated in Figure I-1. Volume II contains a description of the Design Reference Model and presents the analyses that were conducted to establish the propulsion systems' checkout and monitoring criteria.

The Design Reference Model is comprised of a baseline mission, vehicle, propulsion systems, and electronics systems; these elements are fully described in this volume. The mission, which includes ground as well as flight operations, was defined by establishing those events and activities which required propulsion functions. The booster and orbiter main, auxiliary and airbreathing propulsion systems were defined in terms of hardware, ie., subsystems and components. The propulsion configuration was then related to the mission activities by defining the propulsion system functional requirements necessary to perform the mission operations. The propulsion systems were then further analyzed, using the functional requirements as guidelines, to generate the criteria for checkout and monitoring. A failure modes and effects analysis (FMEA) was conducted to the propulsion components level (to the parts level in certain cases) to determine detection requirements and candidate detection techniques. Line replaceable units (LRUs) were identified, both because of the requirement to conduct in-flight fault isolation to the LRU level, and to determine the checkout functions required during LRU replacement in maintenance activities.

The control requirements of the propulsion systems were defined in the form of sequence and logic diagrams. These evaluations were necessary to provide sufficient visibility to the control functions (such as the sequential activities associated with main engine start) and the corresponding monitoring functions.

These definitions and analyses are described in this volume, and the results represent the criteria for propulsion checkout and monitoring. The evaluation of these criteria and the resultant propulsion systems on-board checkout and monitoring concept are described in Volume III.

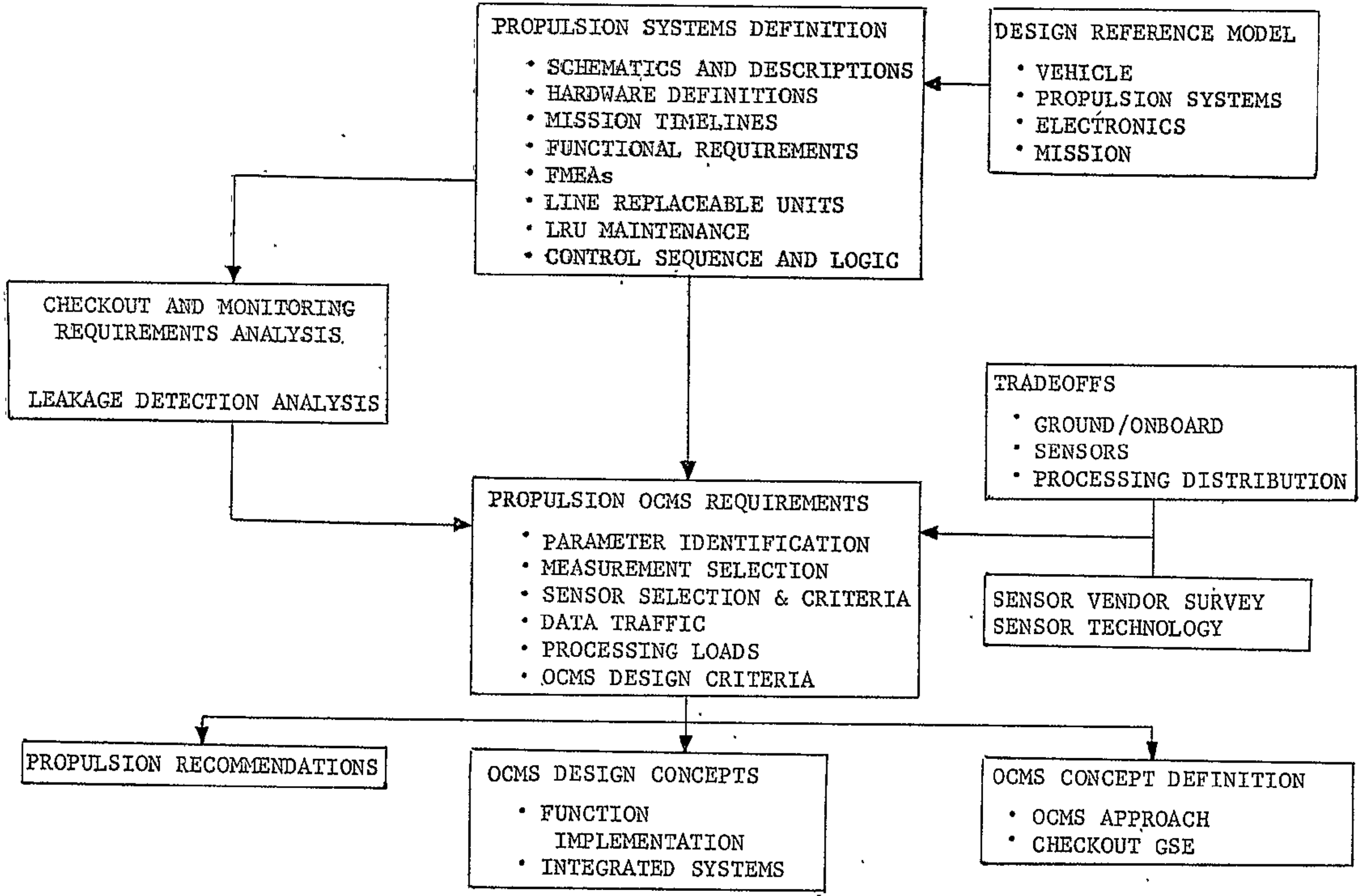


FIGURE I-1 TECHNICAL APPROACH

A. SPACE SHUTTLE VEHICLE

The Space Shuttle vehicle configuration selected as the Design Reference Model for this study is a design derived from Martin Marietta Corporation Phase A work, and studied as a high cross range design option under the joint McDonnell-Douglas Martin Marietta Phase B study contract. The configuration is a fully reusable, two-stage manned vehicle which is vertically launched and recovered by horizontal landing (VTOHL). The booster stage consists of twin bodies connected by forward and aft wings. The orbiter stage is a fixed geometry, double delta wing configuration. The primary propulsion systems of both stages consist of high performance, high pressure rocket engines using liquid hydrogen and liquid oxygen propellants.

1. Basic Configuration Concept

The basic flight operation sequence is depicted in Figure II-1. The vehicle is launched in the nested configuration and utilizes sequential burn during ascent, i.e., the orbiter engines are ignited after booster engine burnout. Staging occurs at an altitude of approximately 240,000 ft. and an inertial velocity of approximately 13,000 ft/sec. Separation of the stages is accomplished by firing 20 rocket engines on the booster. Four modules of five thrusters each are located so that the torques about the center of gravity are equal. Separation occurs inverted (booster below) so that booster lift can be used to lower the apogee, reduce booster reentry heating, and minimize flyback range. After separation, the booster reenters and returns to the launch site for a horizontal landing. The booster angle of attack and bank angle are modulated to minimize reentry heating, limit the total acceleration to 4 g's, and assist in minimizing flyback range requirement. Hydrogen fueled airbreathing turbofan engines mounted in the forward wing are used during the subsonic cruise and landing.

After separation, the orbiter continues to the desired burnout conditions. After the mission is completed, deorbit velocity is applied and the orbiter reenters the atmosphere and glides back to the base. Upon arriving at the base, turbofan engines are deployed for a powered approach and go-around if required.

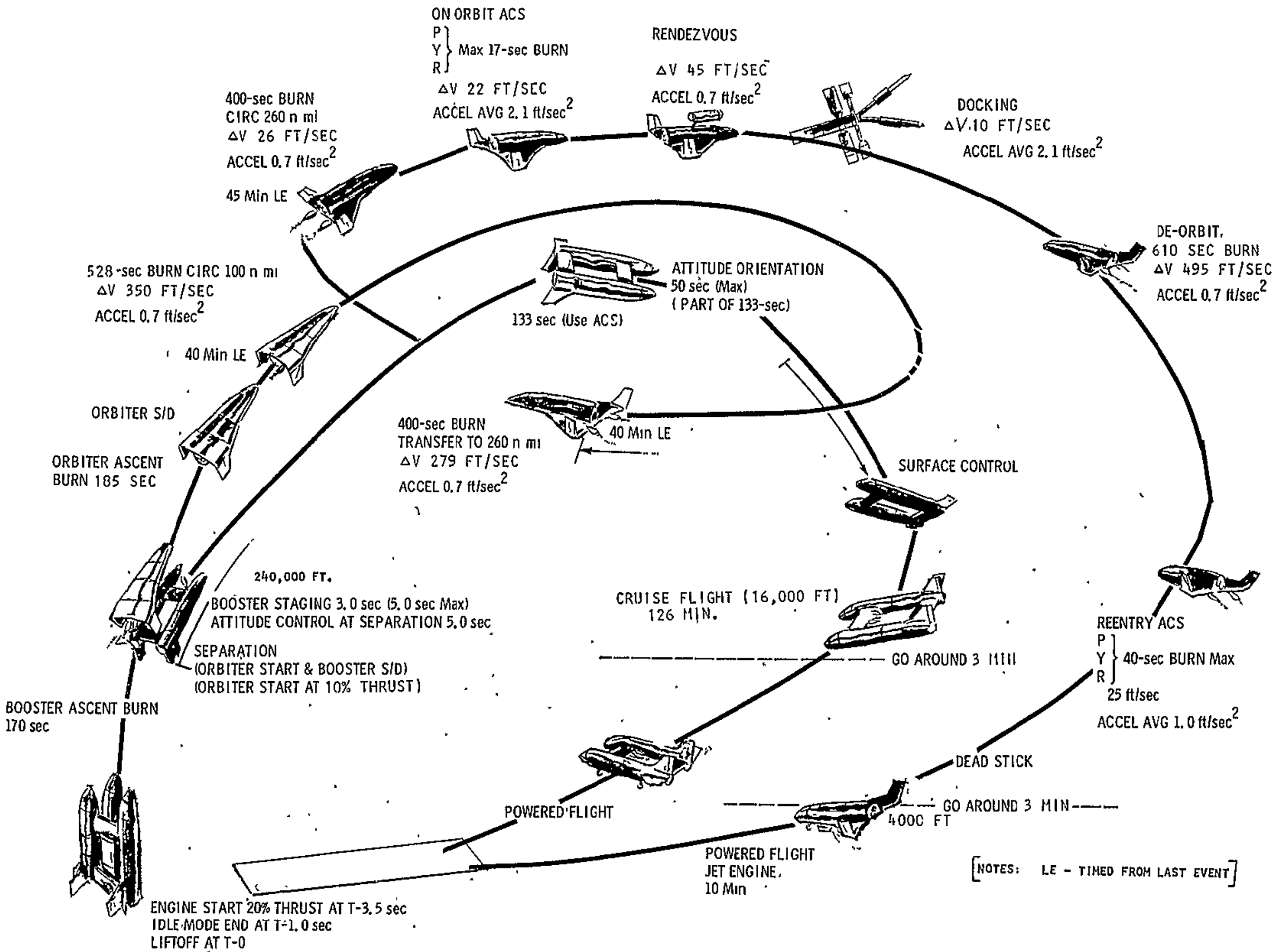


Figure II-1 Flight Operations Sequence

2. Orbiter Configuration

The orbiter configuration is shown in Figure II-2. This configuration features a fixed geometry, double delta winged body configuration. The body, wing and aft flap are designed to provide hypersonic trim control capability from 15° to 50° during entry. Reaction control system (RCS) units are mounted aft where they are protected from entry heating because they are in the wake of the orbiter. These RCS units initialize vehicle attitude and are used to assist in attitude control until the aerodynamic surfaces achieve full control. The wings on the orbiter are sized to provide a landing speed of 180 knots with full payload. Airbreathing engines are extended from the lower surface to provide go-around capability.

The liquid hydrogen and liquid oxygen propellant tanks are arranged to minimize the center of gravity shift between the fully loaded and empty condition. The 15 ft. diameter by 60 ft. long payload compartment is centered around the vehicle center of gravity to minimize c.g. displacement with payload weight and offer maximum flexibility in payload packaging.

3. Booster Configuration

The twin-body tandem wing booster configuration is shown in Figure II-3. This configuration results from shaping the structural ties between the bodies into airfoil shapes and adding tail surfaces for stability and control. The closely spaced elements result in mutual aerodynamic interference effects that are more pronounced than in more conventional configurations. The primary beneficial aspects of this configuration are the end plates on the wings, upwash from bodies to increase local angle of attack on the wings, and boattail to reduce drag; the adverse affects are down wash on the aft wing (from the forward wing) and increased skin friction created by the complex flow. The net result is a high subsonic L/D with smaller wings but a slightly larger body wetted area than for a more conventional configuration. The complex flow patterns will create reentry impingement heating with local hot spots, but the short heat pulse and small areas involved minimize the weight penalty.

The wing, fin, and landing gear structural connections are made in non-tank regions to assure good load distributions at the ends of the integral propellant tanks and to provide free tank expansion characteristics which will not induce severe

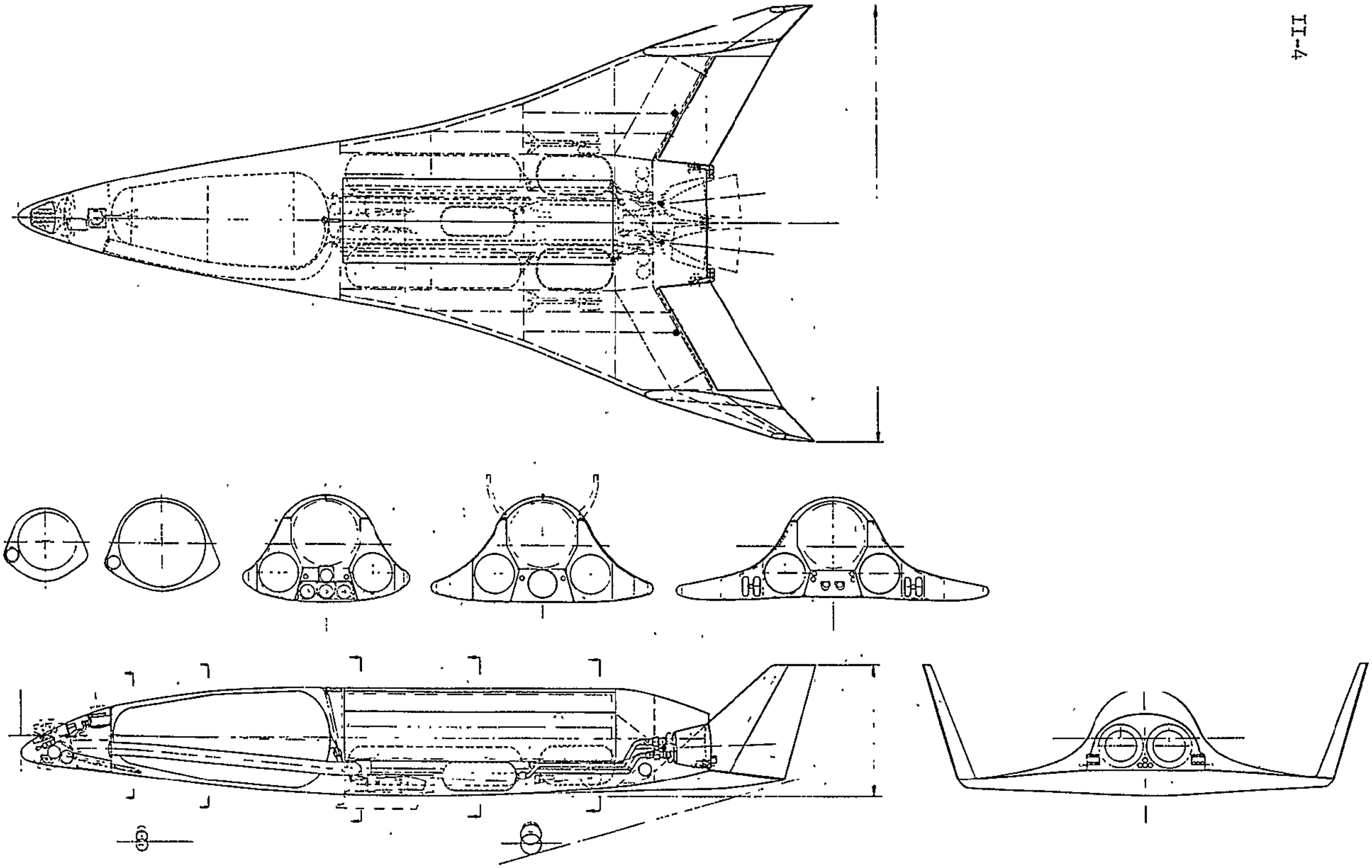


Figure 2   DRM Orbiter

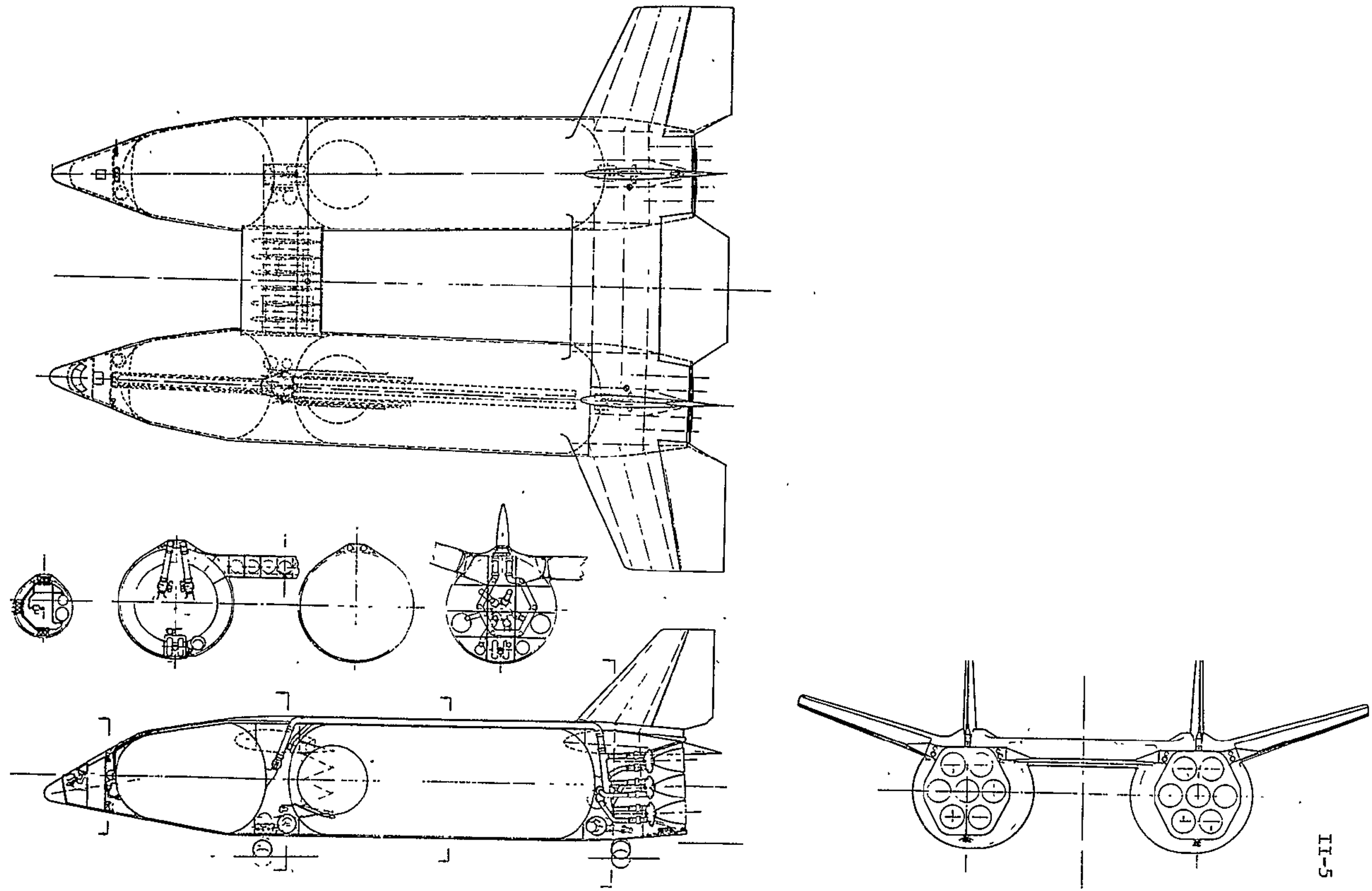


Figure II-3   DRM Booster

thermal strain in the basic load carrying structure of the tanks. The twin-body arrangement offers a simple suspension frame for the orbiter. The launch configuration is shown in Figure II-4.

The flyback turbofan engines are installed in the forward wing. The turbofan engines are protected from the ascent and reentry environments by leading edge and jet flap mechanisms. After high heating rates are passed, the movable leading edge opens to form an inlet, the jet flap is rotated to open the exit nozzle, and the engines are started.

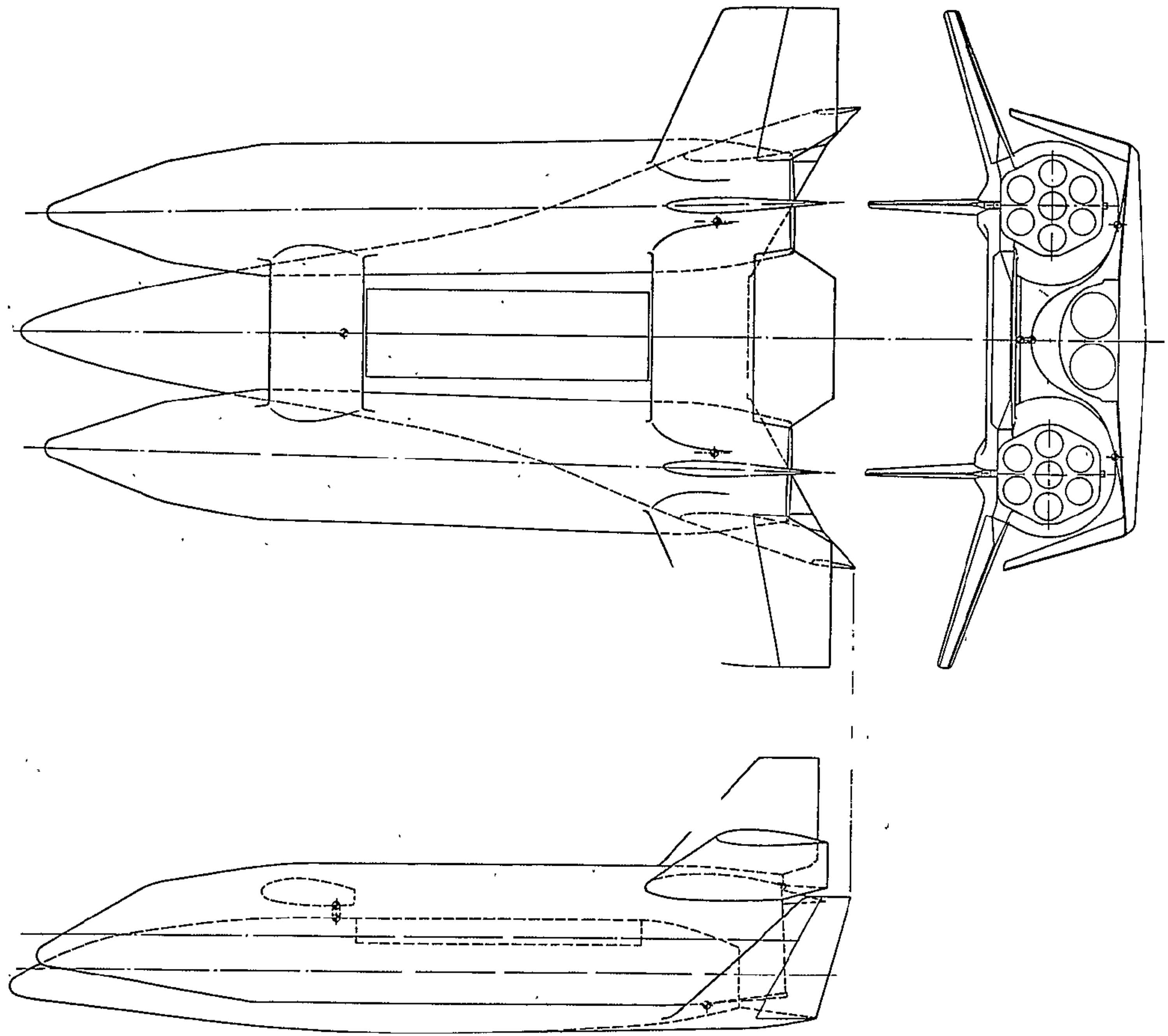


Figure II-4 DRM Launch Configuration

B. MISSION

This chapter presents a definition of the mission which was used as the Design Reference Model. A detailed definition of the mission (in terms of key mission phases, sequences of events, and timelines) was necessary so that the propulsion subsystems' functional requirements could be established. The mission definition was accomplished with the following hierarchy:

- Overall Mission
  - Operational Modes
    - Mission Phases
      - Sequences of Events

The overall mission used as the Design Reference Model is the logistic resupply of a space station or space base. The operational modes of this mission consist of the following:

1. Flight Operations - The flight operational mode consists of that time and those activities which occur from booster main engine start to touch-down of the shuttle stage at the landing site.
2. Ground Operations - The ground operational mode consists of that time and those activities which occur from touchdown of a shuttle stage at the landing site to subsequent re-launch.
3. Ferry Operations - The ferry operational mode is comprised of the time and activities occuring between roll-out and landing when a stage is being transported to KSC. Either of the following events will require ferry operations:

   Transportation of the orbiter and booster stage from the manufacturer's facility to KSC.

   Transportation of either stage from an alternate landing site to KSC.

An overall description of the flight operations mode of the mission is given in the next section, which is followed by a definition of the mission phases, sequences of events, and timelines.

1. General Description - Flight Operations

The Design Reference mission consists of transporting cargo and personnel to and from a manned space station in earth orbit. The cargo will include food, liquids and gases in addition to experiment modules and operational equipment. The personnel will include, in addition to trained astronauts, individuals who will conduct specific scientific and technological experiments and operations. The mission includes long lead time scheduled resupply and crew rotations as well as discretionary flights.

The flight mission profile is a 14 revolution mission in which the rendezvous sequence is completed in the third orbit. The rendezvous portion of the flight plan is based on a coelliptic maneuver with the final approach being made from below and behind. The target orbit has the characteristics of nearly repeating groundtracks each day. The orbit geometry of the five-impulse coelliptic maneuver sequence for a typical third-orbit rendezvous is presented in Figure II-5.

The lift-off of the Space Shuttle is assumed to occur on July 2, 1975, from Cape Kennedy at $15^h19^m26^s$ Greenwich mean time (G.m.t.) $10^h19^m26^s$ eastern standard time (e.s.t.) . The Space Shuttle achieves insertion approximately 7.5 minutes after lift-off. At insertion, the Space Shuttle trails the space station approximately 23.3° and is in the target plane. After verification of orbital insertion and engine cutoff, the Space Shuttle maneuvers to the local horizontal, crew heads down, with the +X-body axis in the direction of motion, and with an orbital rate imparted to maintain the local attitude. Approximately 41.7 minutes elapse from the time of insertion until the space shuttle reaches the 100-n. mi. apogee where the first on orbit maneuver is executed. During this time, the postinsertion checks, insertion orbit determination, and preburn targeting must be completed. At approximately 39^m15^s g.e.t., the Space Shuttle maneuvers to the preburn attitude (-10 min. before ignition) and then maintains an inertial attitude hold until ignition. At 49^m15^s g.e.t., the Space Shuttle reaches apogee and executes a horizontal, posigrade phasing burn of 350 fps. The maneuver is calculated to give the shuttle the desired trailing displacement from the space station at the time of the terminal phase initiation (TPI) maneuver. The resulting apogee and perigee altitudes are 249 n. mi. and 100 n. mi. respectively.

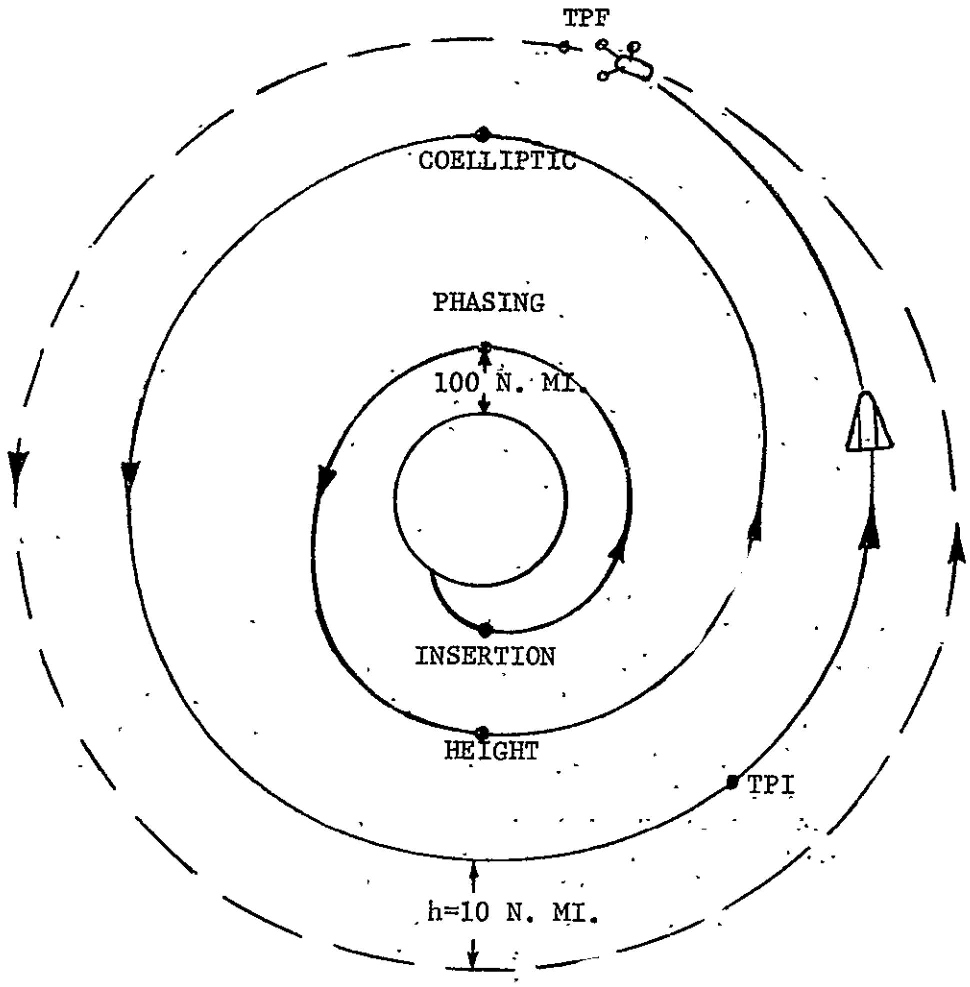


Figure II-5 Orbit Geometry of a Five-Impulse Coelliptic Maneuver

Shortly after the burn, the Space Shuttle maneuvers from the burn cutoff attitude, if necessary, to track the space station. A roll maneuver may be necessary to place onboard sensors in a position to determine the relative state vectors of the Space Shuttle and space station. Relative tracking and preburn targeting continues until approximately $1^h24^m47^s$ g.e.t. when the shuttle orients for the second on orbit burn, the height maneuver. Ten minutes later, the Space Shuttle executes a horizontal posigrade burn of 279 fps to raise the 100-n. mi. perigee to 260 n. mi. The height maneuver is designed to place one end of the Space Shuttle orbit 10 n. mi. (the desired height difference) below that of the space station.

After the height maneuver, the Space Shuttle returns to a local horizontal attitude and rolls (if necessary) to acquire and track the space station. Relative tracking continues until $2^h11^m45^s$ g.e.t. when the Space Shuttle orients for the coelliptic burn. Then the Space Shuttle reaches apogee at 260 n. mi., a 26-fps horizontal, posigrade burn raises the 249-n. mi. perigee to 260 n. mi. and consequently, circularizes the orbit. Following the coelliptic burn, the orbit will be approximately 10-n. mi. below that of the space station, and the Space Shuttle will trail the space station initially at approximately 120 n. mi.

After the coelliptic burn, the Space Shuttle returns to a horizontal, posigrade, heads-up attitude, and tracking of the space station is resumed. At $3^h40^m56^s$ g.e.t. or approximately 1 hour 19 minutes after the coelliptic burn, the Space Shuttle maneuvers to the Terminal Phase Initiation (TPI) burn attitude.

At $3^h50^m56^s$ g.e.t., the Space Shuttle performs a 22-fps burn which places it on an intercept trajectory with that of the space station. Theoretical intercept occurs at a 130° earth central angle after the TPI or approximately 34 minutes 10 seconds after TPI. The attitude required at TPI ignition is crew heads up, +X-axis inplane, posigrade direction, and 27.5° pitch above the local horizontal. After TPI, the shuttle maintains the X-body axis pointing at the space station, and the reaction control system (RCS) jets are used not only to maintain the required line-of-sight attitude but also to accomplish midcourse corrections and line-of-sight control. The line-of-sight pointing attitude is maintained to allow the onboard sensors to acquire and track the space station between the midcourse corrections and the braking maneuvers, and to permit flight crew visual backup of primary subsystems. The theoretical braking maneuver (TBF) occurs at $4^h25^m06^s$ g.e.t.

and requires 28 fps. Because the braking is actually accomplished in a series of range-range rate gates, the total ΔV for braking and line-of-sight control would be higher than the theoretical value. A realistic estimate for the total braking sequence would be 45 fps based on previous rendezvous experience.

After the Space Shuttle has closed to within 100 to 200 feet of the space station, the space shuttle station-keeps for a short period of time while preparations are completed for hard docking. Hard docking is completed after approximately 30 minutes of stationkeeping.

With a return-to-earth maneuver scheduled during the twenty-third hour of the mission, the return-to-earth sequence of the mission begins with undocking. The Space Shuttle then maneuvers to a position behind the space station before applying a 10-fps retrograde RCS separation burn. The separation burn is timed to allow approximately two revolutions between separation and deorbit, and the 10-fps ΔV should be of sufficient magnitude to preclude the possibility of Space Shuttle and space station recontact. At $22^h43^m30^s$ g.e.t., the Space Shuttle assumes a retrograde, heads-down, inplane attitude; and, 10 minutes later at $22^h53^m30^s$ g.e.t., the shuttle executes a 495-fps deorbit burn. After verification of the maneuver, the flight crew maneuvers the shuttle to the entry attitude which corresponds to an angle of attack of $\sim 60^o$ at the time of entry at 400,000 feet and maintains an inertial attitude hold until entry at $23^h25^m30^s$ g.e.t. The resultant entry conditions at 400,000 feet for this particular profile are inertial velocity, 25,949 fps, and inertial flight-path angle, -1.85^o. Landing occurs at approximately $24^h05^m30^s$ g.e.t.

A sequence of the major events for this mission is provided in Table II-1, and a summary of the Space Shuttle attitude profile is given in Table II-2.

2. Mission Phases

The recovery and reuse of Space Shuttle dictates a repetitive cycling through the mission operational modes and mission phases, as illustrated in Figure II-6. The ferry, ground and flight operations are depicted in Figures II-7, II-8 and II-9. Seventeen mission phases, each with a distinct boundary, were identified and are defined in this section.

TABLE II-1 SEQUENCE OF EVENTS, SPACE STATION RESUPPLY

Event	Δt between events, Hr:min:sec	Propulsion System	Total ΔV, fps	Latitude, deg	Position Longitude, deg	Altitude, n. mi.
Insertion		N/A	N/A	TBD	TBD	TBD
	00:41:41					
Phasing		OMS	350	31.1S	89.6E	100
	00:45:32					
Height		OMS	279	31.2N	101.9W	249
	00:46:59					
Coelliptic		OMS	26	31.3S	66.2E	260
	01:29:11					
TPI		OMS	22	16.3S	30.3E	260
	00:34:10					
Braking		RCS	45	23.9S	171.7E	270
	00:30:00					
Docking		RCS	10	55.0N	94.4W	270
	14:58:24					
Separation		RCS	10	55.0S	134.7W	270
	03:00:00					
Deorbit		OMS	495	36.7S	120.0E	270
	00:32:00					
Entry		N/A	N/A	6.0S	105.0W	65.8
	00:40:00					
Landing		N/A	N/A	28.5N	80.6W	0

TABLE II-2 - ATTITUDE PROFILE SUMMARY, SPACE STATION RESUPPLY

Event	Approximate mission time, hr:min:sec	Attitude maneuver
Prethrust attitude maneuver	03:40:56	Maneuver to desired burn attitude and then inertial hold attitude
TPI burn	03:50:56	Posigrade, pitched up 27°, heads up
Relative tracking of space station	03:50:56	Maneuver to and maintain line-of-sight attitude: heads up
Braking (theoretical)	04:25:06	Maintain LOS attitude during burn
Stationkeeping and docking	04:55:06	Maneuver as required
Undocking	19:53:30	Maneuver as required
Separation Maneuver	19:53:30	Retrograde maneuver, crew heads up; +X-axis inplane
Preburn targeting	19:59:30	Maneuver to local horizontal, heads down; then orbital rate
Prethrust attitude maneuver	22:43:30	Maneuver to desired burn attitude; then inertial attitude hold
Deorbit burn	22:53:30	Maintain attitude during burn. Burn attitude is +X-axis inplane, retrograde, heads down
Entry attitude maneuver	22:53:30	Maneuver to +X-axis inplane, pitched up 60° above local horizontal. Hold attitude until entry
Entry	23:25:30	Maneuver as required

TABLE II-2 ATTITUDE PROFILE SUMMARY, SPACE STATION RESUPPLY (Cont.)

Event	Approximate mission time,	Attitude maneuver
Insertion	00:07:34	Maintain cutoff attitude; verify engine
Insertion orbit determination and prethrust targeting	00:08:00	Maneuver to local horizontal, heads down; then orbital rate to maintain local attitude
Prethrust attitude maneuver	00:39:15	Maneuver to desired burn attitude; then hold inertial attitude
Phasing burn	00:49:15	Horizontal, inplane, posigrade, heads-up maneuver: hold attitude
Relative tracking of space station; prethrust targeting	00:49:15	Maneuver to local horizontal; then orbital rate, heads-up attitude
Prethrust attitude maneuver	01:24:47	Maneuver to desired burn attitude; then hold inertial attitude
Height adjustment burn	01:34;47	Horizontal, inplane, posigrade, heads-up maneuver: hold attitude
Relative tracking of space station; preburn targeting	01:34:47	Maneuver to local horizontal; then orbital rate, heads-up attitude
Prethrust attitude Maneuver	02:11:45	Horisontal, inplane, posigrade, heads-up maneuver: hold attitude
Coelliptic burn	02:21:45	Horizontal, inplane, posigrade, heads-up maneuver: hold attitude
Relative tracking of space station; preburn targeting	02:21:45	Maneuver to line-of sight attitude and maintain line of sight to space station attitude

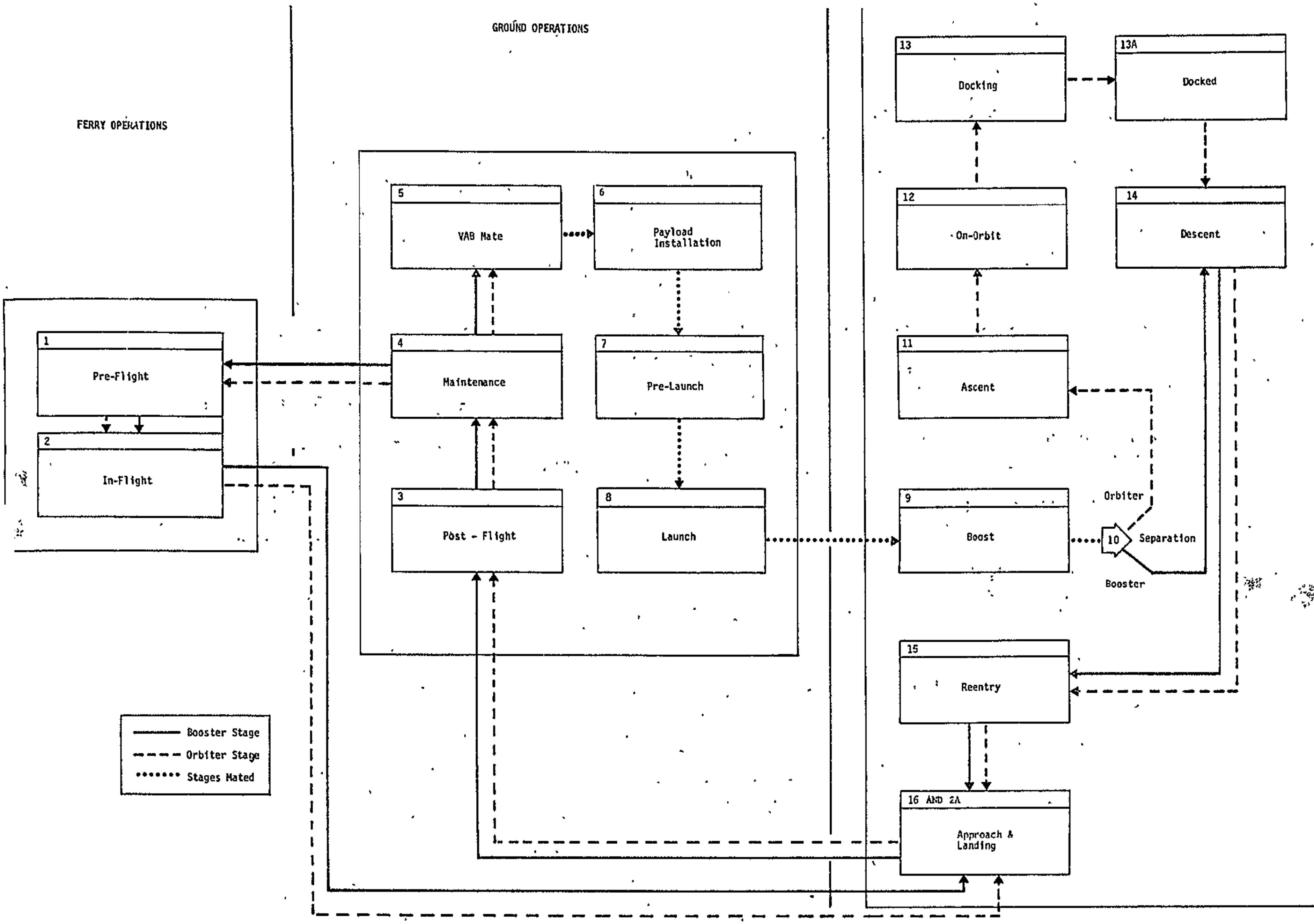


Figure II-6 Flow Diagram of Space Shuttle Mission

a. <u>Ferry Operations - Phase (1) and (2)</u>. As shown in Figure II-7, the booster and orbiter are both rolled out from the manufacturer's plant to the landing strip for take-off to the KSC launch site. The ferry operations mode consists of two phases:

The preflight phase starts at the arrival of the stage at the landing/takeoff strip and includes the following sequence of events:

1) Prepare other vehicle subsystems for ferry flight.
2) Load LH_2 for airbreathing propulsion system.
3) Pressurize LH_2 tanks.
4) Perform pre-flight checkout of systems.
5) Start engines and perform engine checkout at full throttle setting.
6) Taxi stage to takeoff apron.

The in-flight phase starts at the take-off roll of the stage (T_F + 8 hours) and includes the following sequence of events:

1) Clear runway and start climb.
2) Achieve cruise altitude.
3) Cruise to KSC area.

This ends the ferry mission and the shuttle stages now proceed into the ground operations mode.

During each ferry flight the turbofan engines will accumulate up to four hours of flight time. This will provide an opportunity to assess the operation of these engines before the orbital shuttle mission and still not add significantly to the engine cumulative operating time.

b. Ground Operations - Phases 3, 4, 5, 6, 7, and 8. The entire ground operational mode covers a timespan of 14 calendar days which comprise 10 working days. Ground activities are indicated by timeline in Figure II-10 and pictorially in Figure II-8.

As shown in Figure II-8, the booster and orbiter are first placed in the purge and safing revetment. It is planned that this area will be barricaded and so located with respect to occupied areas such that it does not represent a hazard. At this time the removal and/or safing of ordnance items; removal of any remaining fuels and purge of tankage will be accomplished. This is followed by a general clean-up and preparation of the stage for the next phase.

A more detailed timeline for Phase 3, Post-Landing Phase is shown in Figure II-11 with the key assumptions and sequences delineated. The total time for this mission phase is 12 hours.

Phase 4, Maintenance Phase occurs in the maintenance facility which is located in the VAB at KSC. This area will house the booster and orbiter vehicles in a horizontal position in a low bay area. This phase includes the removal of access doors and required corrective maintenance. Component replacement and reverification if required must be accomplished during the five working days allocated for this phase. A more detailed timeline for Phase 4 is shown in Figure II-12 with the key assumptions and all sequences defined.

After completion of the maintenance phase, each stage is taken into the high bay area of VAB where both stages are erected into a vertical position. During the VAB phase, Phase 5, the stages are mated (both mechanically and electrically) and are placed on the mobile launcher. Next, the payload is installed in the orbiter stage as shown in Figure II-13, Phase 6. The prelaunch phase, Phase 7, follows payload installation. A more detailed timeline for VAB mate, payload installation and prelaunch is shown in Figure II-13.

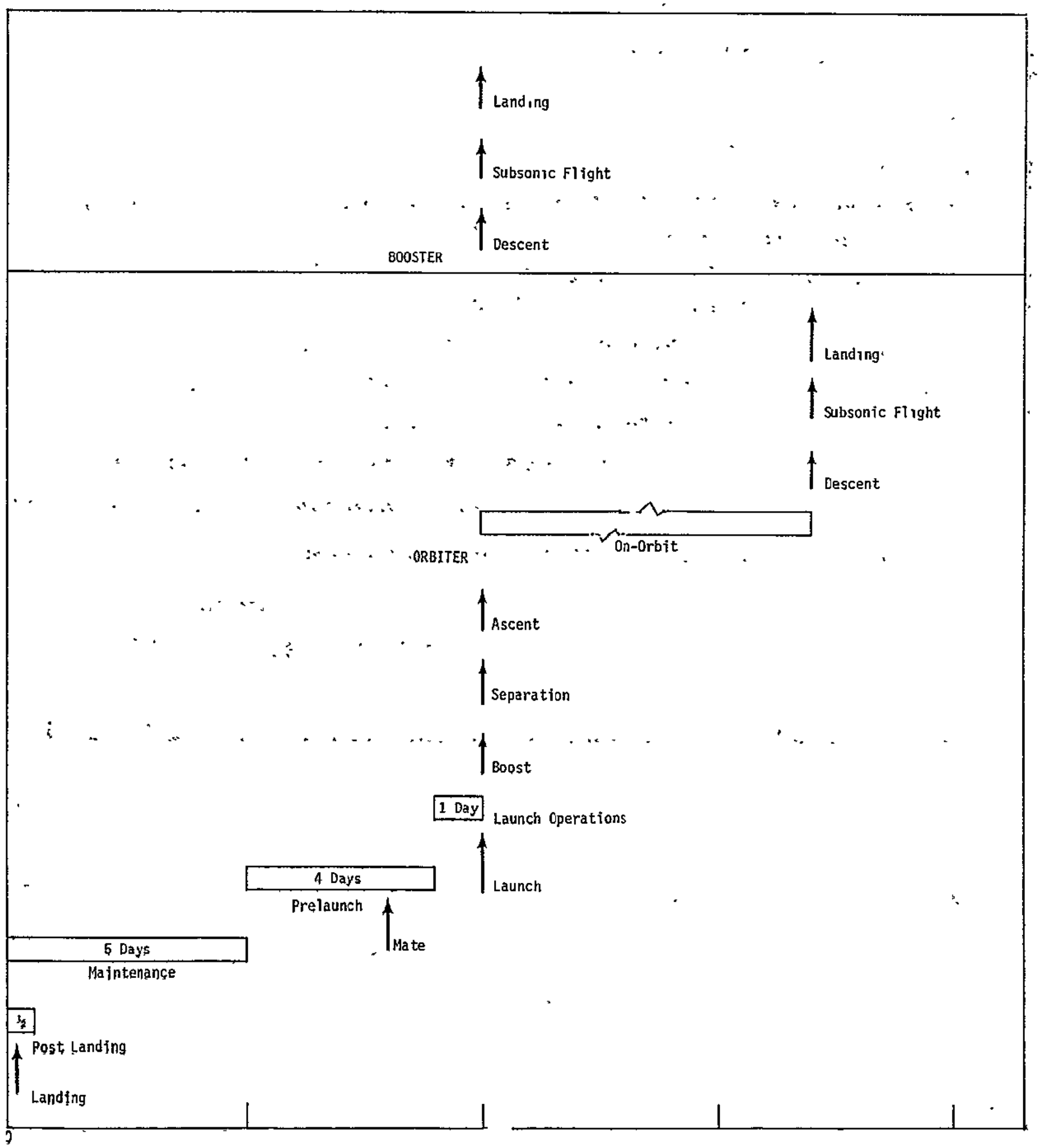


Figure II-10 Ground and Flight Events

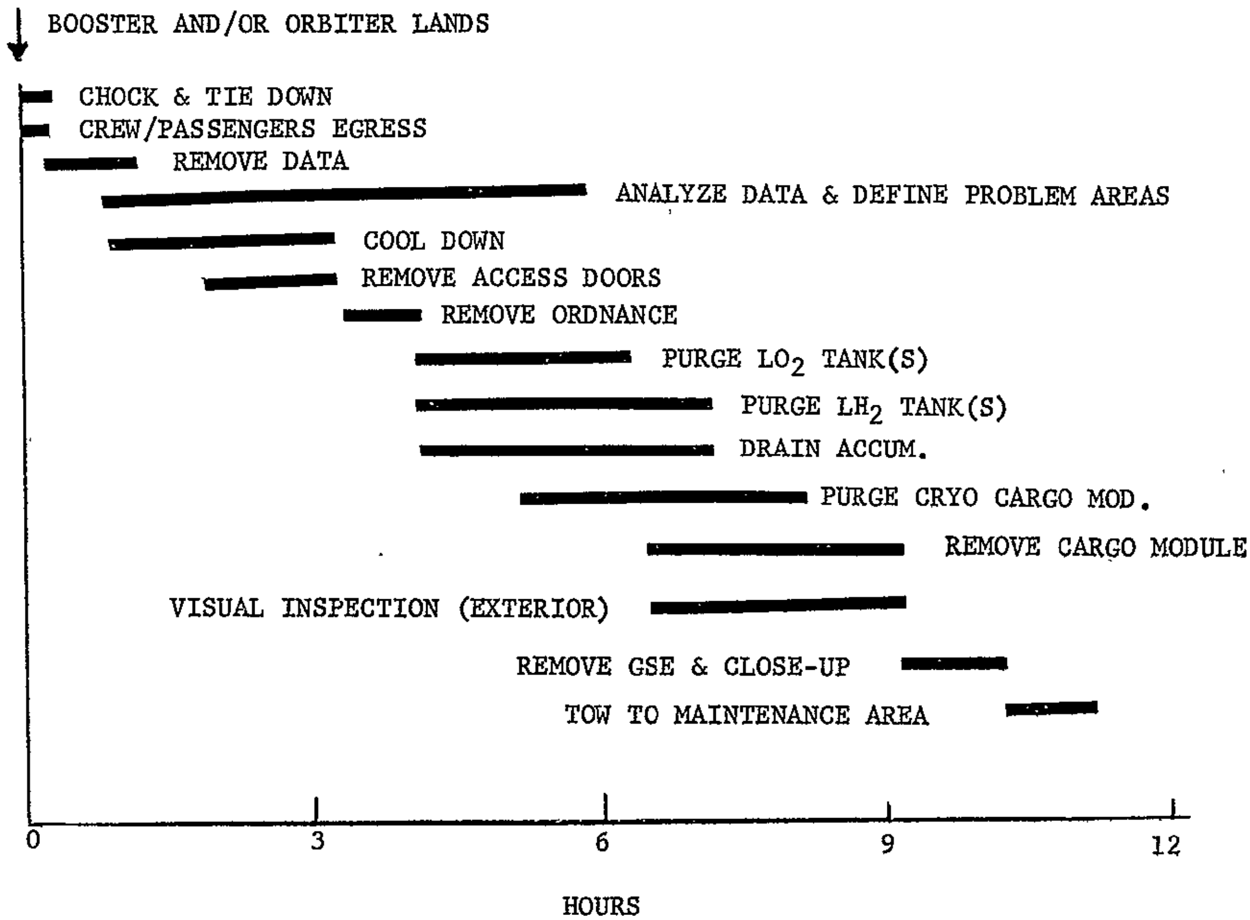


Figure II-11 Post Landing Phase Timeline

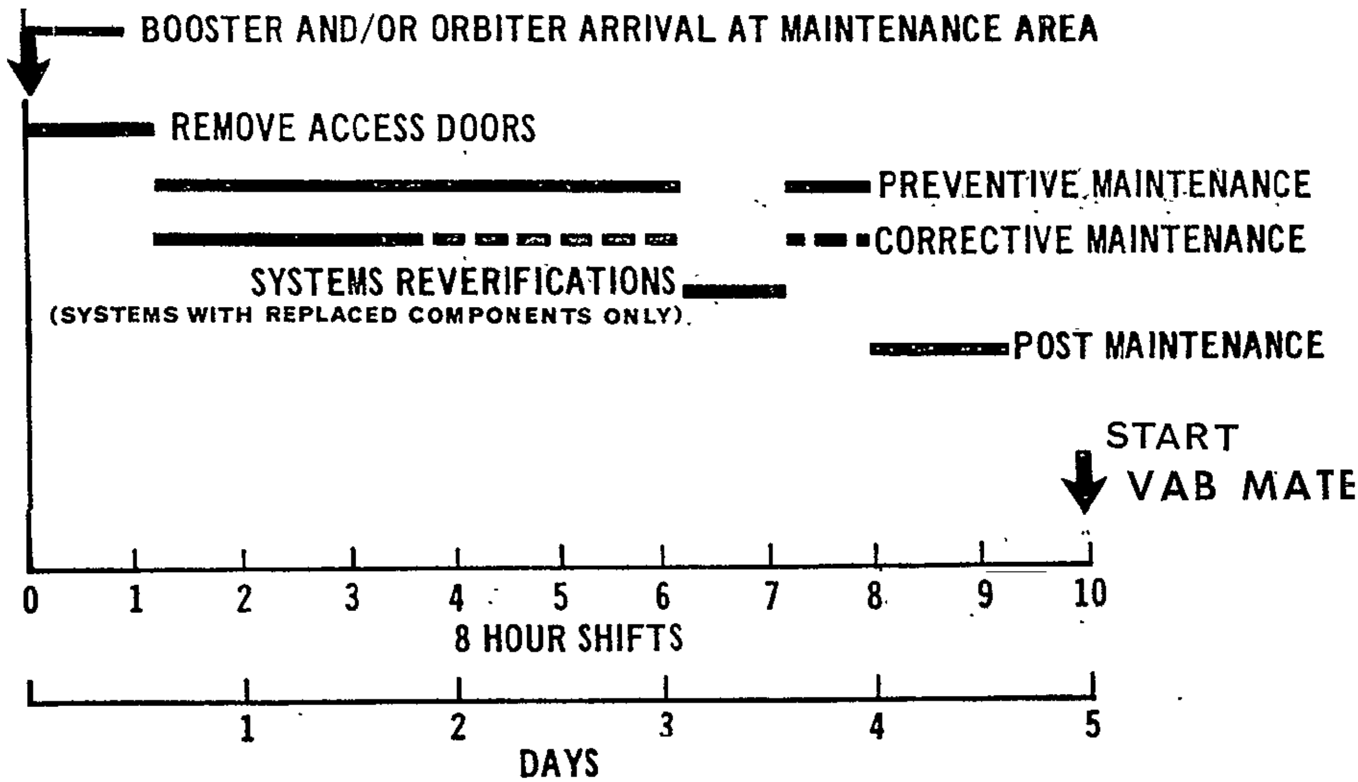


Figure II-12 Maintenance Timeline

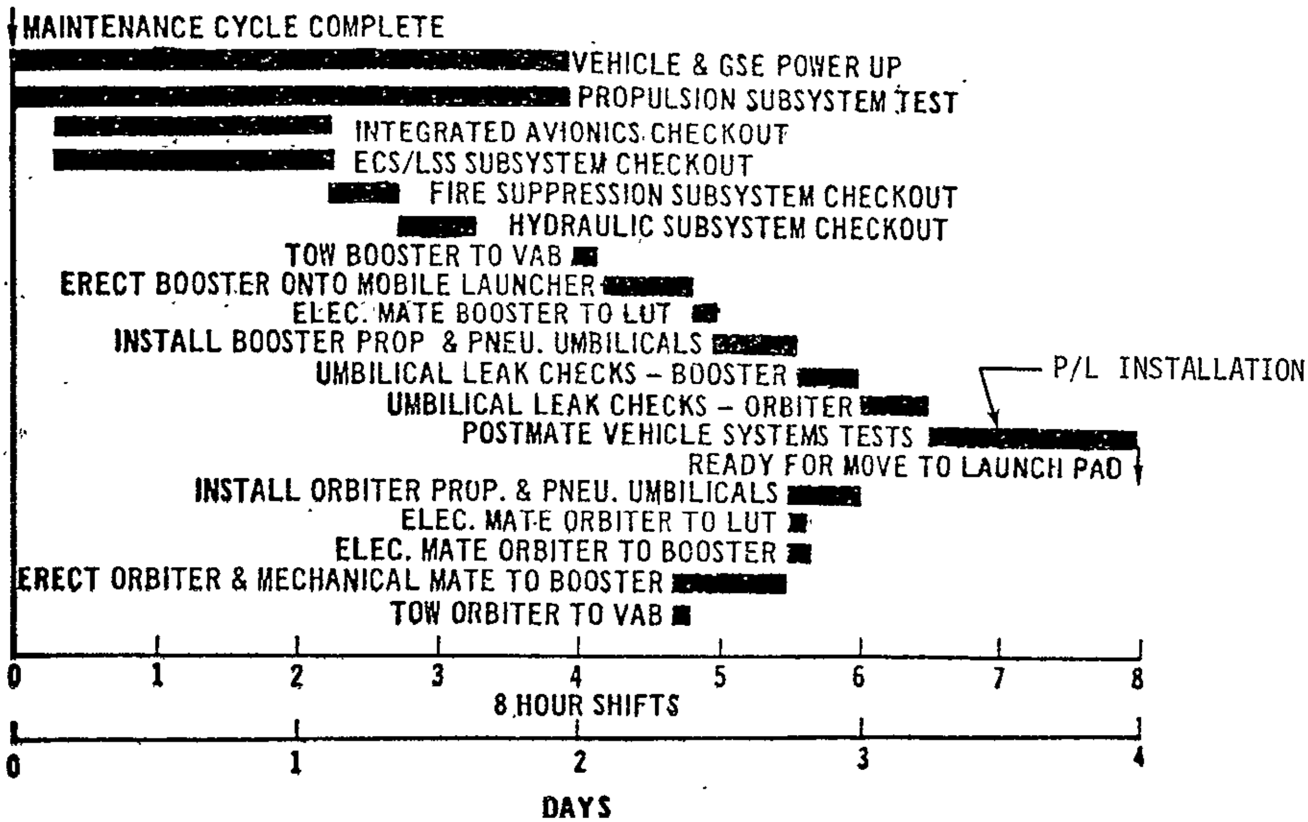


Figure II-13 VAB Mate P/L Installation and Prelaunch Timeline

The launch phase, Phase 8, is shown in Figure II-14 and is comprised of the time period from transfer of the vehicle to the launch site through main engine Fire Signal. Figures II-15 illustrates the transport of the shuttle to the launch complex.

c. Flight Operations - Phases 9, 10, 11, 12, 13, 14, 15 and 16. All flight activities are shown by timeline in Figure II-10 and pictorially in Figure II-1. The first phase of the flight operations (Phase 9) occurs at Booster Main Engine Fire Switch. It then requires 7 secs to clear the tower and To +12 secs to perform the pitch over and roll maneuvers.

The guidance and navigation is fully autonomous in the flight phase with no active crew control. The major engine controls are those required for main engine gimbaling for vehicle steering, mixture ratio control, and throttling at about 130 seconds to keep the axial g's no greater than 4. The main engines are then shut down upon propellant depletion after approximately 170 seconds firing duration.

Staging is accomplished by a sequenced shutdown of the booster engines, ignition of the orbiter engines and firing of the separation rockets to move the booster down and away from the orbiter. At the start of Phase 10, Orbiter Booster Separation, the booster engines are operating at 80% thrust level to limit axial acceleration to 4 g's; the thrust reduces to the 10 percent level in approximately 1 second. The remaining portion of the thrust decay is accomplished in approximately 1.25 seconds. Orbiter ignition command is given at the same time as booster shutdown and the orbiter engines reach 10 percent thrust two seconds later. Approximately 2 seconds after the start of booster shutdown the thrust/weight ratios are equal for the booster and orbiter, and separation is initiated. The separation is accomplished by twenty engines which are fired for 3 seconds to pitch the booster stage down and away from the orbiter stage which continues on trajectory. The orbiter thrust can then start to be increased to 100% after another 2 second thrust time delay.

The start of Phase 11, Orbiter Ascent, is accomplished by the ignition of the two orbiter main engines. These engines burn for 185 seconds, and are then shut down as the orbiter reaches its elliptical orbit of 45 by 100 nautical miles.

The On-Orbit Phase, Phase 12, includes the coast of the orbiter stage to apogee of its elliptical orbit and the subsequent circularization of this orbit to a 100 nautical mile orbit. During this key phase of the mission, five major events occur as follows: Phasing, height change, coelliptic burn, intercept, and braking. It is

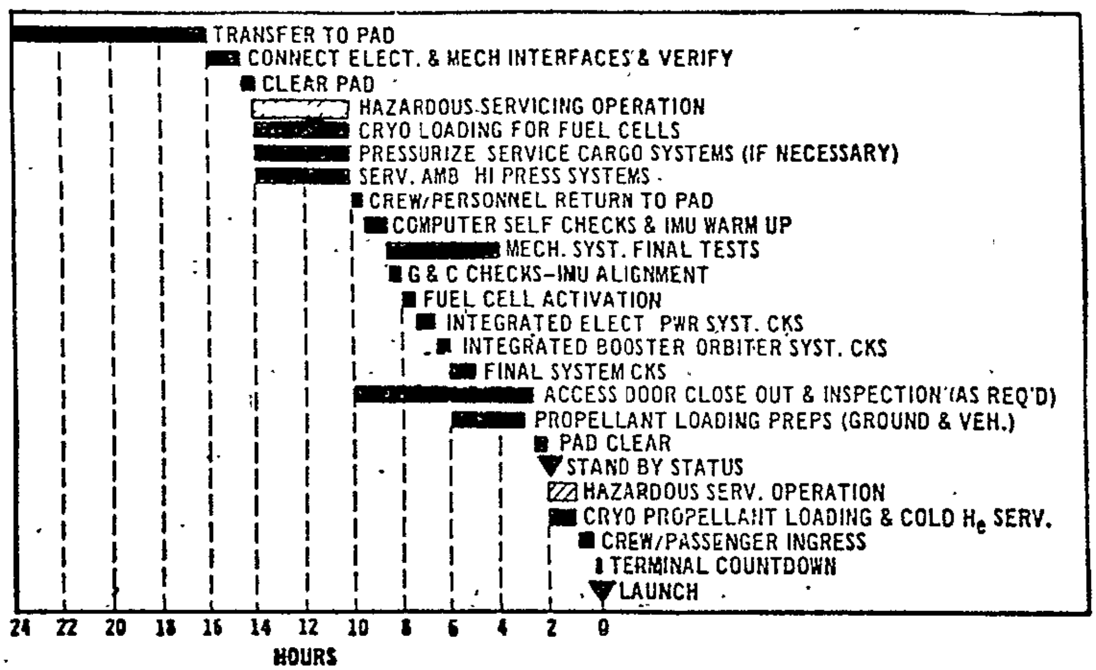


Figure II-14 Launch Phase Timeline

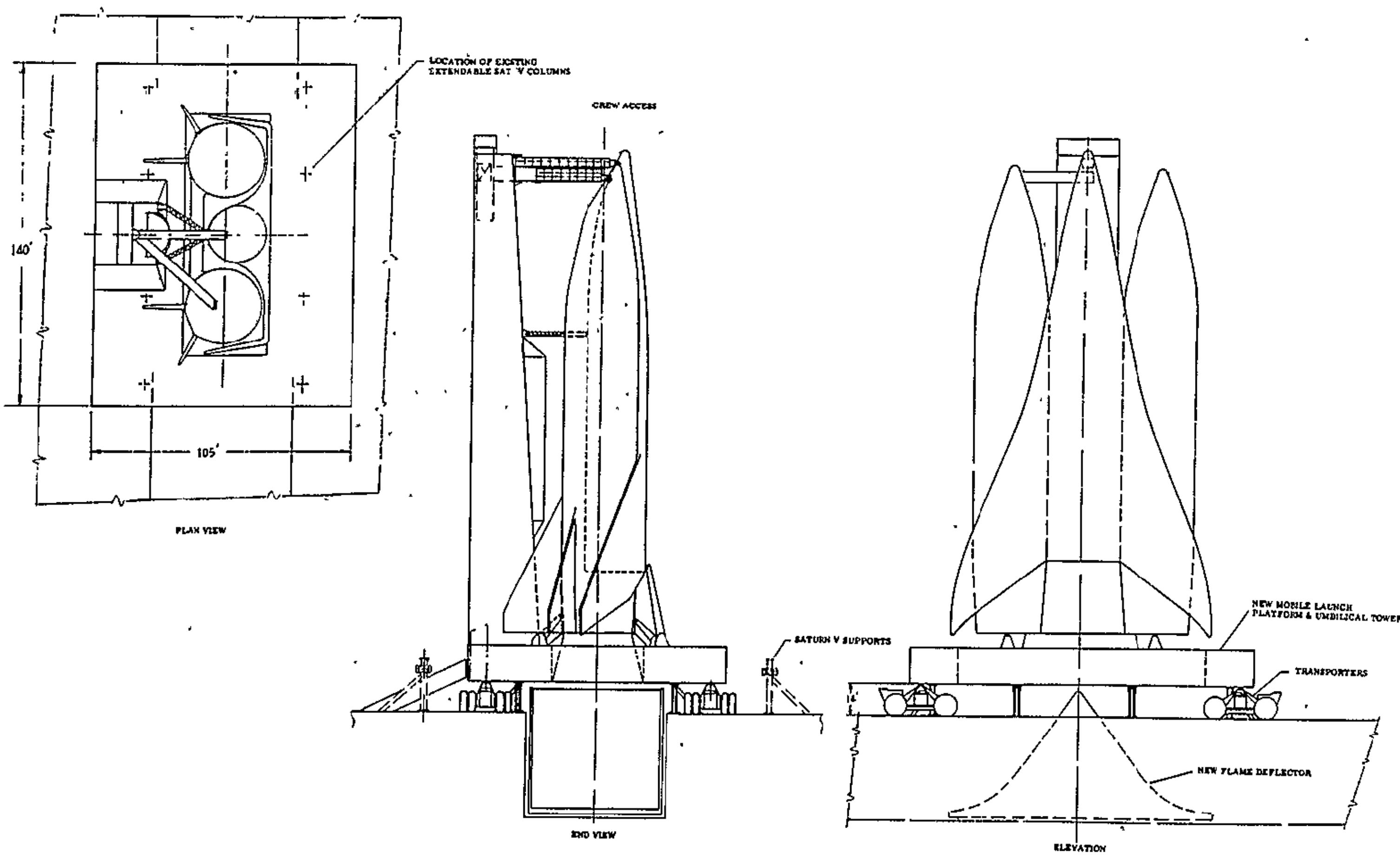


Figure II-15 Shuttle-Transport to Launch Complex assumed that these propulsion events will be accomplished through the use of the Orbital Maneuvering Subsystem (OMS) and Reaction Control Subsystem (RCS) engines, which are a part of the Auxiliary Propulsion System. The first on-orbit burn is the horizontal posigrade phasing burn requiring a ΔV of 350 feet per second. The OMS engines are burned for 528 seconds to accomplish this maneuver. The second on-orbit burn is the height change maneuver. This is a horizontal posigrade burn requiring a ΔV of 279 feet per second to raise the 100 nautical mile perigee to 260 nautical miles. The OMS engines are again fired for 400 seconds to accomplish this maneuver. The third on-orbit burn is the coelliptic burn. This is also a horizontal, posigrade burn which raises the 249 nautical mile perigee to 260 nautical miles. (i.e., circularization of the orbit.) Since the ΔV required is only 26 feet per second, the OMS engines are used with a series of minimum impulse bit firings. The fourth on-orbit burn is the terminal phase initiation (TPI) burn. This is a 22 feet per second ΔV which places the space shuttle on an intercept trajectory with the space station. This is accomplished with the OMS engines in another series of minimum impulse bit firing. After TPI, the reaction control engines are used as required to maintain line-of -sight attitude, accomplish midcourse corrections and line-of-sight control. The last on-orbit burn is the terminal phase finalization (TPF) burn. This is a braking maneuver and based on previous rendezvous experience, could require a ΔV of 45 feet per second. This is accomplished by firing the RCS engines on demand.

The docking phase (Phase 13) occurs when the space shuttle is within 100 to 200 feet of the space station. There is a short period of station-keeping while preparations are made for the docking. The docking maneuver is accomplished by the RCS engines on the shuttle with a total ΔV required of 10 feet per second. The docked phase (Phase 13A) is the time when the orbiter and space station are connected. During this period, a minimum of vehicle electrical power is utilized. The orbiter descent phase (Phase 14) starts with the space shuttle separation from the space station. This is accomplished by a 10 feet per second retrograde RCS separation burn. Approximately 10 minutes later, the orbiter assumes a retrograde, heads down, inplane attitude with the rear of the stage facing the forward trajectory and executes a 495 feet per second burn. This firing utilizes the OMS engines which burn for 610 seconds.

After separation, the booster enters into a descent phase (Phase 14) by coasting to a peak altitude of about 260,000 feet.

The reentry phase (Phase 15) although shown as one block on Figure II-6 does have two arrows as inputs and thus, this phase takes place at different times for the two stages. Both are discussed in this paragraph. The booster starts its reentry by trimming to a high angle of attack ($\sim 45^{\circ}$). After the booster has slowed to subsonic speeds, the airbreathing engines are ignited and used to cruise back to the landing site. Orbiter reentry starts at 400,000 feet altitude with a velocity slightly less than 25,000 fps and a flight path angle of -1.25°. After the orbiter has slowed to subsonic speeds, the airbreathing engines are ignited and used to cruise back to the landing site.

The last phase of the flight is Phase 16, the approach and landing phase. Again, both the booster and orbiter are discussed. The booster engine inlet and exit are opened and the engines are started. Level-flight thrust is available at a cruise altitude of 16,000 feet, and fuel is sufficient for 2.1 hours of flight with an additional 0.3 hour reserve.

For descent and landing, the flaps are extended and the engine power is reduced to 55%, resulting in a 7° descent angle. The final approach path is a 5° descent angle and is initiated 5 nautical miles from the landing point.

A free roll of 3 seconds, covering 730 feet, is allowed to complete the touchdown and apply brakes; this is followed by a 0.2 g braked roll of 4200 feet. After the landing rollout is complete, the vehicle will taxi to the vehicle safing area or will be towed if necessary. The proper environment will be established in the crew area to allow opening up to sea level atmosphere. After opening the crew hatch, the crew will then egress from the vehicle. The ground crews safe the system, release pressure in the tanks and purge the liquid systems. At this point, the booster flight operations are considered to be complete. Refer to Figure II-16 for pictorial representation of booster return cruise and landing.

The orbiter hypersonic entry maneuver is nominally completed at 70,000 feet altitude, Mach Number 1.6, at which time the vehicle is capable of gliding some 65 nautical miles to sea level, at a speed of 215 knots indicated airspeed. For a lesser distance to the landing point, a series of turns is executed so that the vehicle is in position for a 360° overhead landing pattern. During the 360° turn, the airbreathing engines are extended and started. The low key final approach point is 5 nautical miles from the landing point, at an altitude of 4,000 feet, with a glide slope of 7 degrees. Ten seconds before the

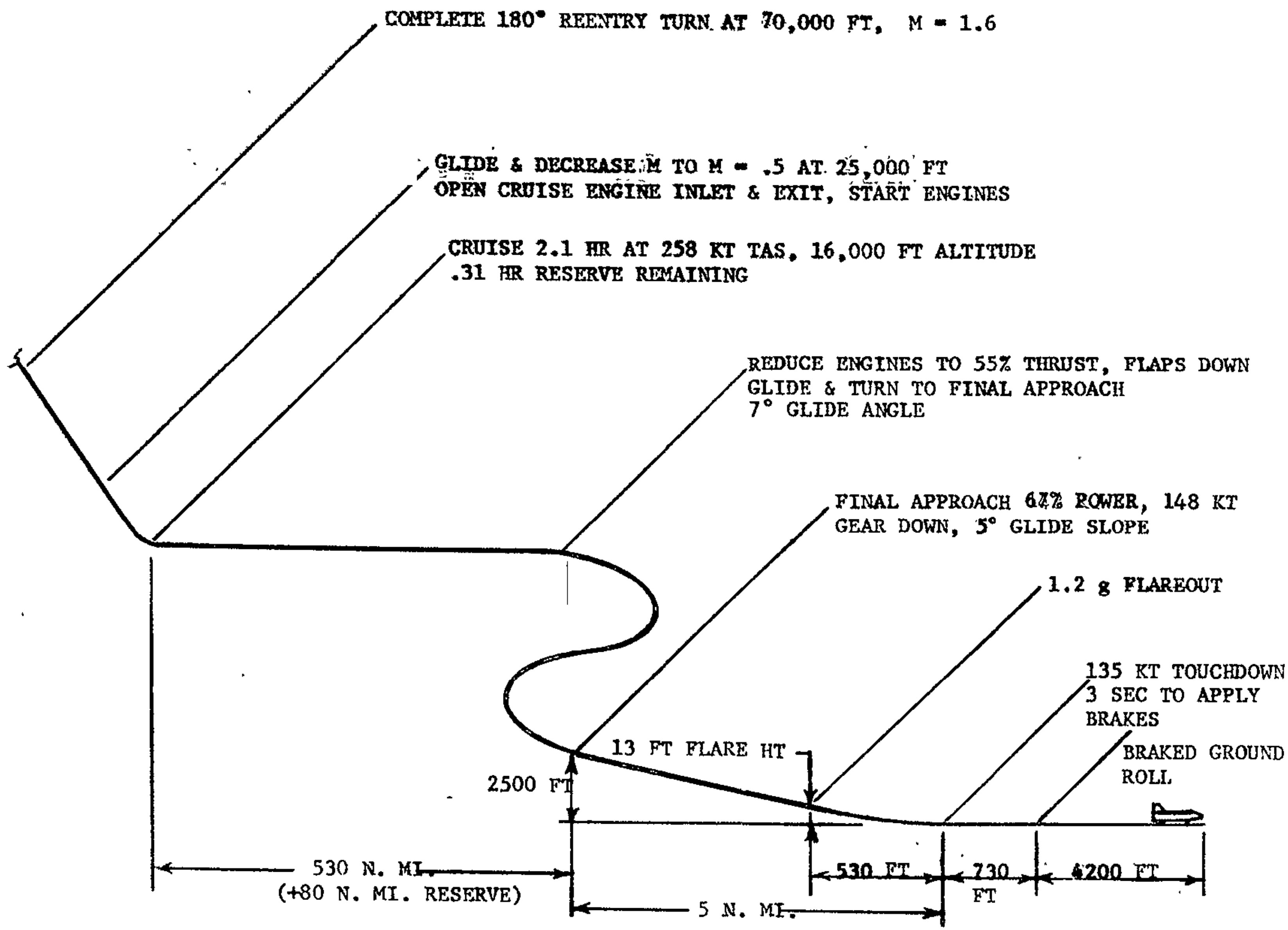


Figure II-16 Booster Subsonic Return Cruise & Landing final flareout, the landing gear is extended; this allows time to initiate a go-around in case of a malfunction. The 1.2 g flareout is initiated at 150 feet altitude; the flare distance is 4,000 feet. Five seconds of free flight are allowed for touchdown, rotation to the three-point position and application of brakes, followed by a 0.2 g braked roll. The total ground roll is 6500 feet. After the landing roll out is complete, the stage will taxi or be towed to the vehicle safing area. The proper environment will be established in the crew area and cargo passenger area to allow opening up to sea level atmosphere. After opening the crew hatch and the cargo doors, the crew and passengers will then egress. At this point, the ground crews will safe the system, release pressure in the tanks and purge the liquid systems. At this point, the orbiter flight operations are considered to be complete. Figure II-17 depicts orbiter subsonic glide and landing.

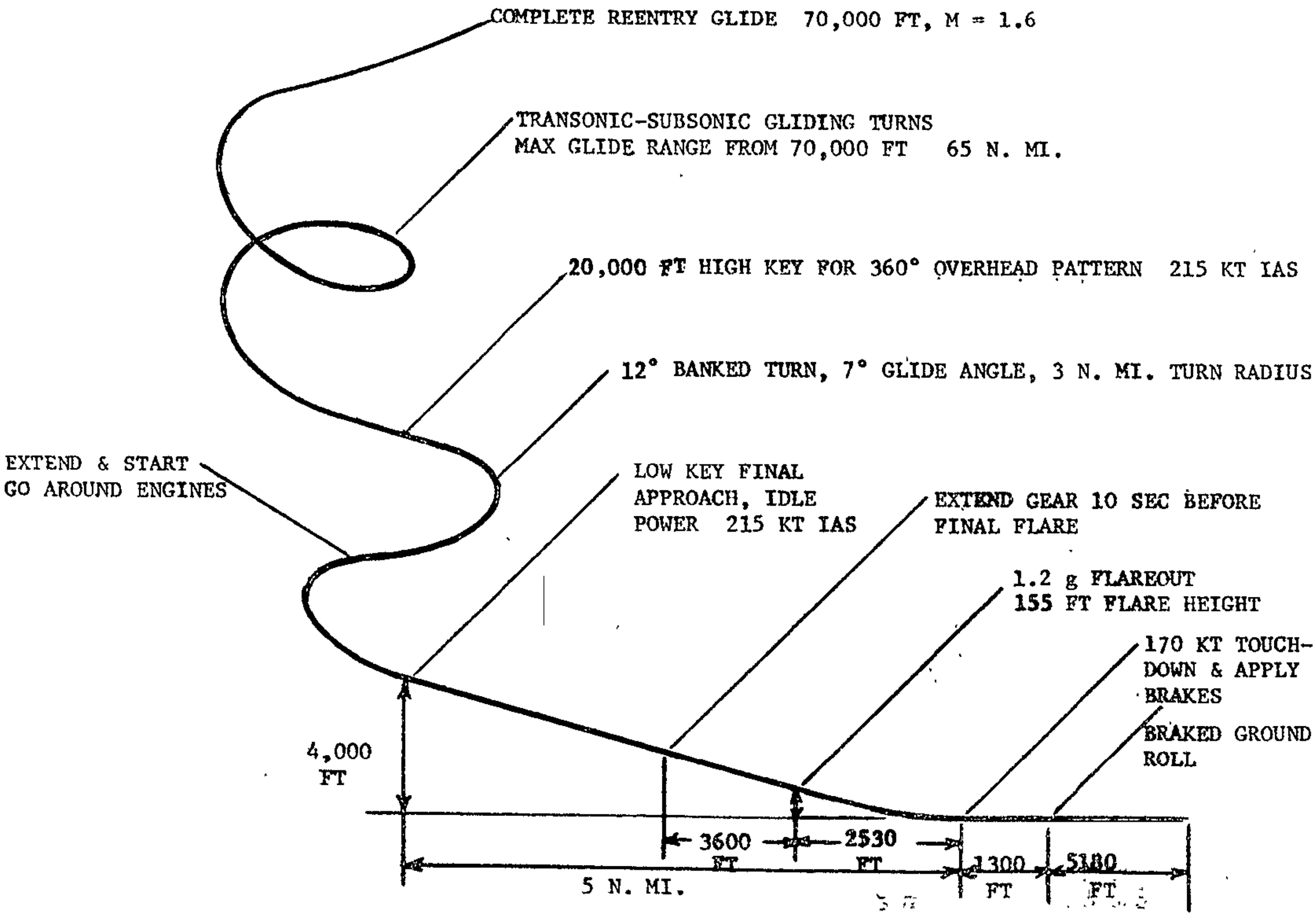


Figure II-17 Orbiter Subsonic Glide and Landing

C. PROPULSION SYSTEMS

The propulsion Design Reference Model is described in this section. The booster and orbiter both have main, auxiliary and airbreathing propulsion systems. Each propulsion system was divided into subsystems, i.e., main engine subsystem; each subsystem into assemblies, i.e., engine power assembly; and each assembly into components, i.e., fuel main valve. This level of detail was necessary so that the required propulsion evaluation studies could be conducted. The booster and orbiter systems and subsystems are identified in Table II-3.

Component definition was accomplished by utilizing those defined in the Space Shuttle Vehicle and Main Engine Phase B studies, or selecting representative components used on the S-II or S-IVB stages of Saturn.

The components are shown in the booster propulsion schematic, Figure II-18, and the orbiter propulsion schematic, Figure II-19. Symbols used in these schematics are defined in Figure II-20. In many cases, a component of a given type is used in two or more places. This commonality of components is identified in Tables II-4 , II-5 , and II-6 , for the main, auxiliary and airbreathing propulsion systems, respectively.

The following pages identify and define the hardware elements of the propulsion systems. The booster main, auxiliary and airbreathing systems are followed by the orbiter main, auxiliary and airbreathing systems.

TABLE II-3

BOOSTER AND ORBITER

PROPULSION SYSTEMS AND SUBSYSTEMS

1.0 Booster Main Propulsion System

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

2.0 Booster Auxiliary Propulsion System

- 2.1 APS Engine Subsystem
- 2.2 APS Propellant Management Subsystem
- 2.3 APS Hydrogen Conditioning Subsystem
- 2.4 APS Oxygen Conditioning Subsystem
- 2.5 APS Separation Engine Subsystem
- 2.6 Auxiliary Power Subsystem

3.0 Booster Airbreathing Propulsion System

- 3.1 Turbofan Engine Subsystem
- 3.2 Propellant Management Subsystem
- 3.3 Pressurization Subsystem

4.0 Orbiter Main Propulsion System

- 4.1 Main Engine Subsystem
- 4.2 Main Propellant Management Subsystem
- 4.3 Main Pressurization Subsystem
- 4.4 On-Orbit Propellant Subsystem
- 4.5 On-Orbit Pressurization Subsystem

5.0 Orbiter Auxiliary Propulsion System

- 5.1 APS Engine Subsystem
- 5.2 APS Propellant Management Subsystem
- 5.3 APS Propellant Conditioning Subsystem
- 5.4 OMS Engine Subsystem

6.0 Orbiter Airbreathing Propulsion System

- 6.1 Turbofan Engine Subsystem
- 6.2 Propellant Management Subsystem

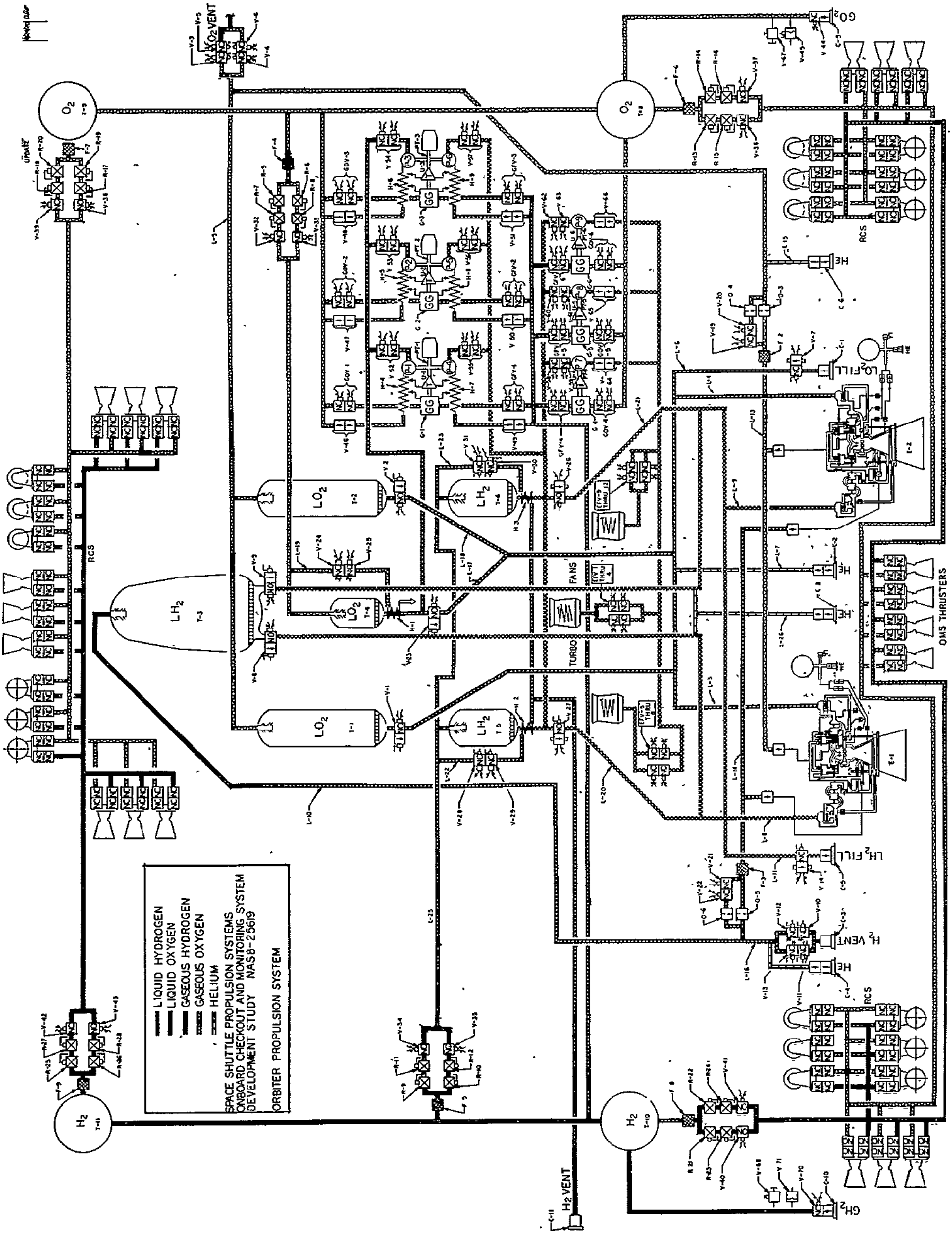


Figure II-19 Orbiter Propulsion Schematic

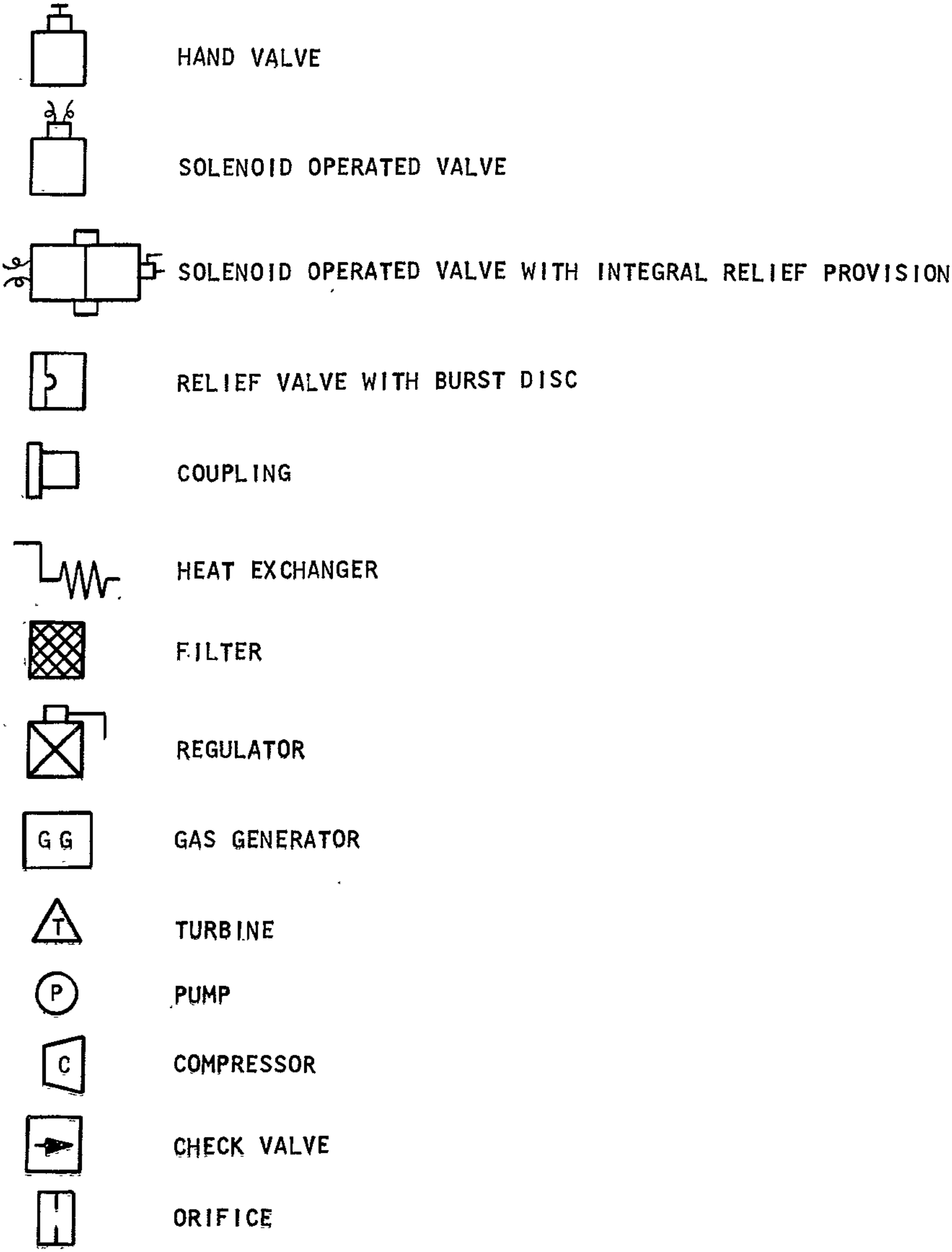


Figure II-20 Symbols - Schematics

1. Booster Main Propulsion System

The booster main propulsion system is illustrated in Figure II-21and depicted schematically in Figure II-22. It is comprised of three subsystems: the main engine subsystem, the main propellant management subsystem, and the main pressurization subsystem.

As shown in the figures, liquid oxygen is transferred from the forward tank through dual suction lines to a manifold in the engine compartment. These dual suction lines provide a means of geyser suppression by natural circulation supplemented by helium lift pumping. Separate feedlines are provided to each engine from the common manifold. Provisions are included for helium bubbling to provide required pump inlet temperatures. Hydrogen is distributed from the hydrogen tank sump by separate, equal-length feedlines to each engine. The lines are insulated to reduce heat leak. Lox and hydrogen are loaded through disconnects in the base region.

Autogenous pressurization of propellant tanks is provided by gaseous hydrogen and vaporized lox from the main engines. The pressurant flow rates are controlled by fixed orifices. Inflight venting of pressurizing gas is not anticipated; however, vent-relief valves are included for ground safety. Hydrogen vent gas is ducted through a vent line to the base of the vehicle where it connects to a ground system.

Fourteen 400,000-pound-thrust, high chamber pressure, Lox/LH_2 engines are used on the booster, seven on each of the booms.

Each of the three main propulsion subsystems are described in greater detail in the following pages, and the components are identified.

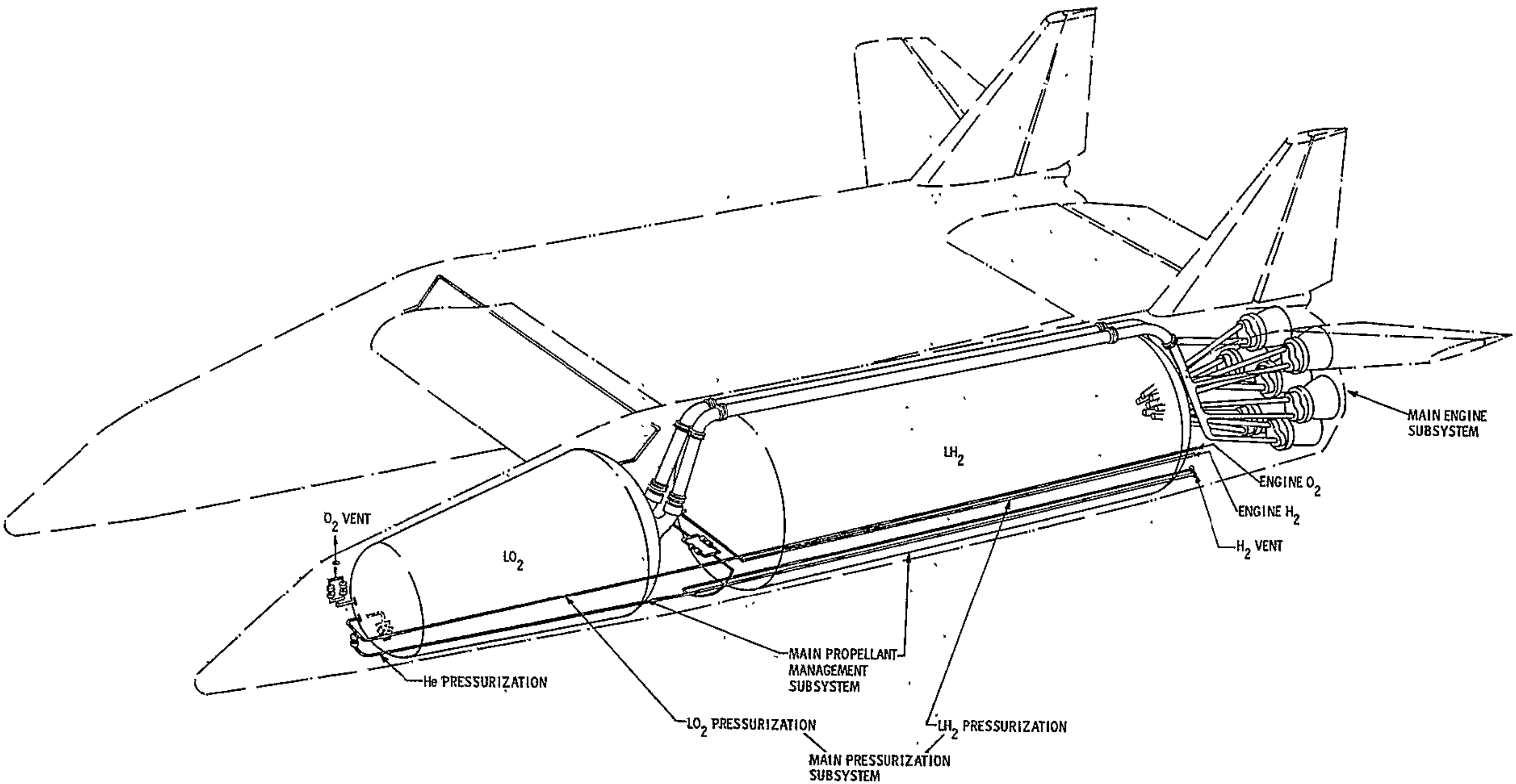


Figure II-21 Main Booster System

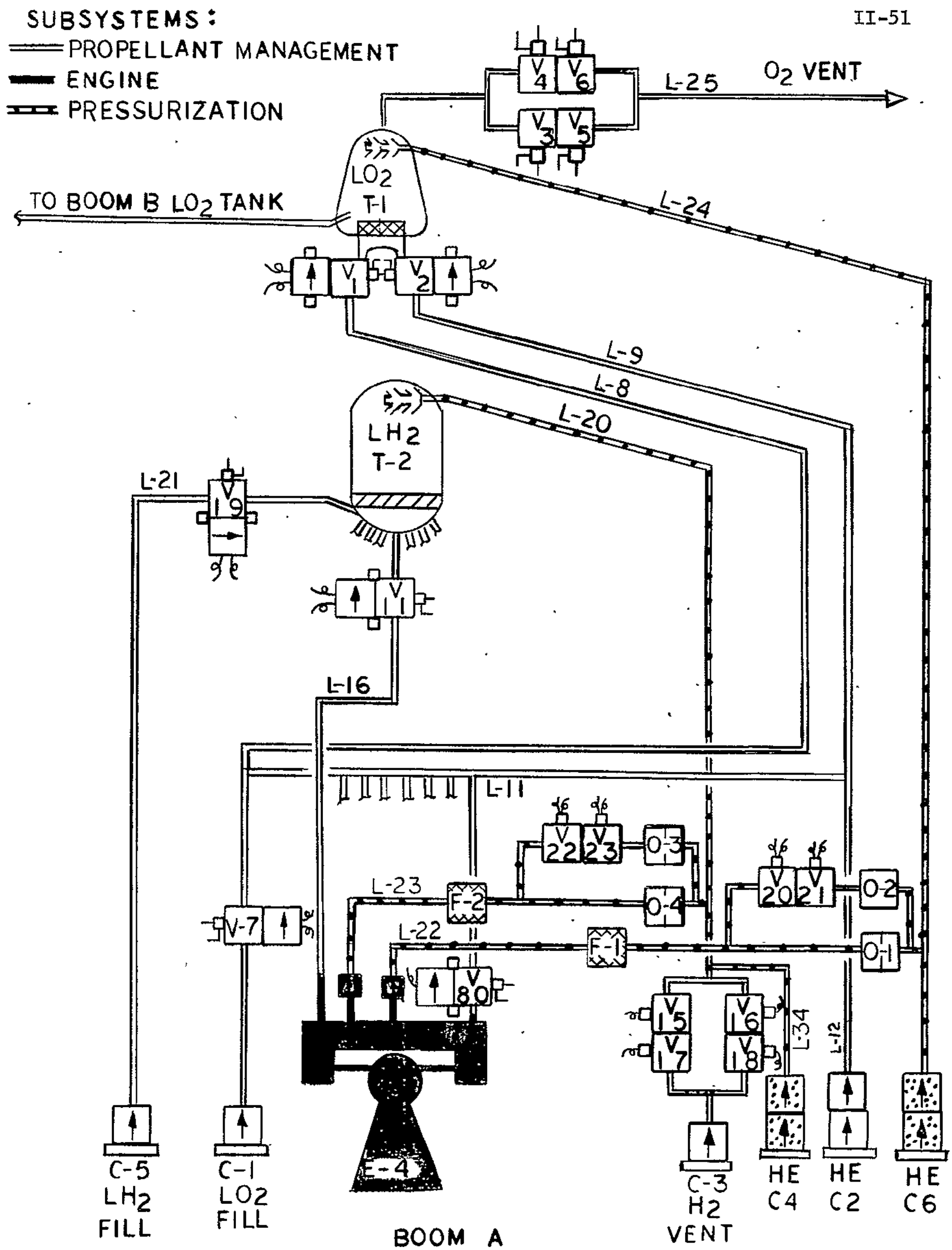


Figure II-22 Main Propulsion System - Booster

a. Booster - Main Engine Subsystem (1.1) - The selected AJ-400 staged combustion cycle engine is shown pictorially in Figure II-23 and in schematic form in Figure II-24. The engine utilizes liquid oxygen as the oxidizer and liquid hydrogen as the fuel. The propellants are introduced at the engine suction lines (engine interface) at a specified pressure and temperature:

$$\left.\begin{array}{l}\text{Oxygen at } 164^{o}\text{R and 100 psia} \\ \text{Hydrogen at } 37^{o}\text{R and 30 psia}\end{array}\right\} \quad \text{starting condition}$$

All of the hydrogen, except that used for cooling thrust chamber, is combusted with a small amount of oxygen in two individual preburners to produce turbine drive gas. After passing through the turbines, the hot gas is exhausted into the thrust chamber where it is burned with the remaining oxidizer. Modulated preburner propellant supply valves are incorporated to facilitate mixture ratio control and thrust control. During operation, the engine supplies pressurant gasses for main propellant tank pressurization. Hydrogen gas is tapped from the thrust chamber coolant jacket and is supplied to the engine interface at about 1.7 lbs/sec. Oxidizer is tapped from the high pressure oxidizer pump discharge line, passed through a heat exchanger, and supplied at the engine interface at approximately 4.4 lbs/sec.

The main structural component is the gas manifold, which has preburners and main turbopumps attached to its outer members, the gimbal block affixed to the upper side of the center body, and the thrust chamber attached to the lower side. The boost pumps are vehicle-mounted. Gimballing is accomplished by means of articulating propellant lines attached to the main pumps. Hydraulic gimbal actuators are attached to the vehicle through upper clevises and by radial arms on the thrust chamber. The actuators can be locked in the null position when not in use or on command. The booster engines utilize fixed, fuel cooled, 53:1 area ratio nozzle.

The booster main engine operates at three power levels:

Normal power level (NPL)	100% thrust at MR 6.0
Emergency power level (EPL)	115% thrust at MR 6.0
Minimum power level (MPL)	50% thrust at MR 6.0

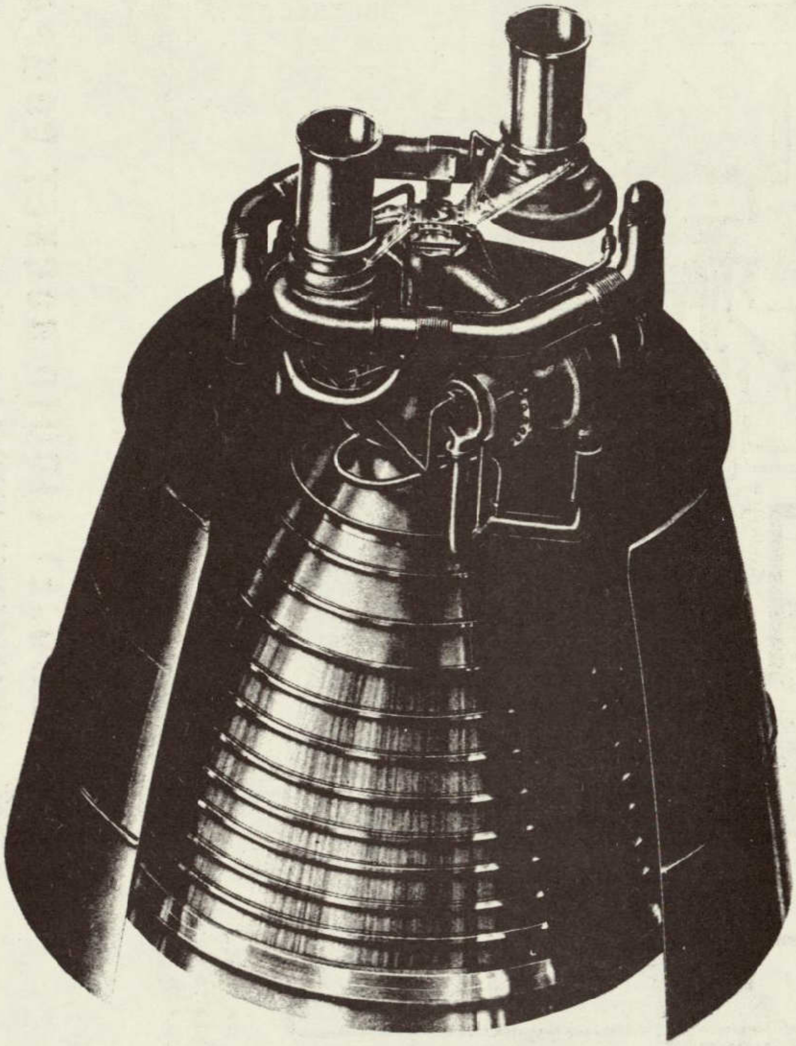
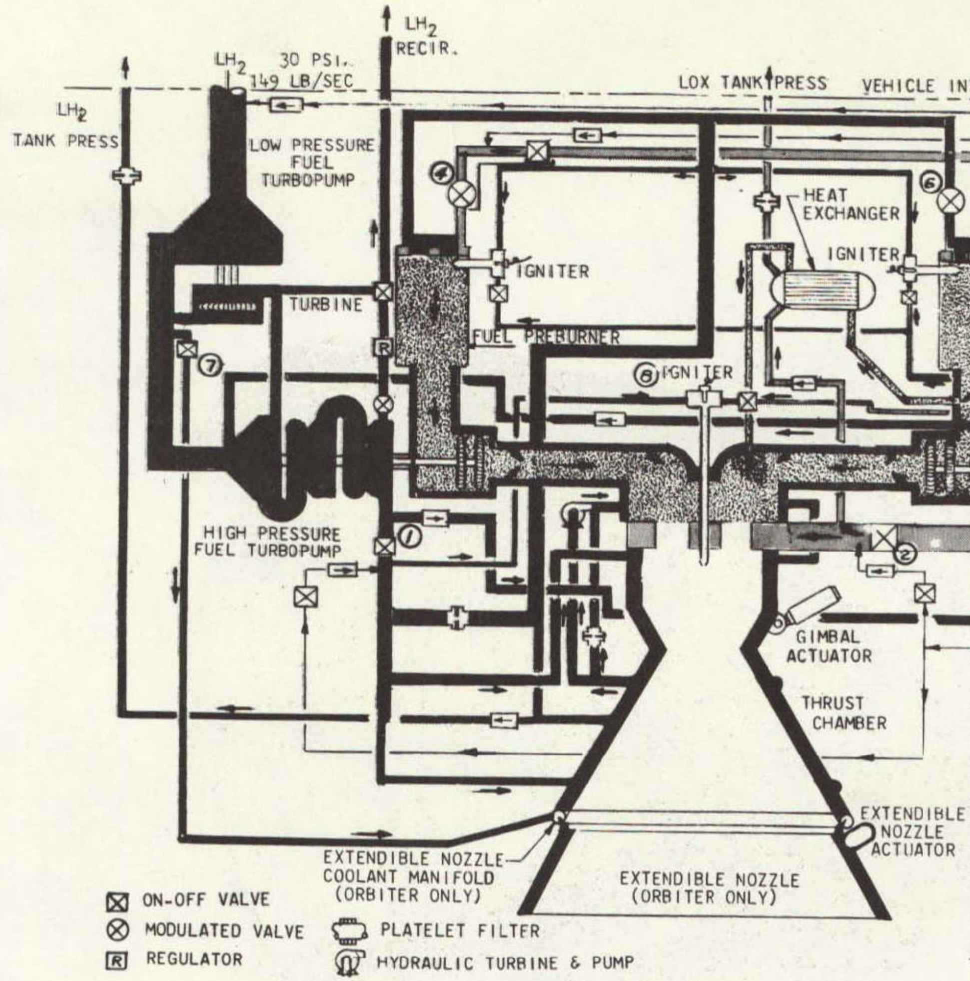


Figure II-23 AJ-400 Engine



ITEM	OUTLINE NO.	DESCRIPTION
1	1.1.1.8	FUEL MAIN VALVE
2	1.1.1.9	OXIDIZER MAIN VALVE
3	1.1.1.13	OXIDIZER PREBURNER SHUTOFF VALVE
4	1.1.1.12	OXIDIZER CONTROL VALVE, FUEL PREBURNER
5	1.1.1.11	OXIDIZER CONTROL VALVE, OXIDIZER PREBURNER
6	1.1.1.10	FUEL CONTROL VALVE, OXIDIZER PREBURNER
7	1.1.8.2	EXTENDIBLE NOZZLE COOLANT VALVE (ORBITER ONLY)
8	1.1.3.1	MAIN TCA IGNITER

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Figure II-24 Main Engine Flow Schematic

Engine rated thrust is 400,000 lbs at sea level and 462,000 lbs at hard vacuum. The engine design life is 10 hours or 100 starts at NPL and one start at EPL.

The engine is equipped with an integral closed loop controller, which is described in the Design Reference Model Electronics section of this volume.

The engine assemblies and components are listed below.

- 1.1.1 Engine Power Assembly
  - 1.1.1.1 Low Pressure Fuel Turbopump
  - 1.1.1.2 High Pressure Fuel Turbopump
  - 1.1.1.3 Low Pressure Oxidizer Turbopump
  - 1.1.1.4 High Pressure Oxidizer Turbopump
  - 1.1.1.5 Fuel Preburner
  - 1.1.1.6 Oxidizer Preburner
  - 1.1.1.7 Hot Gas Manifold
  - 1.1.1.8 Fuel Main Valve
  - 1.1.1.9 Oxidizer Main Valve
  - 1.1.1.10 Fuel Control Valve, Oxidizer Preburner
  - 1.1.1.11 Oxidizer Control Valve, Oxidizer Preburner
  - 1.1.1.12 Oxidizer Control Valve, Fuel Preburner
  - 1.1.1.14 Interconnect Articulating Lines
  - 1.1.1.15 Interconnect Lines
  - 1.1.1.16 Oxidizer Recirculation Select Valve
  - 1.1.1.17 Fuel Recirculation Select Valve
  - 1.1.1.18 Fuel Recirculation Control Valve
  - 1.1.1.19 Fuel Recirculation Regulator
- 1.1.2 Thrust Chamber Assembly
  - 1.1.2.1 Main Injector
  - 1.1.2.2 Main Combustion Chamber
  - 1.1.2.3 Booster Nozzle
  - 1.1.2.5 Gas Distribution Plate
  - 1.1.2.6 Interconnect Lines (3 line sections)
- 1.1.3 Ignition Assembly
  - 1.1.3.1 Ignitors (Ox Preburner, Fuel Preburn, Main TCA)
  - 1.1.3.2 Interconnect Lines (4 line sections)
- 1.1.4 TVC Assembly
  - 1.1.4.1 Gimbal Block
  - 1.1.4.2 Gimbal Actuator and Power Pack
- 1.1.5 Engine Control Assembly
  - 1.1.5.1 Engine Controller
  - 1.1.5.2 Ignition and Valve Control Harness
  - 1.1.5.3 Instrumentation Harness
  - 1.1.5.4 Sensors

1.1.6 Tank Pressurant Assembly

- 1.1.6.1 Fuel Tank Pressurant Check Valve
- 1.1.6.2 Oxidizer Tank Pressurant Check Valve
- 1.1.6.3 Oxidizer Heat Exchanger
- 1.1.6.4 Interconnect Lines (5 line sections)

1.1.7 Engine Purge Assembly

1.1.7.1 Purge Valves

Solenoid Valves:

Preburner Oxidizer Purge
Main TCA Fuel Purge
Main TCA Oxidizer Purge
H.P. OTPA Seal Cavity Purge
Engine System Purge Control
Two-way GN_2/GHe Select Valve

Check Valves:

Oxidizer Preburner Oxidizer Inlet Purge
Fuel TPA Preburner Oxidizer Inlet Purge
Main TCA Fuel Inlet Purge
Main TCA Oxidizer Inlet Purge
H.P. OTPA Seal Cavity Purge
Fuel Suction Line Purge
Oxidizer Suction Line Purge

1.1.7.2 Interconnect Lines (5 line sections)

b. Booster - Main Propellant Management Subsystem (1.2) - The main propellant management subsystem provides feed, distribution and storage of liquid hydrogen and liquid oxygen propellants. Uninsulated LOX tanks are located forward and are 15,175 ft^3 each. The LH_2 tanks are insulated to prevent air condensation, minimize ascent propellant heating, and to limit re-entry ullage vapor heating. The volume of each LH_2 tank is 47,650 ft^3. The fill system is configured to permit use of base mounted umbilicals, thereby minimizing re-entry thermal protection system penetrations and swing arm functions. The LOX feed system is composed of two uninsulated 18" diameter lines. These lines form a closed loop permitting recirculation for geyser prevention. The engine suction lines are routed from the loop to each of the seven engines. The uninsulated LOX ground vent line is routed from each tank to the vehicle skin. The insulated GH_2 vent line is routed to the base where a ground umbilical can be attached.

The propellant management subsystem is comprised of ten assemblies and 114 components (component identification numbers in parentheses relate to the booster propulsion system schematic, Figure II- 18). Each boom has the following components and assemblies:

1.2.1 Oxidizer Feed Assembly
  1.2.1.1 Oxidizer Feed Line (L-1 through L-7)
  1.2.1.2 Oxidizer Prevalve (V-77 through V-83)

1.2.2 Oxidizer Distribution Assembly
  1.2.2.1 Oxidizer Distribution Line (L-8 and L-9)
  1.2.2.2 Oxidizer Isolation Valve (V-1 and V-2)

1.2.3 Oxidizer Tank Vent Assembly
  1.2.3.1 Oxidizer Vent Line (L-25)
  1.2.3.2 Oxidizer Vent Valve (V-3 through V-6)

1.2.4 Oxidizer Fill and Drain Assembly
  1.2.4.1 Oxidizer Fill and Drain Line (L-11)
  1.2.4.2 Oxidizer Fill Valve (V-7)
  1.2.4.3 Oxidizer Fill Coupling (C-1)

1.2.5 Oxidizer Tank Assembly
  1.2.5.1 Oxidizer Tank (T-1)
  1.2.5.2 Oxidizer Tank Sump (S-1)
  1.2.5.3 Gas Diffuser (D-1)

1.2.6 Geyser Suppression Assembly (Oxidizer)
  1.2.6.1 Helium Line (L-12)
  1.2.6.2 Helium Coupling (C-2)

1.2.7 Fuel Feed Assembly
  1.2.7.1 Fuel Feedline (L-13 through L-19)
  1.2.7.2 Fuel Isolation Valve (V-8 through V-14)

1.2.8 Fuel Vent Assembly
  1.2.8.1 Fuel Tank Vent Line (L-20)
  1.2.8.2 Fuel Vent Coupling (C-3)
  1.2.8.3 Fuel Vent Valve (1-15 through V-18)

1.2.9 Fuel Fill and Drain Assembly
  1.2.9.1 Fuel Fill Line (L-21)
  1.2.9.2 Fuel Fill Coupling (C-5)
  1.2.9.3 Fuel Fill Valve (V-19)

1.2.10 Fuel Tank Assembly
- 1.2.10.1 Fuel Tank (T-2)
- 1.2.10.2 Fuel Tank Sump (S-2)
- 1.2.10.3 Gas Diffuser (D-2)

c. Booster - Main Pressurization Subsystem (1.3) - The pressurization system provides the necessary NPSH for the main engines. The ullage gas pressure, the available liquid head, frictional losses in suction lines, and the propellant vapor pressures were analyzed to determine the following tank pressure ranges:

	PRE-PRESSURIZATION SWITCH psia	VENT SWITCH psia	MECHANICAL RELIEF VALVE psia	AUTOGENOUS BAND psia
Booster LOX	20 - 25	26 - 31	26 - 31	20 - 25
Booster Hydrogen	35 - 40	41 - 46	41 - 46	35 - 40

Minimum levels are based on 16ft of LOX and 60ft of hydrogen NPSH requirements and estimated line losses, temperature ranges, and acceleration heads. These tank pressures will accommodate approximate propellant temperatures of 163°R for LOX and 37°R to 41°R for LH_2.

Pressurization is also required to prevent implosion of the cryogenic tanks during ground loading and during re-entry. Implosion circumvention during initial loading can be assured by closure of the ground vents and pre-pressurization to the required level (1-5 psig estimated). Venting of the tanks to a predetermined level prior to re-entry is anticipated to circumvent unacceptable pressure build-up or venting due to heating.

The main pressurization subsystem is comprised of two assemblies, and thirty two components. Each boom has the following assemblies and components:

1.3.1 Autogenous Pressurization Assembly
- 1.3.1.1 Oxidizer Pressurization Line (L-22)
- 1.3.1.2 Oxidizer Pressure Control Orifice (0-1 and 0-2)
- 1.3.1.3 Oxidizer Pressure Control Valve (V-20 and V-21)
- 1.3.1.4 Oxidizer Pressure Filter (F-1)
- 1.3.1.5 Fuel Pressurization Line (L-23)
- 1.3.1.6 Fuel Pressure Control Orifice (0-3 and 0-4)
- 1.3.1.7 Fuel Pressure Control Valve (V-22 and V-23)
- 1.3.1.8 Fuel Pressurant Filter (F-2)

1.3.2 Helium Pressurization Assembly
- 1.3.2.1 Helium Line - Oxidizer (L-24)
- 1.3.2.2 Helium Coupling - Oxidizer (C-6)
- 1.3.2.3 Helium Line - Fuel (L-34)
- 1.3.2.4 Helium Coupling - Fuel (L-4)

2. Booster Auxiliary Propulsion System

The booster auxiliary propulsion system (APS) uses gaseous oxygen and hydrogen for attitude control and separation thrust, and provides GOX and GH_2 to operate the Auxiliary Power Units (APU) and to transfer liquid hydrogen to the airbreathing engines. The locations of the Reaction Control System (RCS) and separation thrusters are shown in Figure II-25 . The RCS thrusters are redundant in that two spare thrust chambers are carried for each module. The separation and attitude control system thrust chambers are essentially identical; dual thrust ratings are obtained by orificing to obtain different chamber pressures. Single separation thruster failure is accommodated by using RCS pitch thrusters to eliminate the pitch transient due to the failure. Figures II-26 and II-27 illustrate the locations of APS components and assemblies within the booster vehicle.

The booster auxiliary propulsion system is shown schematically in Figure II-28 and pictorially in Figure II- 29 . Residual LOX vapors and autogenous gas are compressed in a turbocompressor unit and stored under high pressure in accumulators. Liquid hydrogen, stored in a tank within the main hydrogen tank, is removed by a turbopump, vaporized in a heat exchanger, and stored in accumulators for RCS and separation thruster usage. Liquid hydrogen is also pumped to the airbreathers and vaporized by airbreather engine heat exchangers.

The gas generators utilize gaseous oxygen and hydrogen from the accumulators and produce gas to drive turbines for the liquid hydrogen pumps, oxygen compressors, and the hydraulic pumps, as well as producing gas to augment turbine exhaust flow to the heat exchangers.

The booster auxiliary propulsion system consists of six subsystems which are made up of 404 components. The subsystems, assemblies and components are identified in the following paragraphs.

a. RCS Engine Subsystem (2.1) - The booster RCS engine subsystem is composed of eighteen reaction control thrusters (three pitch up and three pitch down per boom, three yaw right and three yaw left). The thrusters are hard mounted to the booster airframe

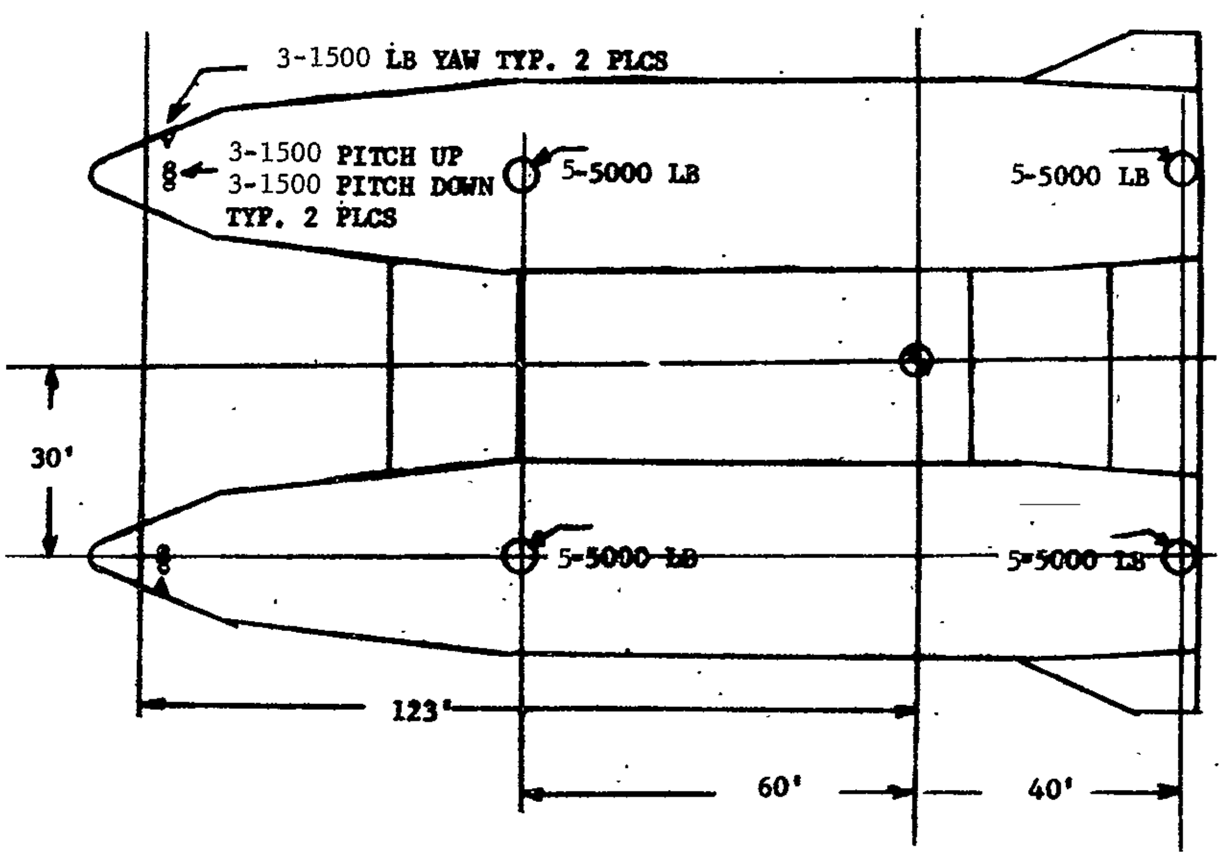


Figure II-25 Booster APS Thruster Locations

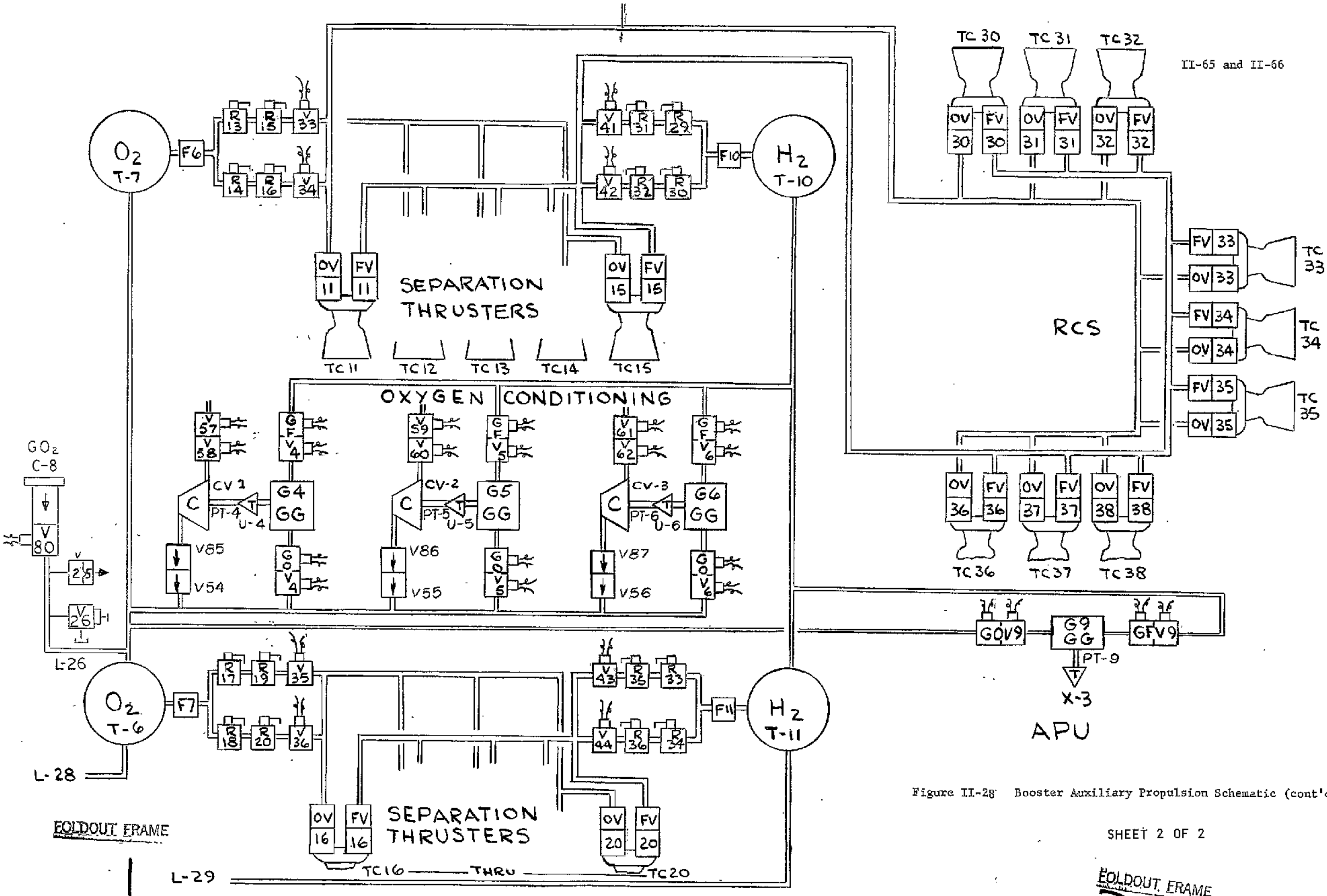


Figure II-28 Booster Auxiliary Propulsion Schematic (cont'd)

SHEET 2 OF 2

FOLDOUT FRAME 1

FOLDOUT FRAME 2

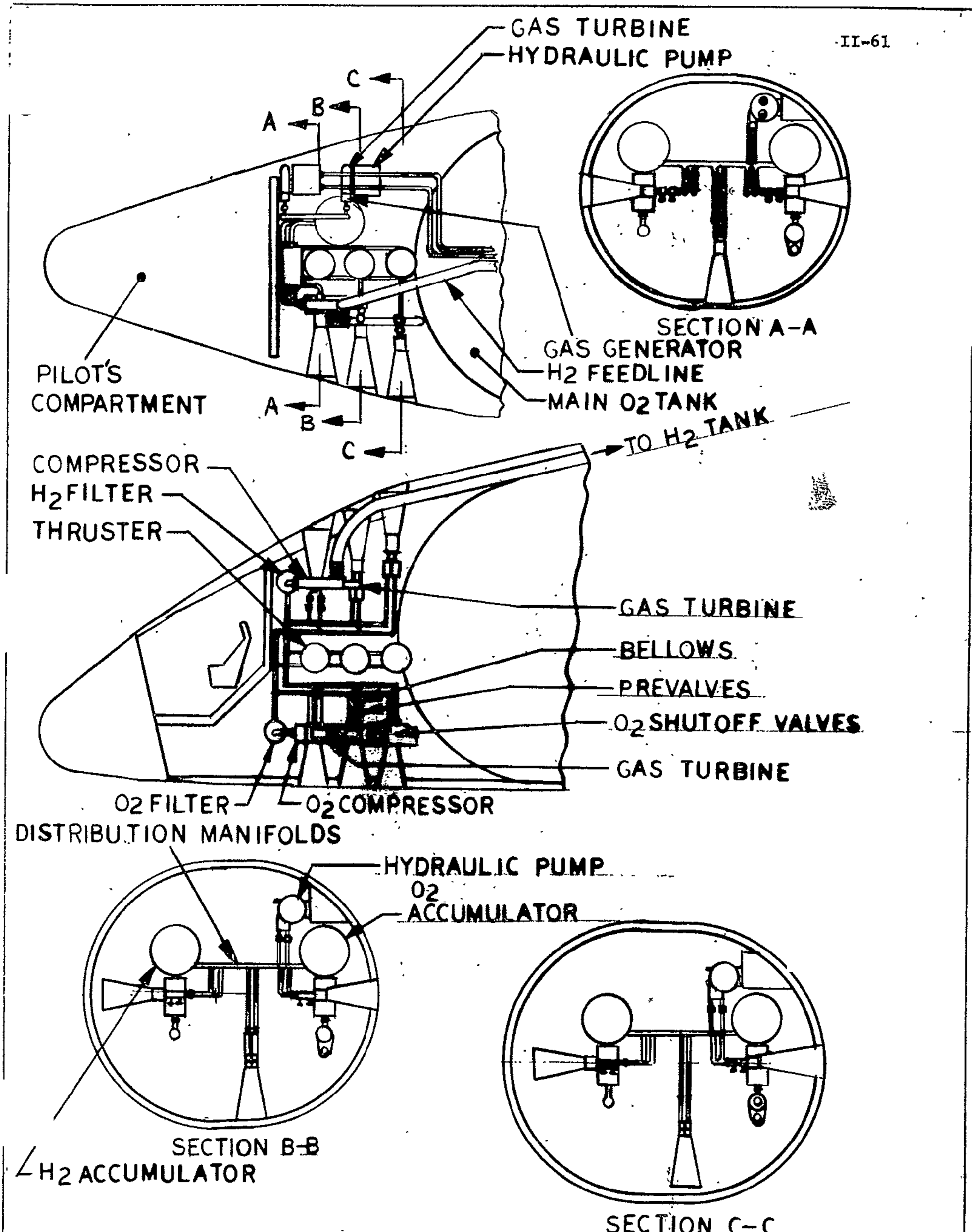


Figure II-26 Booster RCS Subsystem Configuration

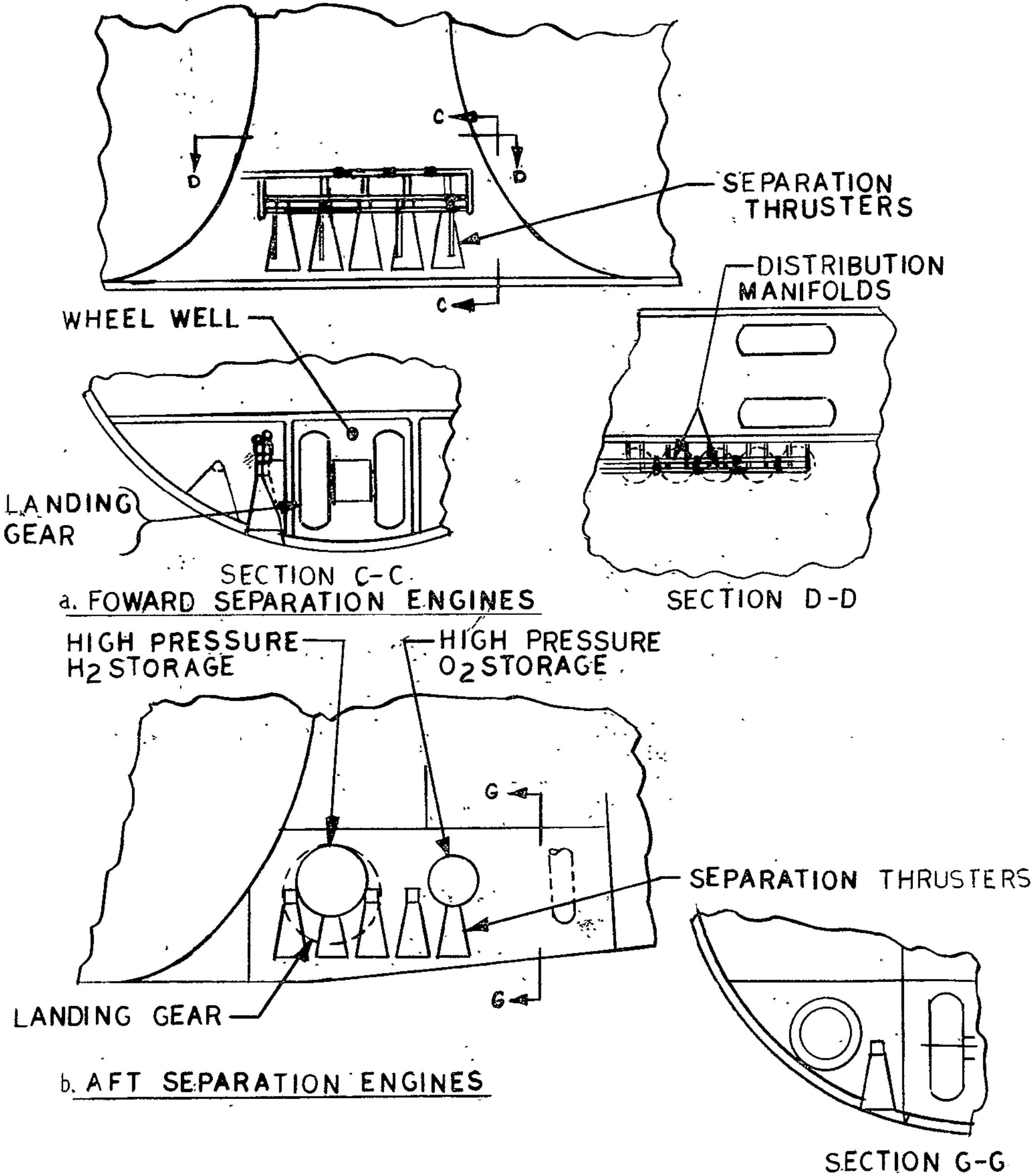


Figure II-27 Booster Separation Engine Subsystem Configuration

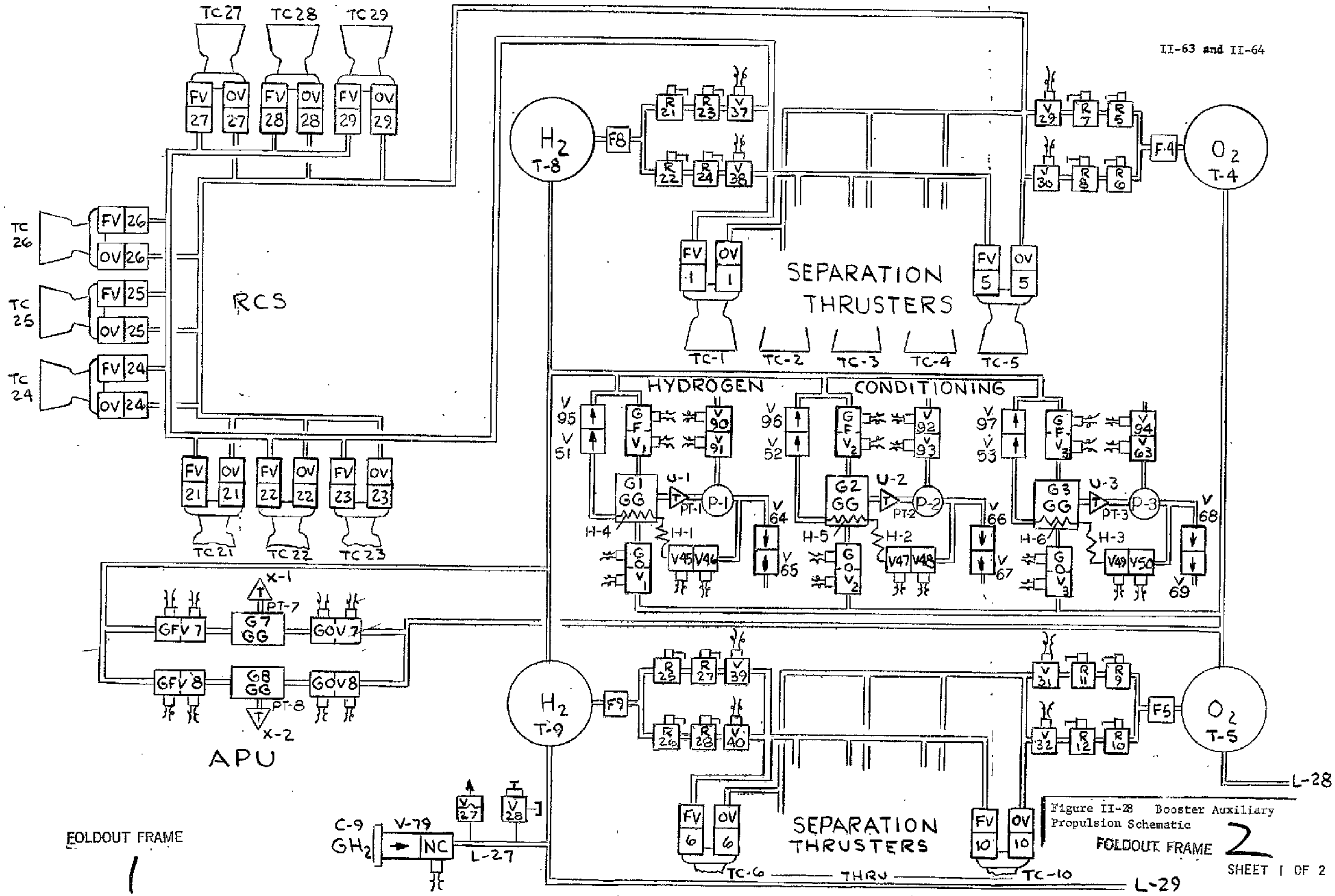


Figure II-28 Booster Auxiliary Propulsion Schematic

FOLDOUT FRAME 1

FOLDOUT FRAME 2

SHEET 1 OF 2

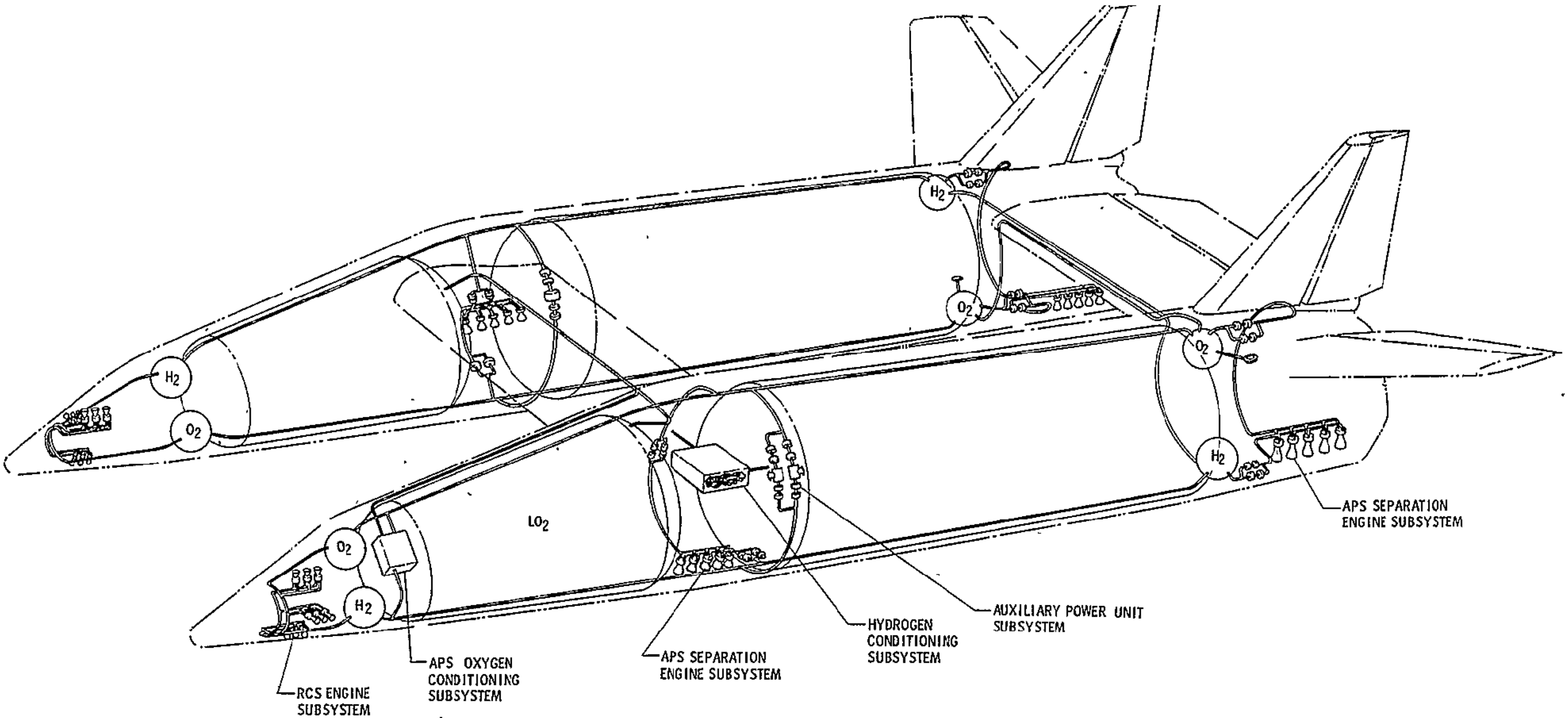


Figure II-29 Booster Auxiliary Propulsion System immediately forward of the main LOX tanks. The mounting configuration and location of other APS components are shown in Figure II-26. These thrusters are used for vehicle orientation during main engine shutdown and for attitude control and maneuvering during separation and re-entry. An isometric cutaway of a typical RCS thruster is shown in Figure II-30 and a flow schematic is shown in Figure II-31. The RCS engine subsystem consists of the following assemblies:

2.1.1 - Thrust Chamber Assembly - The thrust chamber assembly is a fixed nozzle, film cooled engine which operates on GOX and GH_2 propellants at approximately 500°R inlet temperature and 375 psia inlet pressure. Chamber pressure is approximately 1500 pounds. The thrust chamber consists of propellant inlet manifolds, an impinging coaxial injector, and a dump/film-cooled steel thrust chamber. The combustion chamber nozzle is covered with high temperature insulation material, limiting backside temperature to 800°F. The expansion ratio is approximately 40:1.

2.1.2 - Ignition Assembly - A GOX/GH_2 torch igniter is used for engine ignition. The igniter assembly consists of separate oxidizer and fuel valves, a spark plug and spark plug exciter. Valves are solenoid actuated and are separate from the main thruster valve. The exciter unit is separate from the spark plug, but is close-coupled. Operational temperature range is -160°F to +200°F.

2.1.3 - Valve Assembly - An electrically actuated bi-propellant main thrust chamber valve is used to admit GOX and GH_2 to the thrust chamber.

b. APS Propellant Management Subsystem (2.2) - The APS propellant management subsystem is used for storage and delivery of GOX and GH_2 propellants to the RCS engine, separation engine, propellant conditioning, and auxiliary power unit subsystems. The propellant management subsystem consists of four GH_2 and four GOX accumulator spheres, gas filters, regulators, valves, and associated propellant delivery line assemblies. These assemblies and components are described in the following paragraphs.

2.1.1 - Accumulator Assembly - Eight accumulators (four GOX and four GH_2) are provided to minimize the number of restarts on the conditioning equipment and provide a source of gas to bootstrap the gas generators on the hydrogen and oxygen conditioning subsystems. Two accumulators (one GOX and one GH_2) are mounted forward of the main LOX tank in each boom

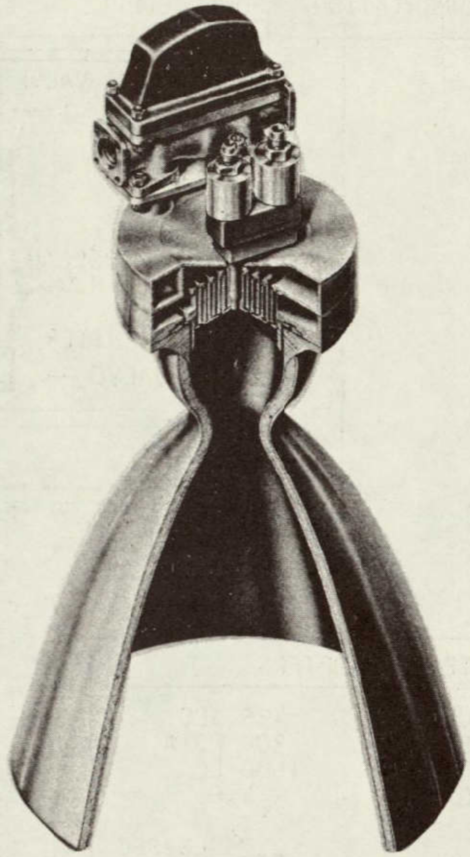
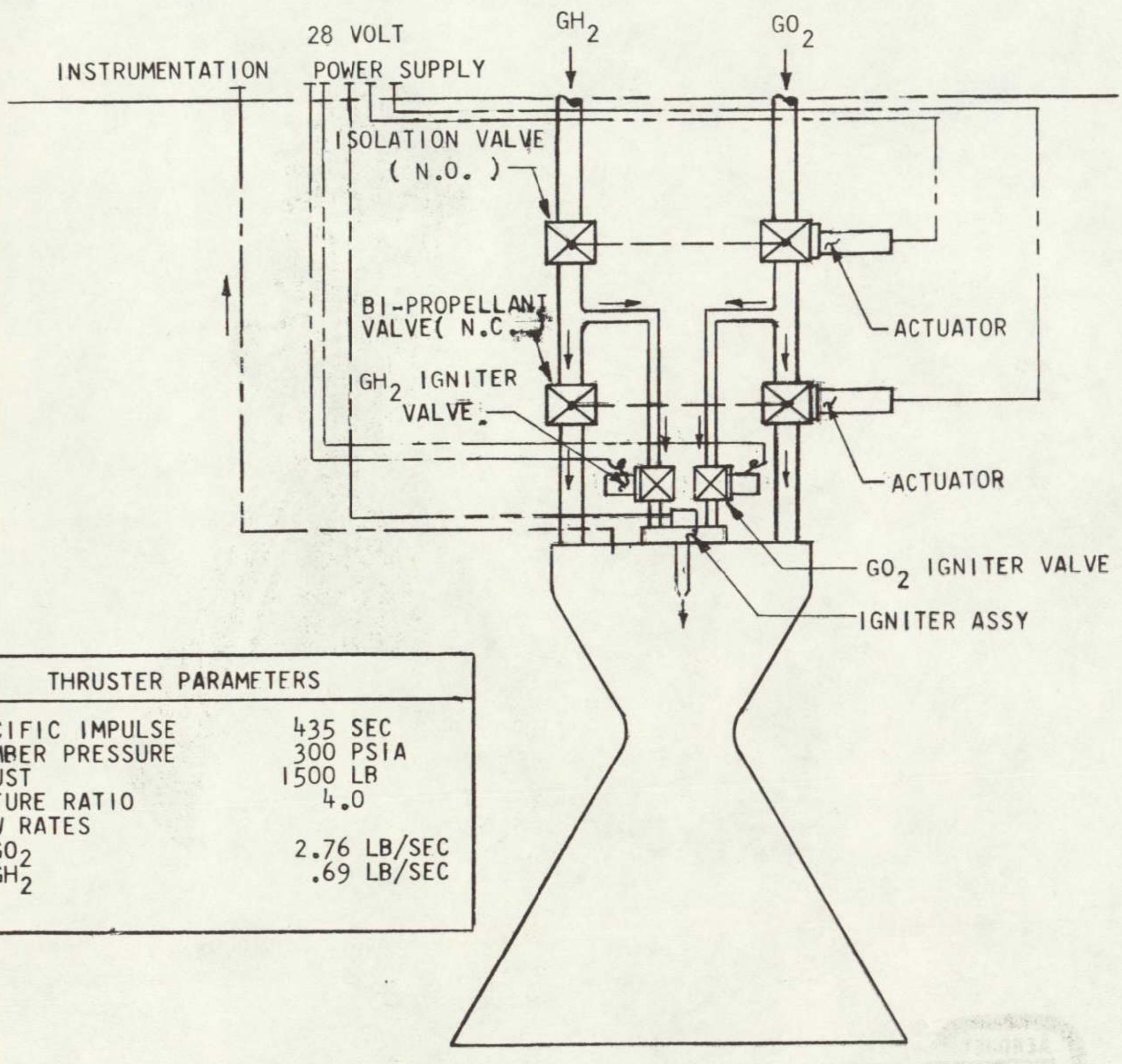


Figure II-30 RCS Thruster



THRUSTER PARAMETERS	
SPECIFIC IMPULSE	435 SEC
CHAMBER PRESSURE	300 PSIA
THRUST	1500 LB
MIXTURE RATIO	4.0
FLOW RATES	
GO_2	2.76 LB/SEC
GH_2	.69 LB/SEC

Figure II-31 RCS Thruster Flow Schematic as shown in Figure II- 26 and two accumulators (one GOX and one GH_2) are located behind the main LH_2 tank in the aft separation engine compartment of each boom as shown in Figure II- 27 . All like-propellant accumulators are connected by high pressure lines. The accumulator assembly is comprised of the following major components:

2.2.1.1 Accumulator Tank (T-4 through T-11)
2.2.1.2 Filter (F-4 through F-11)
2.2.1.3 Regulator (R-5 through R-36)
2.2.1.4 Solenoid Valve (V-29 through V-44)
2.2.1.5 Lines and Connectors (L-28, L-29)

2.2.2 - Propellant Fill Assembly - The propellant fill assembly consists of the control valves, lines, and quick disconnects required to precharge the GOX and GH_2 accumulators prior to flight and for drain and purge operations after landing. The following components are identified for the propellant fill assembly:

2.2.2.1 Quick Disconnect Coupling (C-8, C-9)
2.2.2.2 Solenoid Valve (V-79, V-80)
2.2.2.3 Relief Valve (V-25, V-27)
2.2.2.4 Manual Valve (V-26, V-28)
2.2.2.5 Lines and Connectors (L-26, L-27)

2.2.3 - Propellant Feed Assembly - The propellant feed assembly is composed of the lines and connectors required for delivery of GOX and GH_2 propellants to the RCS engines and separation thrusters. This assembly can be broken down into the following major components:

2.2.3.1 GH_2 Feed Lines and Connectors
2.2.3.2 GOX Feed Lines and Connectors

c. Hydrogen Conditioning Subsystem (2.3) - The hydrogen conditioning subsystem has a dual purpose function. During APS operation, LH_2 is withdrawn from the cruise tank by a turbopump, heated in a heat exchanger, and delivered to the GH_2 accumulators in gaseous form for resupply. For the airbreathing engine operation phase the hydrogen conditioning subsystem is used to deliver LH_2 to the seven turbofan engines. The hydrogen conditioning subsystem is located between the main LOX and LH_2 tanks in the vicinity of the turbofan engine compartment. This subsystem is composed of the following assemblies and components:

2.3.1 Turbopump Assembly - Three turbopump assemblies are used in the hydrogen conditioning subsystem to remove LH_2 from the cruise tank and deliver it to the heat exchangers or airbreathing engines. The pumps are driven by individual gas turbines which are powered by bootstrapping gas generators. The turbopump assembly is made up of the following components:

2.3.1.1 Turbine (U-1 through U-3)
2.3.1.2 Power Train (PT-1 through PT-3)
2.3.1.3 Pump (P-1 through P-3)
2.3.1.4 LH_2 Solenoid Valve (V-90, V-91, V-29, V-93, V-94, V-63)
2.3.1.5 LH_2 Check Valve (V-64 through V-69)
2.3.1.6 GH_2 Accumulator Resupply Subassembly
2.3.1.6.1 Heat Exchanger (H-1, through H-3)
2.3.1.6.2 LH_2 Solenoid Valve (V-45 through V-50)
2.3.1.7 Lines and Connectors

2.3.2 Gas Generator Assembly - Three high pressure gas generators are used to provide turbine drive gases for the turbopump and a high temperature heat source for the heat exchangers. These bipropellant generators burn GOX and GH_2, producing a fuel-rich mixture at a gas temperature of approximately 1800°R. To overcome the ignition problem of the fuel-rich mixture ratio of the gas generator, primary ignition is accomplished with an oxidizer-rich igniter or with a slight oxidizer lead. The following major components will be used to construct the gas generator assembly:

2.3.2.1 Gas Generator (G-1 through G-3)
2.3.2.2 Heat Exchanger (H-4 through H-6)
2.3.2.3 GH_2 Solenoid Valve (GFV-1 through GFV-3)
2.3.2.4 GOX Solenoid Valve (GOV-1 through GOV-3)
2.3.2.5 GH_2 Check Valve (V-51 through V-53, V-95 through V-97)
2.3.2.6 Lines and Connectors

d. Oxygen Conditioning Subsystem (2.4) - The oxygen conditioning subsystem removes residual GOX from the booster main LOX tanks and pressurizes it to approximately 1500 psia for pressure resupply of the GOX accumulators. This subsystem is located between the main LOX tank and the pilot's compartment as shown in Figure II-26. This subsystem includes the following assemblies and components:

2.4.1 Turbocompressor Assembly - The turbocompressor assembly consists of three high-head multistage compressors which are driven by individual, multistage, pressure compounded, impulse bladed axial flow turbines. The turbines are driven by fuel-rich gas from three bootstrapping gas generators operating at a pressure of 100 to 500 psia, and at a temperature of 1600 to 2400°R. The following components are used to construct the turbocompressor assembly:

2.4.1.1 Turbine (U-4 through U-6)
2.4.1.2 Power Train (PT-4 through PT-6)
2.4.1.3 Compressor (CV-1 through CV-3)
2.4.1.4 GOX check valve (V-54 through V-56, V-85 through V-87)
2.4.1.5 GOX Solenoid Valve (V-57 through V-62)
2.4.1.6 Lines and Connectors

2.4.2 <u>Gas Generator Assembly</u> - Three high-pressure gas generators are used to provide turbine drive gases for the turbocompressor propellant feed systems. These bipropellant generators burn GOX and GH_2, producing a homogeneous fuel-rich mixture at a gas temperature of approximately 1800°R. The gas generator assembly includes the following components:

2.4.2.1 Gas Generator (G-4 through G-6)
2.4.2.2 GOX Solenoid Valve (GOV-4 through GOV-6)
2.4.2.3 GH_2 Solenoid Valve (GFV-4 through GFV-6)
2.4.2.4 Lines and Connectors

e. <u>APS Separation Engine Subsystem</u> (2.5) - The separation engine subsystem consists of 20 thrusters which translate the booster from the orbiter. The thrusters are separated into four modules having five thrusters per module and are located so that the torques about the center of gravity are equal. Thus, pure translation is attained. The forward separation modules are located between the main LOX and LH_2 tanks of each boom as shown in Figure II-27. The aft separation modules are located behind the main LH_2 tanks of each boom as shown in Figure II-27. The thrust level for each thruster is 5000 pounds (100,000 pounds total) and the burning time is three seconds. The thruster design for the separation system is the same as the thruster used for the separation system is the same as the thruster used for the RCS engine subsystem. The APS separation engine subsystem is made up of the following assemblies and components:

2.5.1 <u>Thrust Chamber Assembly</u> - The thrust chamber assembly is a single fixed-nozzle film cooled engine which operates on GOX and GH_2 propellants at approximately 500°R inlet temperature and 575 psia inlet pressure. Chamber pressure is approximately 500 psia and vacuum thrust is approximately 5000 pounds. This assembly is similar to the RCS thruster assembly discussed in paragraph 2.1.1.

2.5.2 Ignition Assembly - A GOX/GH_2 torch igniter is used for engine ignition. The igniter assembly is similar to the RCS igniter assembly discussed in paragraph 2.1.2.

2.5.3 Valve Assembly - An electrically actuated bi-propellant main thrust chamber valve is used to admit GOX and GH_2 to the thrust chamber.

f. Auxiliary Power Unit Subsystem (2.6) - The auxiliary power unit subsystem is designed to provide hydraulic and electrical power to the booster control systems during the boost and flyback mission phases. The propellant supply for the APU is taken from the GOX and GH_2 accumulators at 1500 psi and approximately 500°R. Three auxiliary power units are provided for the booster. Each APU drives a hydraulic pump and an alternator and is rated at approximately 244 shaft horsepower. The following assemblies and components make up the auxiliary power unit subsystem:

2.6.1 Turbine Drive Assembly - A single-stage axial flow turbine is used to drive the hydraulic pump and alternator. The turbine is driven by a fuel-rich gas generator system operating at a pressure of 100 to 500 psia and at a temperature of 1600 to 2400°R. The turbine drive assembly consists of the following major components:

2.6.1.1 Gas Generator (G-7 through G-9)
2.6.1.2 Turbine (X-1 through X-3)
2.6.1.3 Power Train (PT-7 through PT-9)
2.6.1.4 GH_2 Solenoid Valve (GFV-7 through GFV-9)
2.6.1.5 GOX Solenoid Valve (GOV-7 through GOV-9)
2.6.1.6 Lines and Connectors

3. Booster Airbreathing Propulsion System

The booster airbreathing propulsion system is shown pictorially in Figure II-32 and schematically in Figure II-33. It consists of a turbofan engine subsystem, a propellant management subsystem, and a pressurization subsystem. Liquid hydrogen is used as the fuel. The system is required to operate during ferry operations and during the approach and landing phase of flight operations. Seven turbofan, twin-spool, nonafterburning engines are located in the booster forward wing between the two booms. The leading and trailing edges of the wing retract to form the subsonic inlet and exhaust exit for the engines. The retractable inlet diffuser, exit doors, inlet diffuser and exhaust nozzle are not considered part of the propulsion system.

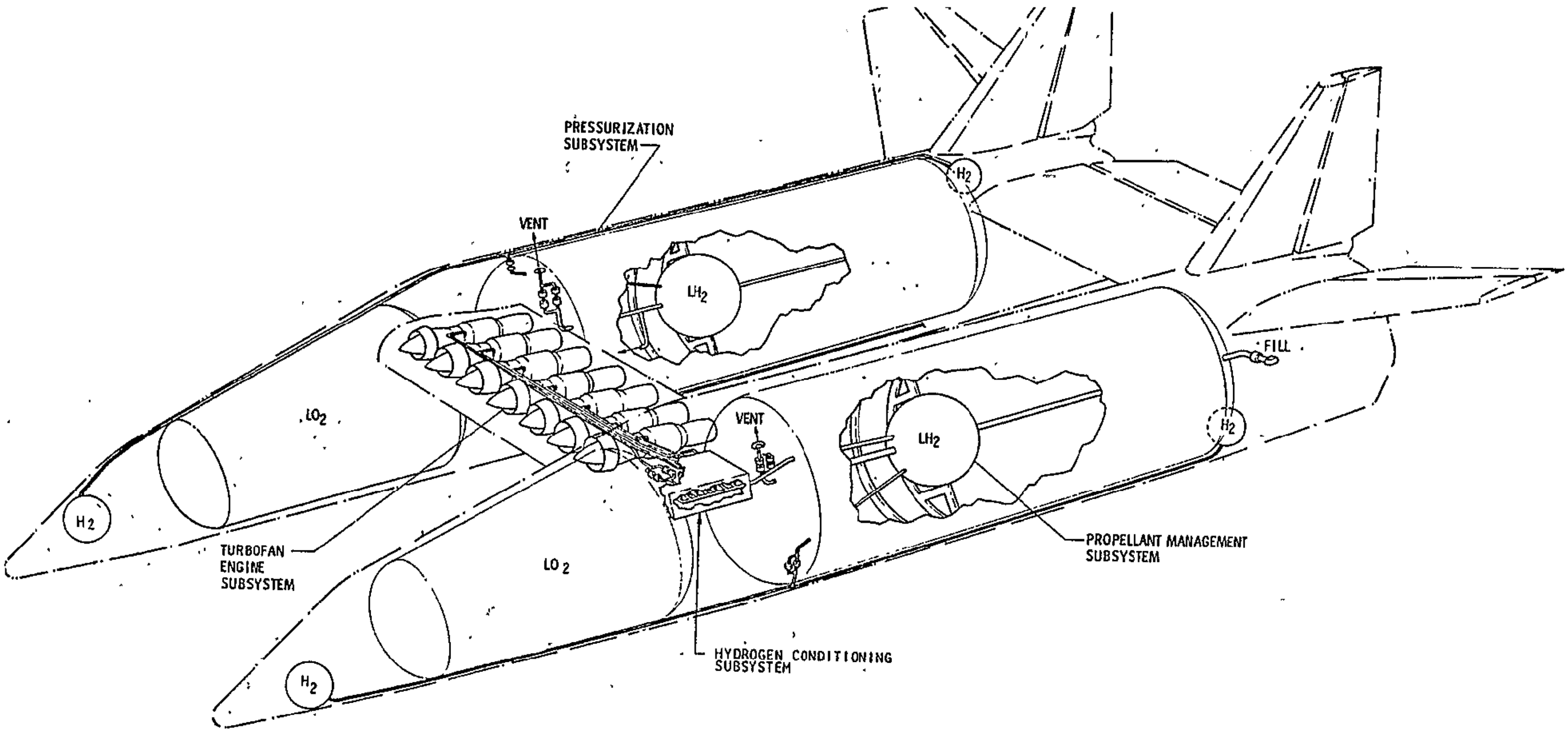


Figure II-32 Booster Airbreathing System

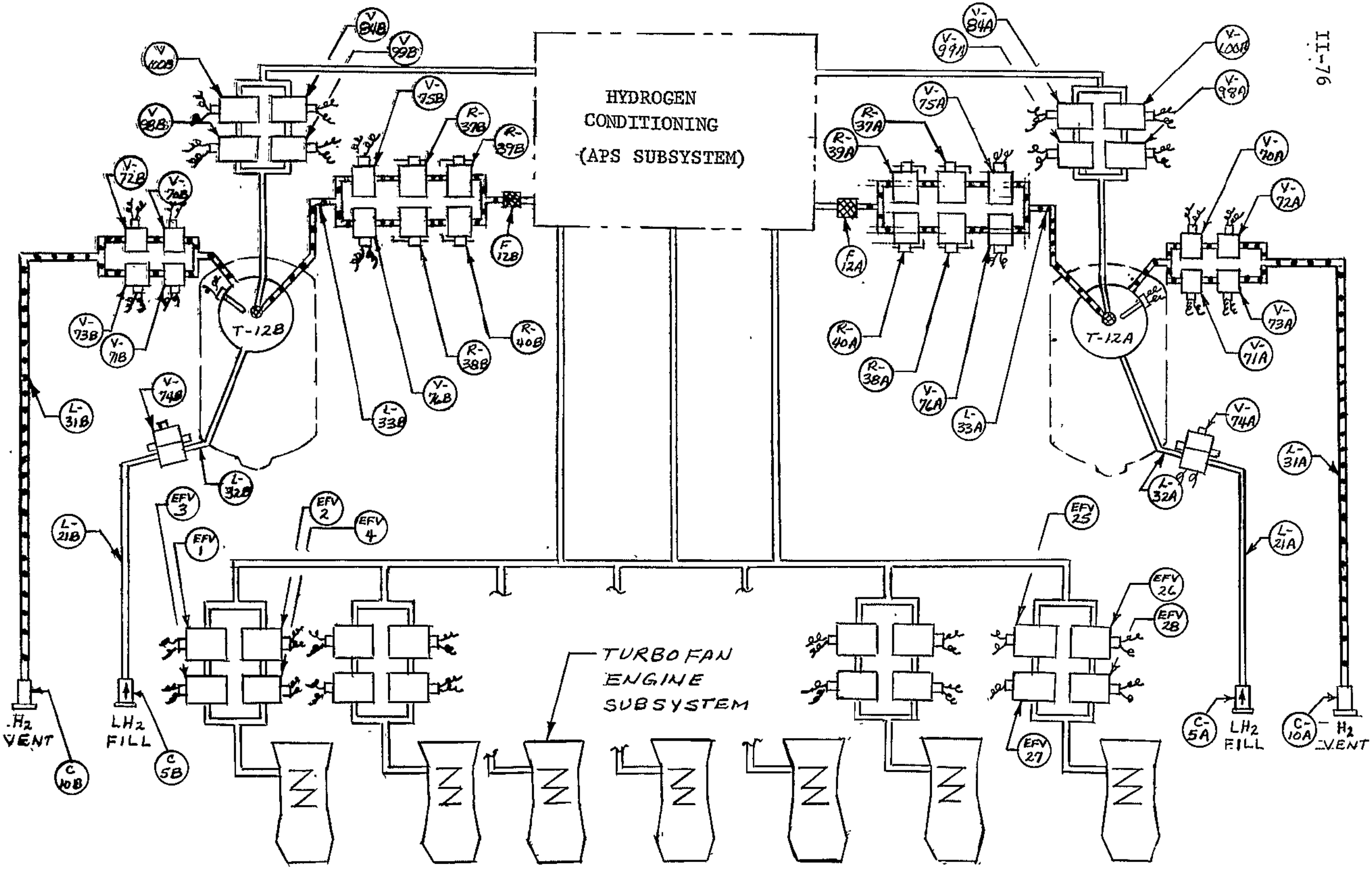


Figure II-33 Booster Airbreathing System Schematic

The subsystems and assemblies which comprise the booster airbreathing propulsion system are discussed in the following paragraphs, and the components are identified.

a. <u>Turbofan Engine Subsystem</u> (3.1) - The approach used in the definition of a turbofan engine for this study has been to select components, assemblies and subsystems which define a typical engine configuration. Both Pratt and Whitney Aircraft and General Electric Company have contributed to this typical engine selection. A specific engine design was not possible due to the classified and proprietary nature of such engines. The assemblies which make up the turbofan engine are shown in Figure II-34.

3.1.1 <u>Engine Power Assembly</u> - Combustion is attained through ignition of air (oxidizer) and gaseous hydrogen (fuel). The resultant combustion products drive the turbines which in turn rotate the compressors, and provides propulsive force from the exhaust gas. Part of the air which enters the fan passes through the compressors and is used for the combustion process. The remainder of the air which enters the fan is diverted around the power assembly casing and contributes to thrust. The fan produces thirty to sixty percent of the propulsive force. The Engine Power Assembly contains the following components:

3.1.1.1 Fan
3.1.1.2 Low Pressure Compressor
3.1.1.3 High Pressure Compressor
3.1.1.4 Burner
3.1.1.5 High Pressure Turbine
3.1.1.6 Low Pressure Turbine

3.1.2 <u>Fuel Control Assembly</u> - The Fuel Control Assembly accepts liquid hydrogen from the Propellant Management Subsystem, pumps the liquid through a heat exchanger that converts the liquid to a vapor, and, as commanded by the desired thrust setting, feeds hydrogen vapor to the power assembly burner. The desired thrust setting is input to an electronic controller which evaluates the power assembly performance and the need for greater or less fuel supply. The components in the Fuel Control Assembly are as follows: (The electronic controller is discussed in the DRM Electronics section of this report).

3.1.2.1 Inlet Shutoff Valve
3.1.2.2 Variable Displacement Vane Pump

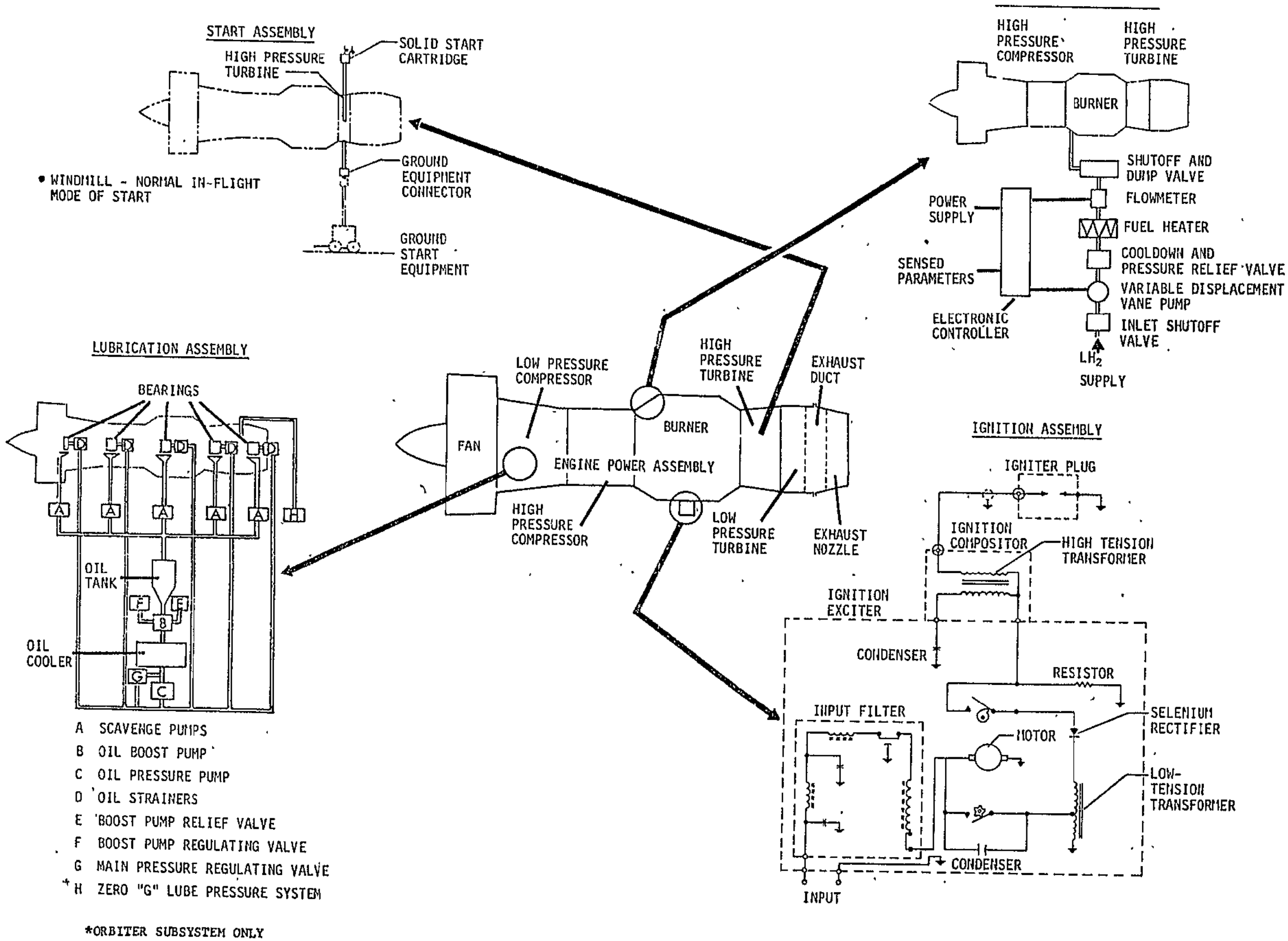


Figure II-34 Turbofan Engine Subsystem

3.1.2.3 Cooldown and Pressure Relief Valve
3.1.2.4 Fuel Heater
3.1.2.5 Flowmeter
3.1.2.6 Shutoff and Dump Valve
3.1.2.7 Electronic Controller

3.1.3 <u>Lubrication Assembly</u> - Oil in a gas turbine engine serves the twofold purpose of cooling and lubricating the bearings. A pressurized oil system carries the oil directly to the compressor, turbine and accessory drive bearings. The lubrication assembly is calibrated because each bearing has its oil specifically controlled by a calibrated orifice which provides the proper oil-flow at all engine operating speeds. The Lubrication Assembly illustrated in Figure II-34 is referred to as a "hot tank" system because hot oil from the engine scavenge pumps is returned directly to the oil storage tank where it is deaerated and then fed into an oil boost pump. From the boost pump, the oil passes through an air-oil cooler to the main oil pressure pump. Pressurized oil is then directed to the various bearings, gearboxes and other locations where lubrication or cooling is required. The oil is then scavenged by the scavenge pumps, and is returned to the oil tank, which completes the cycle. During conditions of zero gravity environment, a gaseous low-pressure oil pressurization system is employed to prevent oil evaporation. The following components are contained in this assembly:

3.1.3.1 Scavenge Pumps
3.1.3.2 Oil Boost Pumps
3.1.3.3 Oil Strainers
3.1.3.4 Boost Pumps Relief Valve
3.1.3.5 Boost Pump Regulating Valve
3.1.3.6 Main Pressure Regulating Valve

3.1.4 <u>Starter Assembly</u> - Gas turbine engines are started by rotating the compressor. In the case of twin-spool compressors, the high pressure compressor is usually the only one rotated. It is necessary to accelerate the compressor to provide sufficient air, under pressure, to support combustion in the burners. Once fuel has been introduced and the engine has ignited, the starter must continue to assist the engine above the self-accelerating speed. The torque supplied by the starter must be in excess of the torque required to overcome compressor inertia and friction loads of the engine. For altitude starts of the engine, which is required for flight mission flyback, the type of start is dependent upon Mach number and altitude. For example, starts at altitudes greater than 80,000 feet may require use of a combustion starter rather than a windmill start. The starter assembly schematic presented in Figure II-34 permits Ferry Preflight Mission start with the use of ground equipment. The use of ground start equipment minimizes the on-board flight hardware and thus helps to minimize vehicle weight. The Ferry Flight Mission in-flight failure is backed-up with a solid start cartridge. Turbofan engine start during the Flyback Mission Mode is normally through compressor windmill; however, the solid start cartridge is used for back-up in case of windmill technique failure. This component is identified as:

3.1.4.1 Solid Start Cartridge

3.1.5 Ignition Assembly - The ignition system for the turbofan engine must operate at high altitudes where the low temperatures cause a decrease in fuel volatility making it difficult to ignite the fuel-charge. It is necessary to have not only a very high voltage to jump a wide igniter-plug spark-gap but also a spark of high intensity. Figure II-34 presents an electronic component schematic for a typical high-energy, capacitor type ignition system. The input filter permits the flow of direct current to the igniter in one direction, and weakens alternating or pulsating current in the opposite direction toward the vehicle radio. Together with the input filter, the primary part of the ignition system is the ignition exciter unit. When the vehicle turbofan engine switch is turned on, direct current is supplied through the filter to an electric motor which operates two cams. Both cams open and close breaker points to supply intermittent current to transformers. A condenser prevents arcing across the breaker points. The transformer increases the 24-volt input voltage to about 2,000 volts in the system. This voltage is then passed through the selenium rectifier which acts as a one-way check valve, allowing the flow of current into a storage condenser but preventing any flow in return. The storage condenser stores up a huge amount of current each time that the breaker points open. At the same time that the storage condenser is being charged, the single-lobe cam in the compositor closes its breaker point, permitting one pulse of direct current to flow through the primary coil of a high tension transformer. The high-tension transformer increases the voltage to about 28,000 volts. This very high voltage causes a "trigger spark" to jump the wide spark-gap in the igniter plug. Once the path across the igniter plug is bridged, a path of low resistance is established for the discharge of the greater amount of electrical energy stored in the storage condenser. The relatively low voltage in the storage condenser, although capable of producing a very hot spark, is not sufficient, in itself, to bridge the igniter-gap until a path is provided by the trigger or leader spark. The combined result is a very intense spot of heat which is capable of quickly igniting the fuel/air mixture in the gas chamber. The following three components are identifed:

3.1.5.1 Igniter Plug
3.1.5.2 Ignition Compositor
3.1.5.3 Ignition Exciter

b. Propellant Management Subsystem (3.2) - For both ferry and flight operational modes, liquid hydrogen is loaded through a quick-disconnect coupling located at the aft section of each body on the booster. On loading, the propellant passes through a solenoid operated valve with integral relief provision and into spherical storage vessels that are internal to each of the main propulsion system LH_2 tanks. The LH_2 storage vessels are insulated and therefore are not effected by the Main Propulsion System LH_2 tank external environment during a Ferry Mission. During loading the spherical storage vessels are vented to atmosphere through series-parallel solenoid operated valves. The storage vessels are connected by a transfer line with series-parallel operated solenoid valves at each end of the line. During subsystem operation the valves at either end of the transfer line are opened and liquid hydrogen is pumped to the turbofan fuel control assemblies through the hydrogen conditioning system and the series-parallel solenoid operated valves. The hydrogen conditioning system in this application only transfers the liquid hydrogen to the turbofan subsystem. The following assemblies and components make up the booster airbreathing system propellant management subsystem:

3.2.1 Fuel Tank Assembly
- 3.2.1.1 Inlet Pressurization Diffuser
- 3.2.1.2 Hemisphere Segments
- 3.2.1.3 Outlet Line
- 3.2.1.4 Vent Line
- 3.2.1.5 Mounting Brackets

3.2.2 Fuel Distribution Assembly
- 3.2.2.1 Storage Vessel Transfer Line
- 3.2.2.2 Series-Parallel Solenoid Valve Package

3.2.4 Fuel Tank Vent Assembly
- 3.2.4.1 Transfer Line

3.2.4.2 Series-Parallel Valve Package
3.2.4.3 Quick Disconnect Coupling
3.2.5 Fuel Fill and Drain Assembly
3.2.5.1 Quick Disconnect Coupling
3.2.5.2 Transfer Line
3.2.5.3 Solenoid Operated Valve

c. Pressurization Subsystem (3.3) - Hydrogen gas, by means of blowdown from the auxiliary propulsion storage vessels, is passed through a filter, series-parallel regulators, parallel operated solenoid valves, and into the spherical LH_2 tanks contained in each of the main propulsion system LH_2 tanks. The following assembly and components are identified for this subsystem:

3.3.1 Tank Pressurization Assembly
3.3.1.1 Transfer Line
3.3.1.2 Series-Parallel Regulator Package
3.3.1.3 Parallel Solenoid Valve Package
3.3.1.4 Filter

4. Orbiter Main Propulsion System

The orbiter main propulsion system consists of three liquid hydrogen tanks, three liquid oxygen tanks, two main engines with retractable nozzle extensions, pressurization subsystems, and associated lines. The boost tanks contain propellant for the orbiter injection burn. The LOX tank is uninsulated and the hydrogen tank is insulated with membrane surface tension insulation. These tanks are shown in the system schematic (Figure II-35) as the larger single LH_2 tank and the two larger LOX tanks. The on-orbit maneuver tanks are insulated with an external high-performance insulation, which is required because of extended time in orbit. Passive surface-tension propellant orientation devices are utilized for on-orbit propellant management. Although these tanks are primarily used with the orbiter Auxiliary Propulsion System (APS), they are included as part of the main propulsion system since they are a contingency source of propellants for the main engines. Autogenous pressurization is used to pressurize the boost tanks; the pressurants are supplied by the main engines. The on-orbit maneuver tanks are pressurized from the APS high pressure accumulators.

The orbiter main propulsion system is composed of five major subsystems: main engine subsystem, main propellant management subsystem, main pressurization subsystem, on-orbit propellant management subsystem, and the on-orbit pressurization subsystem.

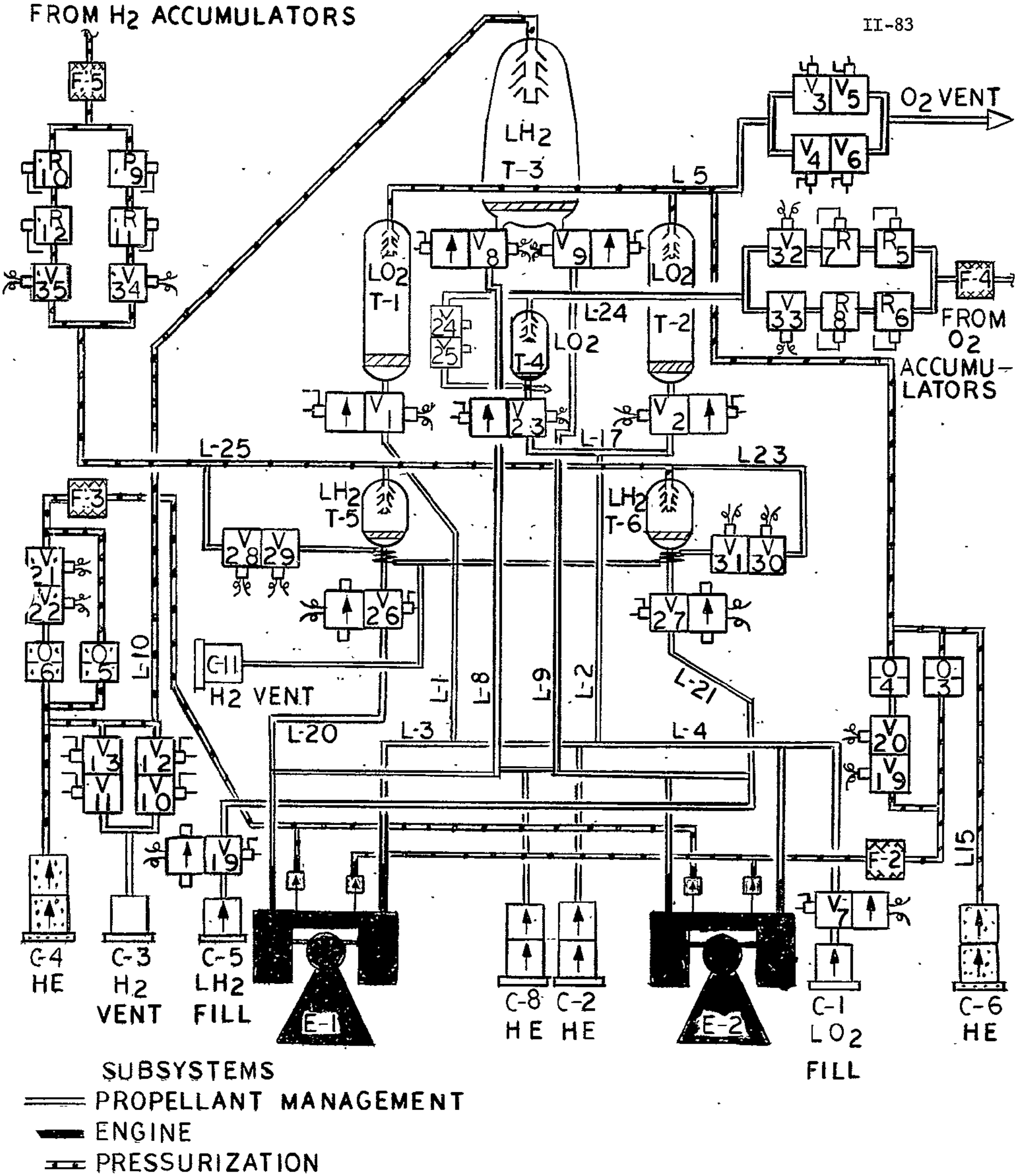


Figure II-35 Orbiter Main Propulsion System Schematic

Figure II-35 illustrates the inter-relation of the subsystems as parts of the orbiter main propulsion system. Figure II- 36 is a pictorial presentation of the orbiter main propulsion system.

a. Main Engine Subsystem (4.1) - The orbiter main engine configuration and features are identical to those of the booster main engines, except that the orbiter main engines utilize a retractable 154:1 area ratio nozzle. The engine system is convertible from booster to orbiter by changing the nozzle downstream of the 4.1 area ratio nozzle section and adding the extendible nozzle assembly.

The orbiter engine assemblies and components are listed below.

4.1.1 Engine Power Assembly
- 4.1.1.1 Low Pressure Fuel Turbopump
- 4.1.1.2 High Pressure Fuel Turbopump
- 4.1.1.3 Low Pressure Oxidizer Turbopump
- 4.1.1.4 High Pressure Oxidizer Turbopump
- 4.1.1.5 Fuel Preburner
- 4.1.1.6 Oxidizer Preburner
- 4.1.1.7 Hot Gas Manifold
- 4.1.1.8 Fuel Main Valve
- 4.1.1.9 Oxidizer Main Valve
- 4.1.1.10 Fuel Control Valve, Oxidizer Preburner
- 4.1.1.11 Oxidizer Control Valve, Oxidizer Preburner
- 4.1.1.12 Oxidizer Control Valve, Fuel Preburner
- 4.1.1.14 Interconnect Articulating Lines
- 4.1.1.15 Interconnect Lines
- 4.1.1.16 Oxidizer Recirculation Select Valve
- 4.1.1.17 Fuel Recirculation Select Valve
- 4.1.1.18 Fuel Recirculation Control Valve
- 4.1.1.19 Fuel Recirculation Regulator

4.1.2 Thrust Chamber Assembly
- 4.1.2.1 Main Injector
- 4.1.2.2 Main Combustion Chamber
- 4.1.2.3 Chamber Coolant Control Valve
- 4.1.2.5 Gas Distribution Plate
- 4.1.2.5 Interconnect Lines (3 line sections)

4.1.3 Ignition Assembly
- 4.1.3.1 Ignitors (Ox Preburner, Fuel Preburner, Main TCA)
- 4.1.3.2 Interconnect Lines (4 line sections)

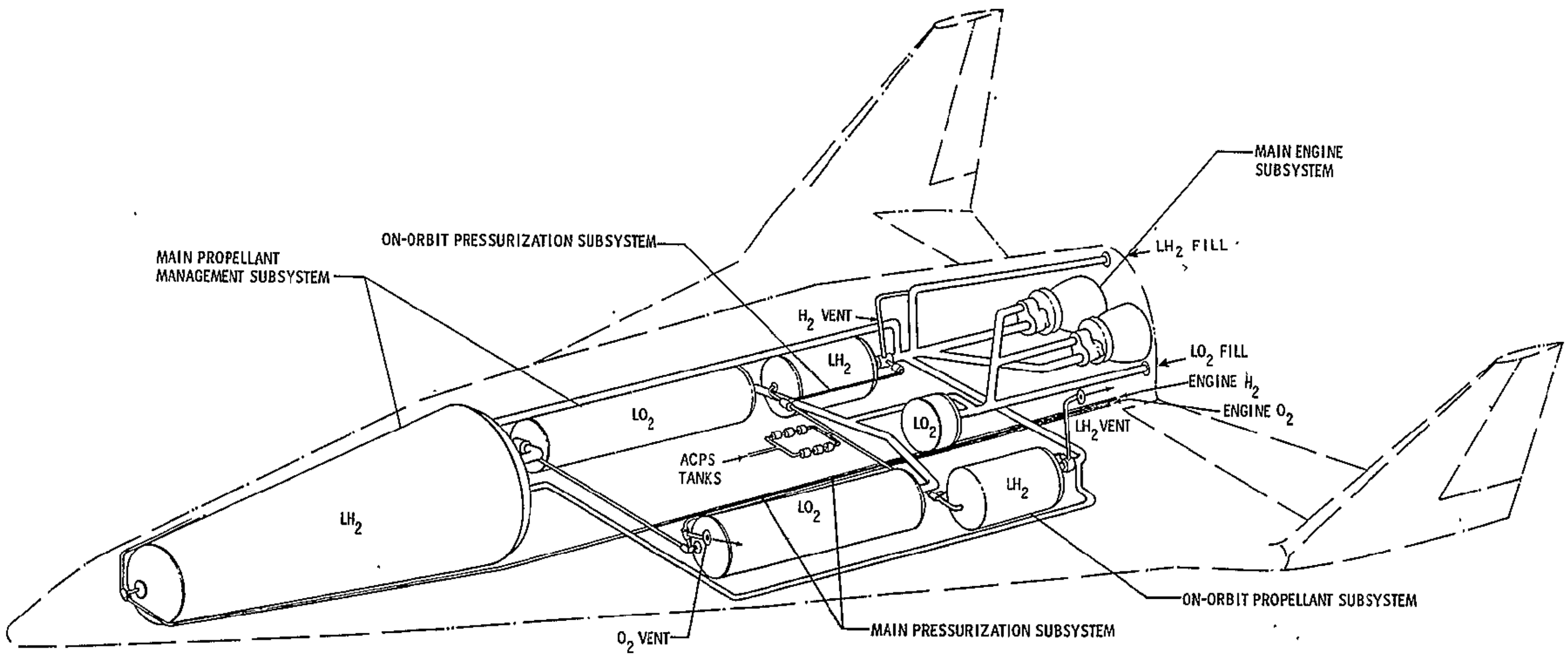


Figure II-36 Orbiter Main Propulsion System

4.1.4 TVC Assembly
- 4.1.4.1 Gimbal Block
- 4.1.4.2 Gimbal Actuator and Power Pack

4.1.5 Engine Control Assembly
- 4.1.5.1 Engine Controller
- 4.1.5.2 Ignition and Valve Control Harness
- 4.1.5.3 Instrumentation Harness
- 4.1.5.4 Sensors

4.1.6 Tank Pressurant Assembly
- 4.1.6.1 Fuel Tank Pressurant Control Valve
- 4.1.6.2 Oxidizer tank Pressurant Control Valve
- 4.1.6.3 Oxidizer Heat Exchanger
- 4.1.6.4 Interconnect Lines (5 line sections)

4.1.7 Engine Purge Assembly
- 4.1.7.1 Purge Valves
  - Solenoid Valves:
    - Preburner Oxidizer Purge
    - Main TCA Fuel Purge
    - Main TCA Oxidizer Purge
    - H.P. OTPA Seal Cavity Purge
    - Engine System Purge Control
    - Two-way GN_2/GH_2 Select Valve
  - Check Valves:
    - Oxidizer Preburner Ox Inlet Purge
    - Fuel TPA Preburner Ox Inlet Purge
    - Main TCA Fuel Inlet Purge
    - Main TCA Ox Inlet Purge
    - H.P. OTPA Seal Cavity Purge
    - Fuel Suction Line Purge
    - Oxidizer Suction Line Purge
- 4.1.7.2 Interconnect Lines (5 line sections)

4.1.8 Extendible Nozzle
- 4.1.8.1 Extendible Nozzle
- 4.1.8.2 Extendible Nozzle Coolant Valve
- 4.1.8.3 Extendible Nozzle Deployment Kit
- 4.1.8.4 Extendible Nozzle Coolant Line

b. Main Propellant Management Subsystem (4.2) - A parallel tankage arrangement is provided for the LOX and LH_2. The LH_2 tank volume is 13,000 ft^3 and each of the two LOX tanks are 2380 ft^3. The LOX tanks are uninsulated while the hydrogen tank is insulated with an internal insulation. Prestart propellant conditioning is accomplished by helium injection for a short period prior to engine ignition. Ambient temperature helium is satisfactory for the LOX system but precooled helium is necessary for the LH_2 suction lines. An uninsulated ground vent line is routed from the LOX tanks through the vehicle skin to atmosphere. An insulated GH_2 vent is routed to the GSE interface where a ground umbilical maybe attached.

The orbiter main propellant management subsystem is comprised of nine assemblies and 40 components.

4.2.1 Oxidizer Feed Assembly
- 4.2.1.1 Oxidizer Feed Line (L-1 thru L-4)
- 4.2.1.2 Oxidizer Isolation Valve (V-1 & V-2)

4.2.2 Oxidizer Tank Vent Assembly
- 4.2.2.1 Oxidizer Vent Line (L-5)
- 4.2.2.2 Oxidizer Vent Valve (V-3 thru V-6)

4.2.3 Oxidizer Fill and Drain Assembly
- 4.2.3.1 Oxidizer Fill and Drain Line (L-6)
- 4.2.3.2 Oxidizer Fill and Drain Valve (V-7)
- 4.2.3.3 Oxidizer Fill and Drain Coupling (C-1)

4.2.4 Oxidizer Tank Assembly
- 4.2.4.1 Oxidizer Tank (T-1 & T-2)
- 4.2.4.2 Oxidizer Tank Sump (S-1 & S-2)
- 4.2.4.3 Gas Diffuser (D-1 & D-2)

4.2.5 Geyser Suppression Assembly
- 4.2.5.1 Helium Line - Oxidizer (L-7)
- 4.2.5.2 Helium Coupling - Oxidizer (C-2)
- 4.2.5.3 Helium Line - Fuel (L-20)
- 4.2.5.3 Helium Coupling - Fuel (C-8)

4.2.6 Fuel Feed Assembly
- 4.2.6.1 Fuel Feed Line (L-8 & L-9)
- 4.2.6.2 Fuel Isolation Valve (V-8 & V-9)

4.2.7 Fuel Tank Vent Assembly
- 4.2.7.1 Fuel Tank Vent Line (L-10)
- 4.2.7.2 Fuel Tank Vent Coupling (C-3)
- 4.2.7.3 Fuel Tank Vent Valve (V-10 thru V-13)

4.2.8 Fuel Fill and Drain Assembly
- 4.2.8.1 Fuel Fill and Drain Line (L-11)
- 4.2.8.2 Fuel Fill and Drain Coupling (C-5)
- 4.2.8.3 Fuel Fill and Drain Valve (V-14)

4.2.9 Fuel Tank Assembly
- 4.2.9.1 Fuel Tank (T-3)
- 4.2.9.2 Fuel Tank Sump (S-3)
- 4.2.9.3 Gas Diffuser (D-3)

c. Main Pressurization Subsystem (4.3) - The pressurization subsystem provides the necessary NPSH for the main engines. The gas pressure in the ullage, the available liquid head, frictional losses in suction lines, and the propellant vapor pressure were analyzed to determine the following tank pressure ranges:

Tank	Prepressurization Switch PSIA	Vent Switch PSIA	Mechanical Relief Valve PSIA	Autogenous Band PSIA
Orbiter LOX	35 - 40	41 - 46	41 - 46	35 - 40
Orbiter Hydrogen	35 - 40	41 - 46	41 - 46	35* - 40

These tank pressures will accommodate approximate propellant temperatures of 163°R to 168°R for LOX and 37°R to 41°R for LH_2.

Pressurization could also be required to prevent implosion of the cryogenic tanks during ground loading and during re-entry. Implosion circumvention during initial loading can be assured by closure of the ground vents and pre-pressurization to the required level (1-5 psig estimated). Autogenous pressurization of propellant tanks is provided by tapping gaseous hydrogen and vaporized LOX from the main engines. The pressurant flow rates are controlled by fixed orifices. The orbiter main pressurization subsystem is comprised of two major assemblies and sixteen components:

4.3.1 Autogenous Pressurization Assembly
- 4.3.1.1 Oxidizer Pressurization Line (L-13)
- 4.3.1.2 Oxidizer Pressure Control Valve (V-19 & V-20)
- 4.3.1.3 Oxidizer Pressure Control Orifice (O-3 & O-4)
- 4.3.1.4 Oxidizer Pressurization Line Filter (F-2)
- 4.3.1.5 Fuel Pressurization Line (L-14)
- 4.3.1.6 Fuel Pressure Control Valve (V-21 & V-22)
- 4.3.1.7 Fuel Pressure Control Orifice (O-5 & O-6)
- 4.3.1.8 Fuel Pressurization Line Filter (F-3)

4.3.2 Helium Pressurization Assembly
- 4.3.2.1 Helium Line - Oxidizer (L-15)
- 4.3.2.2 Helium Coupling - Oxidizer (C-6)

4.3.2.3 Helium Line - Fuel (L-16)
4.3.2.4 Helium Coupling - Fuel (C-4)

d. On Orbit Propellant Subsystem (4.4.) - The orbit maneuver tanks are insulated with an external high performance insulation. The tank volumes are 357 ft^3 for LOX and 902 ft^3 for LH_2. Primarily the on orbit tanks provide propellants for the APS/OMS engine during orbit maneuvers. The hydrogen tanks, however, are also utilized as a propellant source for the airbreathing engines. These tanks can also be utilized as a contingent supply of propellants for the main engines. The on orbit propellant subsystem is comprised of six assemblies and 28 components:

4.4.1 Oxidizer Distribution Assembly
4.4.1.1 Oxidizer Distribution Line (L-17 & L-18)
4.4.1.2 Oxidizer Isolation Valve (V-23)

4.4.2 Oxidizer Tank Vent Assembly
4.4.2.1 Oxidizer Vent Line (L-19)
4.4.2.2 Oxidizer Tank Vent Valve (V-24 & V-25)
4.4.2.3 Oxidizer Vent Heat Exchanger (H-1)

4.4.3 Oxidizer Tank Assembly
4.4.3.1 Oxidizer Tank (T-4)
4.4.3.2 Oxidizer Tank Sump (S-4)
4.4.3.3 Gas Diffuser (D-4)

4.4.4 Fuel Distribution Assembly
4.4.4.1 Fuel Distribution Line (L-20)
4.4.4.2 Fuel Isolation Valve (V-26 & V-27)

4.4.5 Fuel Tank Vent Assembly
4.4.5.1 Fuel Vent Line (L-22 & L-23)
4.4.5.2 Fuel Tank Vent Valve (V-28 through V-31)
4.4.5.3 Fuel Vent Line Heat Exchanger (H-2 & H-3)
4.4.5.4 Fuel Vent Coupling (C-11)

4.4.6 Fuel Tank Assembly
4.4.6.1 Fuel Tank (T-5 & T-6)
4.4.6.2 Fuel Tank Sump (S-5 & S-6)
4.4.6.3 Gas Diffuser (D-5 & D-6)

e. On-Orbit Pressurization Subsystem (4.5) - The pressurization subsystem must provide, on a contingency basis, the required NPSH for the main engines as well as for the airbreathing engine and APS boost pumps. The required tank pressure ranges for the on-orbit propellant tanks are:

Tank	Presurization Switch PSIA	Vent Switch PSIA	Mechanical Relief Valve PSIA
On-Orbit LOX	35 - 40	41 - 46	41 - 46
On-Orbit Hydrogen	35 - 40	41 - 46	41 - 46

Venting of the tanks to a predetermined level prior to re-entry is anticipated to circumvent unacceptable pressure build-up or venting due to heating. Prior to landing, repressurization to levels above atmospheric can be accommodated by the auxiliary propulsion system accumulators. The on-orbit pressurization subsystem is comprised of two major assemblies and sixteen components.

4.5.1 On-Orbit Oxidizer Tank Pressurization Assembly
- 4.5.1.1 Oxidizer Tank Pressurization Line (L-24)
- 4.5.1.2 Oxidizer Tank Pressurization Line Filter (F-4)
- 4.5.1.3 Oxidizer Pressurization Regulator (R-5 thru R-8)
- 4.5.1.4 Oxidizer Pressurization Valve (V-32 & V-33)

4.5.2 On-Orbit Fuel Tank Pressurization Assembly
- 4.5.2.1 Fuel Tank Pressurization Line (L-25)
- 4.5.2.2 Fuel Tank Pressurization Line Filter (F-5)
- 4.5.2.3 Fuel Pressurization Regulator (R-9 thru R-12)
- 4.5.2.4 Fuel Pressurization Valve (V-34 & V-35)

5. <u>Orbiter Auxiliary Propulsion System</u>

The orbiter auxiliary propulsion system provides all propulsive capability for the orbiter after main propulsion engine burnout. Propulsion ΔV to circularize, for orbit changes, and for deorbit are accomplished by four aft thrusters. Maneuvers in orbit are accomplished by the APS system fore and aft thrusters. Attitude control during reentry is accomplished with aft thrusters only. Hydraulic pumps provide power for operating the aileron control surfaces when aerodynamic forces are sufficient. Liquid hydrogen is pumped to the airbreathing engine heat exchangers where it is vaporized upstream of the combustors.

The APS thrusters are contained in modules, with 15 thrusters forward and 22 thrusters aft of the center of gravity. The locations of the RCS and OMS engine thrusters are shown in Figure II-37. Prior to reentry, the forward thrusters are retracted and doors are closed in the thermal protection system. During reentry the aft thrusters are used for yaw, pitch, and roll control. Figures II-38 and II-39 illustrate the locations of the APS accumulators and thrusters within the orbiter vehicle.

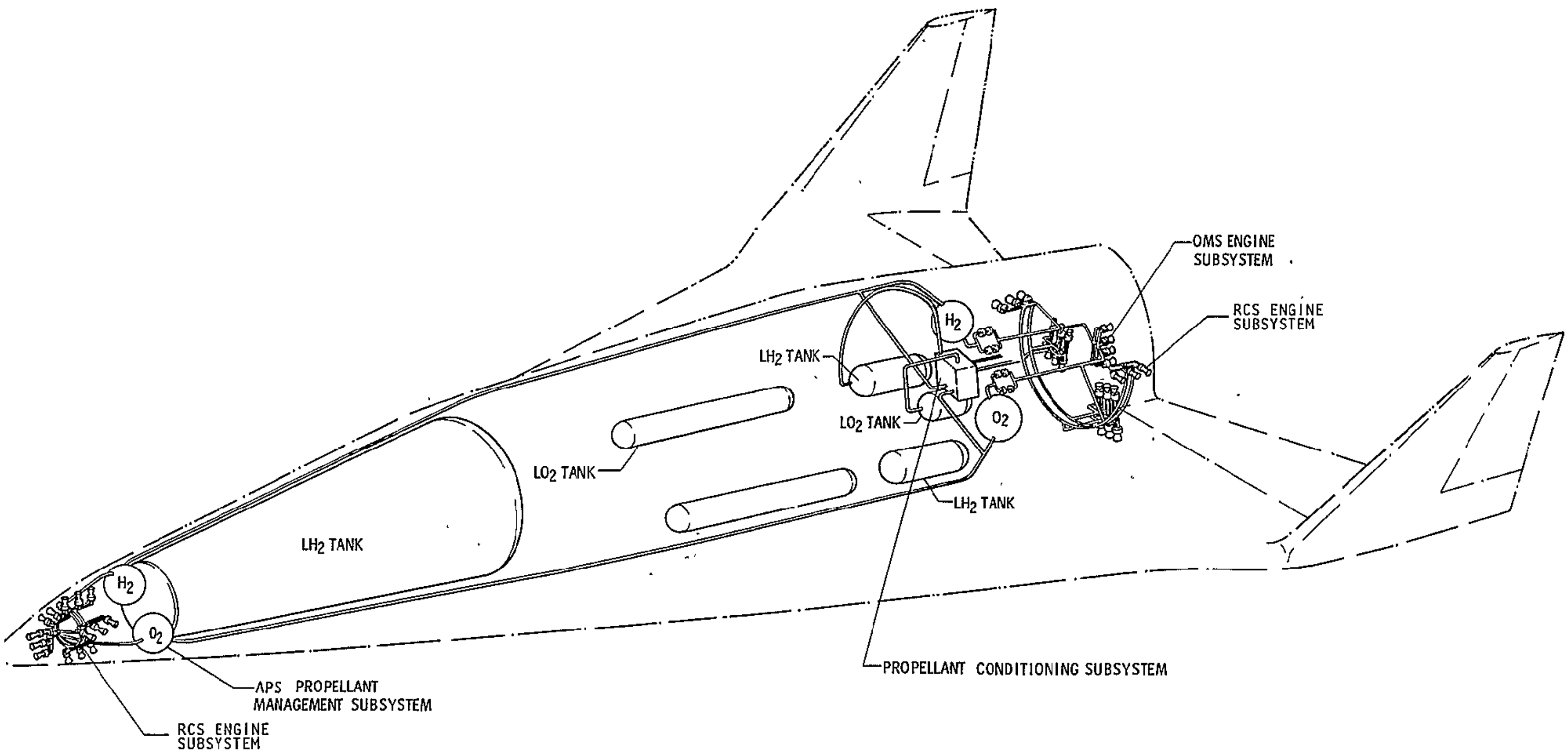


Figure II-37 Orbiter Auxiliary Propulsion System

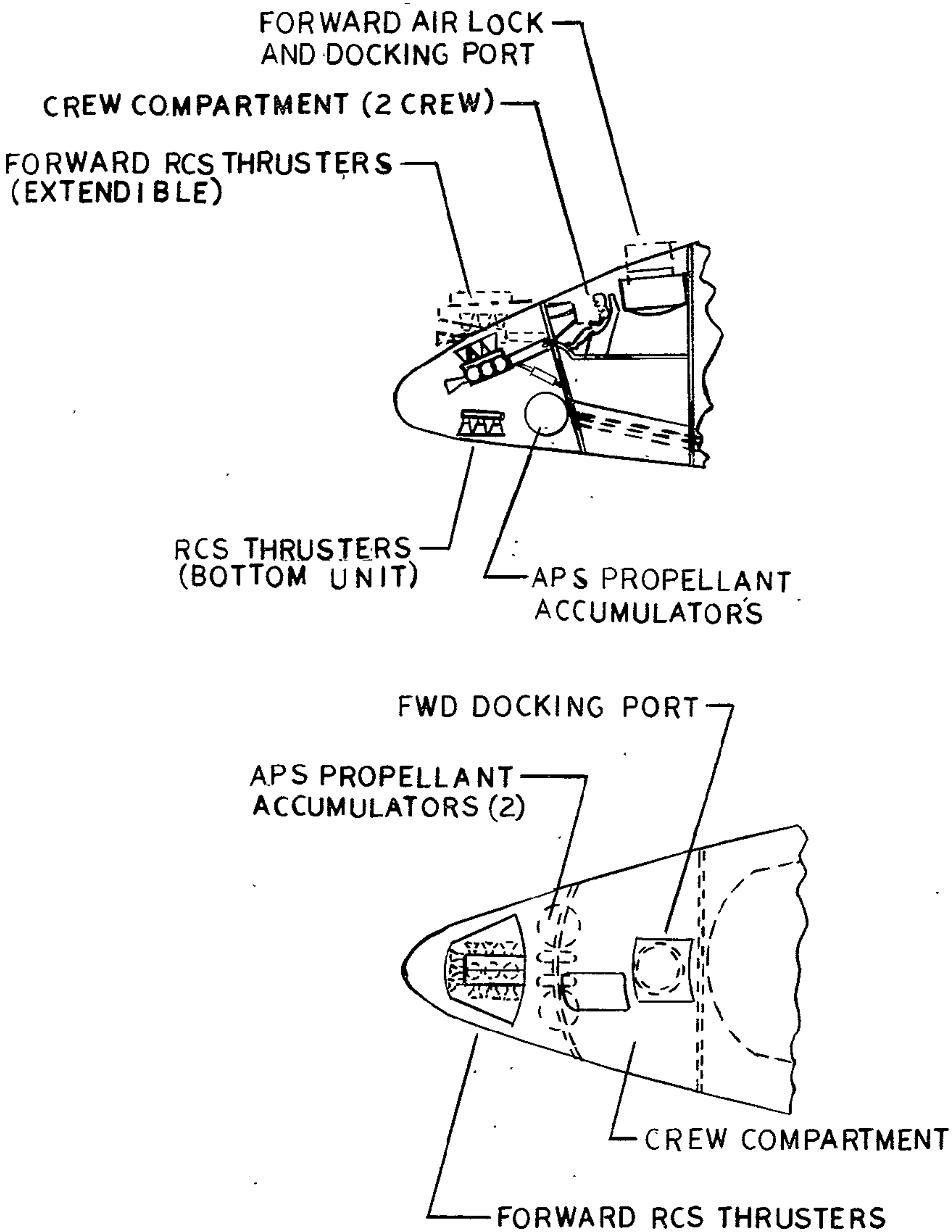


Figure II-38 . Orbiter Forward APS System Configuration

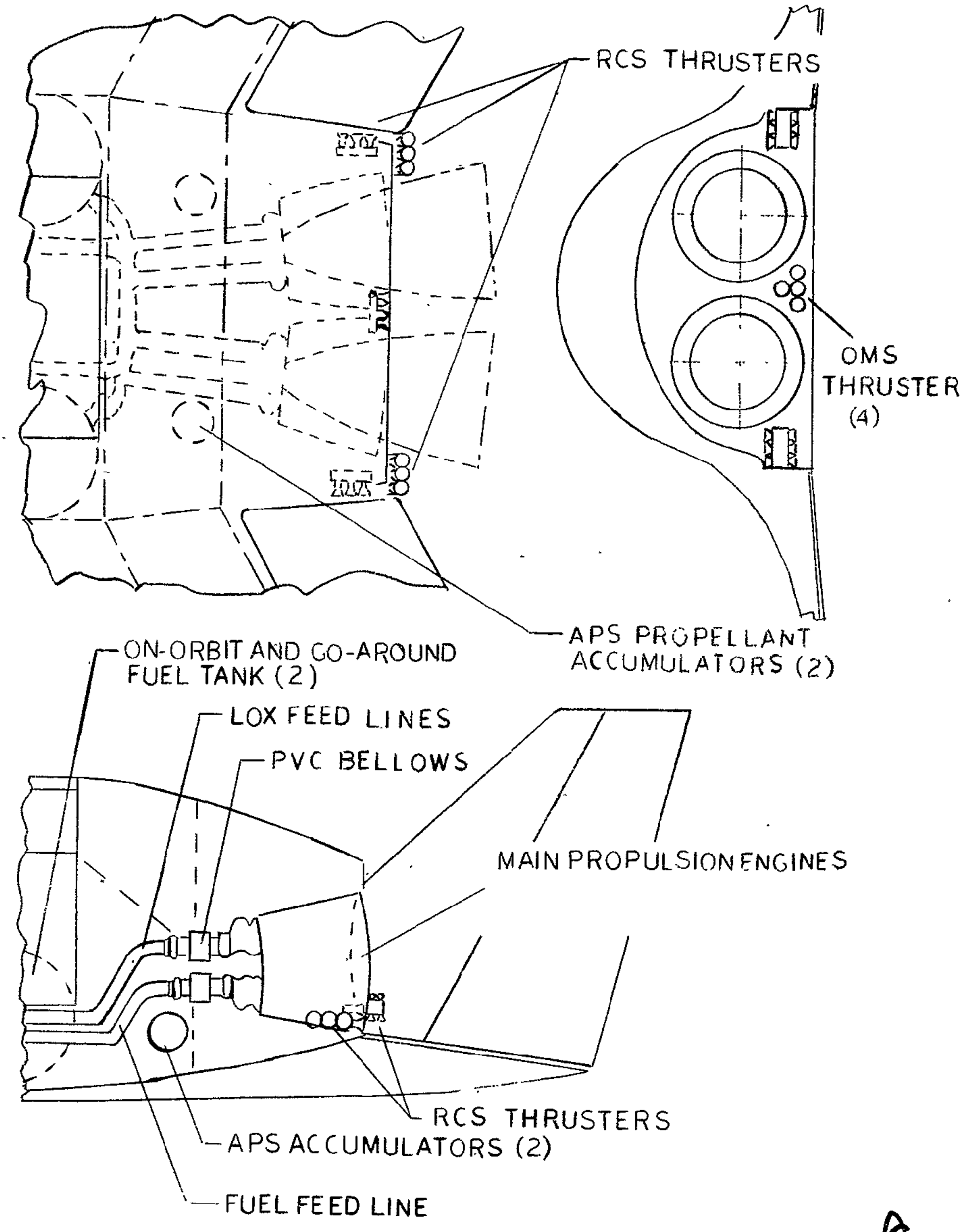


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Figure II-39 Orbiter Aft APS System Configuration

The propellant management system for the on-orbit tanks includes a screen grid in the tanks that provides a source of liquid for the turbopumps. Heat leaks into the tanks result in vaporization between the tank wall and the screen, and boiloff is vented overboard through a refrigeration vent. Expulsion is achieved by increasing the pressure in the inside of the screen device. Liquid/vapor is separated by the liquid surface tension forces, which are greater than the liquid ΔP due to flow. The orbiter APS feed system is shown schematically in Figure II- 40 and pictorially in Figure II- 37 .

a. <u>RCS Engine Subsystem</u> (5.1) - The orbiter RCS engine subsystem consists of 33 reaction control thrusters (9 pitch up, 9 pitch down, 6 yaw right, 6 yaw left, 3 axial translation). The RCS thrusters are contained in modules with three thruster groups per module. Five modules are located forward and six modules aft of the center of gravity. The forward RCS thruster compartment is located in the nose of the orbiter immediately forward of the crew compartment. The braking, yaw, and pitch down thruster modules are mounted on an extendible boom which is deployed for on-orbit maneuvering. The pitch up module is hard mounted to the orbiter airframe. The forward RCS compartment is illustrated in Figure II- 38 . The aft RCS thruster modules are located in the main engine compartment as shown in Figure II- 39 . Maneuvers in orbit are accomplished by the RCS engine subsystem except for ΔV to circularize, for orbit changes, and deorbit, which are accomplished by four OMS engines. The OMS engine subsystem is discussed in Paragraph d. Prior to reentry, the forward thrusters are retracted and doors are closed in the thermal protection system. Attitude control during reentry is accomplished with aft thrusters only. The RCS engine subsystem is composed of the following major assemblies and components:

5.1.1 <u>Thrust Chamber Assembly</u> - The thrust chamber is a single fixed-nozzle film cooled engine which operates on GOX and GH_2 propellants at approximately 500°R inlet temperature and 375 psia inlet pressure. Chamber pressure is approximately 300 psia and vacuum thrust is approximately 1000 pounds. This assembly is similar to the RCS thruster assembly discussed in Paragraph 2.1.1.

5.1.2 <u>Ignition Assembly</u> - A GOX/GH_2 torch igniter is used for engine ignition. The igniter assembly is similar to the RCS igniter assembly discussed in paragraph 2.1.2.

5.1.3 <u>Valve Assembly</u> - An electrically actuated bipropellant main thrust chamber valve is used to admit GOX and GH_2 to the thrust chamber.

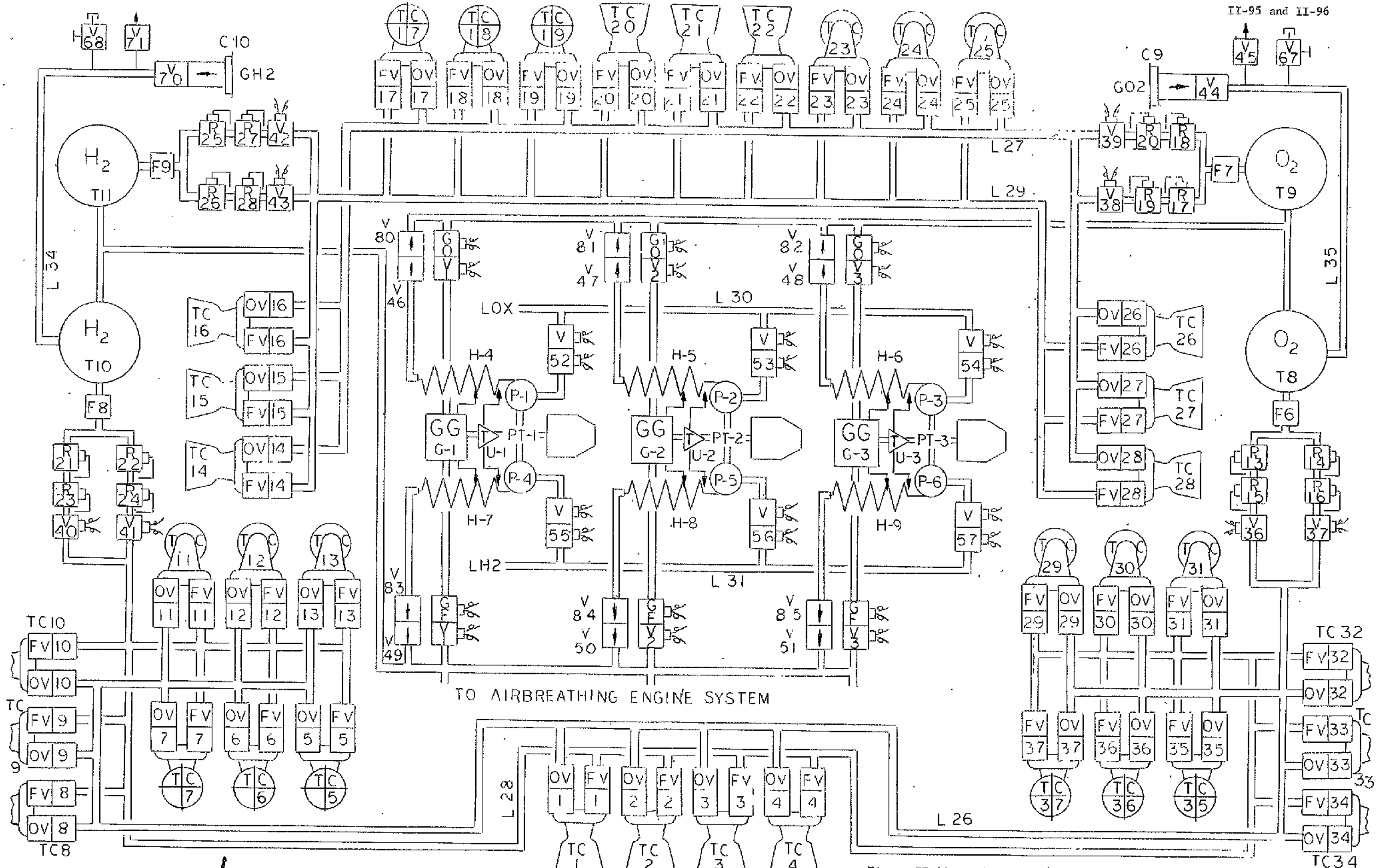


Figure II-40 Orbiter Auxiliary Propulsion System Schematic

b. APS Propellant Management Subsystem (5.2) - The APS propellant management subsystem is used for loading, storage, and distribution of the GOX and GH_2 propellants to the RCS and OMS engine subsystems and the propellant conditioning unit. Two GH_2 and two GOX accumulator spheres are used for gaseous propellant storage. The propellant distribution hardware consists of gas filters, regulators, control valves, and propellant delivery lines. The major assemblies and components of the propellant management subsystem are identified in the following paragraphs.

5.2.1 Accumulator Assembly - Four accumulators (two GOX and two GH_2) are provided to minimize the number of restarts on the propellant conditioning subsystem and to provide a source of gas to bootstrap the gas generators. Two accumulators (one GOX and one GH_2) are mounted in the forward RCS thruster compartment as shown in Figure II- 38 and two accumulators (one GOX and one GH_2) are located in the main engine compartment as shown in Figure II-39 . All like-propellant accumulators are connected by high pressure lines. The accumulator assembly consists of the following major components:

5.2.1.1 Accumulator Tank (T-8 through T-11)
5.2.1.2 Filter (F-6 through F-9)
5.2.1.3 Regulator (R-13 through R-28)
5.2.1.4 Solenoid Valve (V-36 through V-43)
5.2.1.5 Lines and Connectors

5.2.2 Propellant Fill Assembly - The propellant fill assembly consists of the necessary hardware to precharge the GOX and GH_2 accumulators prior to flight and for drain and purge operations after landing. The following major components are identified for this assembly:

5.2.2.1 Quick Disconnect Coupling (C-9, C-10)
5.2.2.2 Solenoid Valve (V-44, V-70)
5.2.2.3 Relief Valve (V-45, V-71)
5.2.2.4 Manual Valve (V-67, V-68)
5.2.2.5 Lines and Connectors (L-34, L-35)

5.2.3 Propellant Feed Assembly - The propellant feed assembly includes the lines and connectors required for delivery of GOX and GH_2 propellants to the RCS and OMS engine subassemblies. This assembly can be broken down into the following major components:

5.2.3.1 GH_2 Feed Lines and Connectors (L-28, L-29)
5.2.3.2 GOX Feed Lines and Connectors (L-26, L-27)

c. APS Propellant Conditioning Subsystem (5.3) - The APS propellant conditioning subsystem is used to resupply the GOX and GH_2 accumulator spheres, drive the auxiliary power unit equipment, and provide GH_2 to the airbreathing engine propellant delivery system. This subsystem is located aft of the on-orbit LOX and LH_2 tanks in the main engine compartment. The major assemblies and components of this subsystem are discussed in the following paragraphs.

5.3.1 Gas Generator Assembly - Three high pressure gas generators provide turbine drive gases for the turbopump and a high temperature heat source for the accumulator resupply heat exchangers. The gas generators burn GOX and GH_2 (from the accumulators), producing a fuel-rich mixture at a gas temperature of approximately 1800°R. The following major components are a part of this assembly.

5.3.1.1 Gas Generator (G-1 through G-3)
5.3.1.2 Heat Exchanger (H-4 through H-9)
5.3.1.3 GOX Solenoid Valve (GOV-1 through GOV-3)
5.3.1.4 GH_2 Solenoid Valve (GFV-1 through GFV-3)
5.3.1.5 GOX check Valve (V-46 through V-48)
5.3.1.6 GH_2 Check Valve (V-49 through V-51, V-80 through V-85)
5.3.1.7 Lines and Connectors

5.3.2 Turbopump Assembly - Three turbopump assemblies remove LOX and LH_2 from the on-orbit tanks and deliver them to separate heat exchangers where they are vaporized and then routed to the GOX and GH_2 accumulators. The pumps are driven by individual gas turbines which are powered by bootstrapping gas generators. The turbopump assembly includes the following major components:

5.3.2.1 Turbine (U-1 through U-3)
5.3.2.2 Power Train (PT-1 through PT-3)
5.3.2.3 Pump (P-1 through P-6)
5.3.2.4 LOX Solenoid Valve (V-52 through V-54)
5.3.2.5 LH_2 Solenoid Valve (V-55 through V-57)
5.3.2.6 Lines and Connectors.

5.3.3 Oxygen Feed Assembly - The LOX feed assembly includes the propellant lines, elbows and connectors required for delivery of liquid oxygen to the three LOX pumps.

5.3.3.1 Lines and Connectors (L-30)

5.3.4 Hydrogen Feed Assembly - The LH_2 feed assembly includes the propellant lines, elbows and connectors required for delivery of liquid hydrogen to the three LH_2 pumps.

5.3.4.1 Lines and Connectors (L-31)

d. OMS Engine Subsystem (5.4) - Propulsion ΔV to circularize, for orbit changes, and for deorbit are accomplished by the OMS engine subsystem. Four OMS engines are contained in a module located in the base of the orbiter vehicle as shown in Figure II-39 . The OMS engine subsystem includes the following major assemblies and components:

5.4.1 Thrust Chamber Assembly - The thrust chamber assembly is a single fixed-nozzle film cooled engine which operates on GOX and GH_2 propellants at approximately 500°R inlet temperature and 375 psia inlet pressure. Chamber pressure is approximately 300 psia and vacuum thrust is approximately 1500 pounds. This assembly is similar to the RCS thruster assembly discussed in paragraph 2.1.1.

5.4.2 Ignition Assembly - A GOX/GH_2 torch igniter is used for engine ignition. The igniter assembly is similar to the RCS igniter assembly discussed in paragraph 2.1.2.

5.4.3 Valve Assembly - An electrically actuated bi-propellant main thrust chamber valve is used to admit GOX and GH_2 to the thrust chamber.

6. Orbiter Airbreathing Propulsion System

The orbiter airbreathing propulsion system consists of a propellant management subsystem and three turbofan engines. The turbofan engines, essentially the same as the booster turbofan engines, are mounted on a cradle which is lowered from the vehicle under carriage when the engines are to be operated. (The cradle, mounting provisions, inlet diffuser and exhaust nozzle are not considered part of the propulsion system). The orbiter airbreathing propulsion system is used during ferry mission operations and during the approach and landing phase of flight missions. The system is illustrated in Figure II-41 and is shown schematically in Figure II-42.

a. Turbofan Engine Subsystem (6.1) - The turbofan engine was described in the booster airbreathing section.

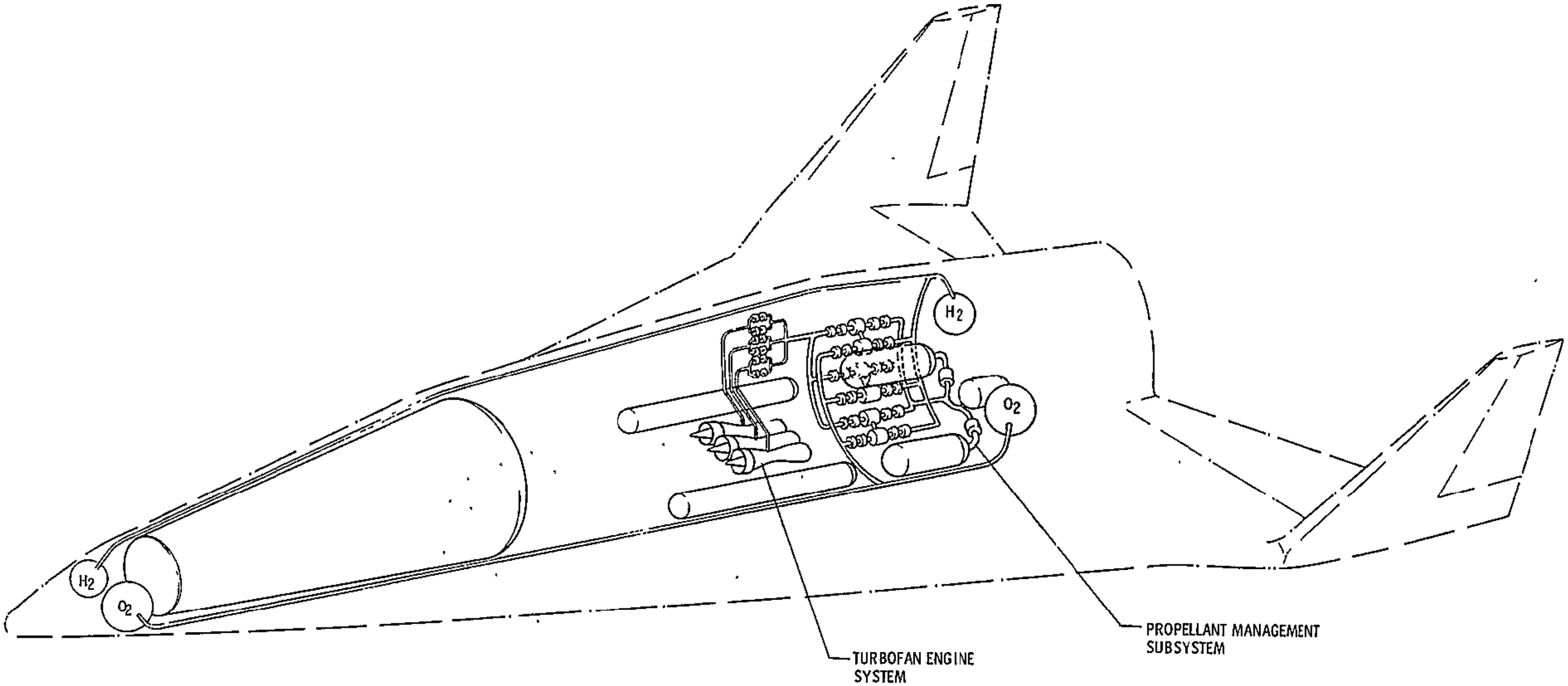


Figure II-41   Orbiter Airbreathing System

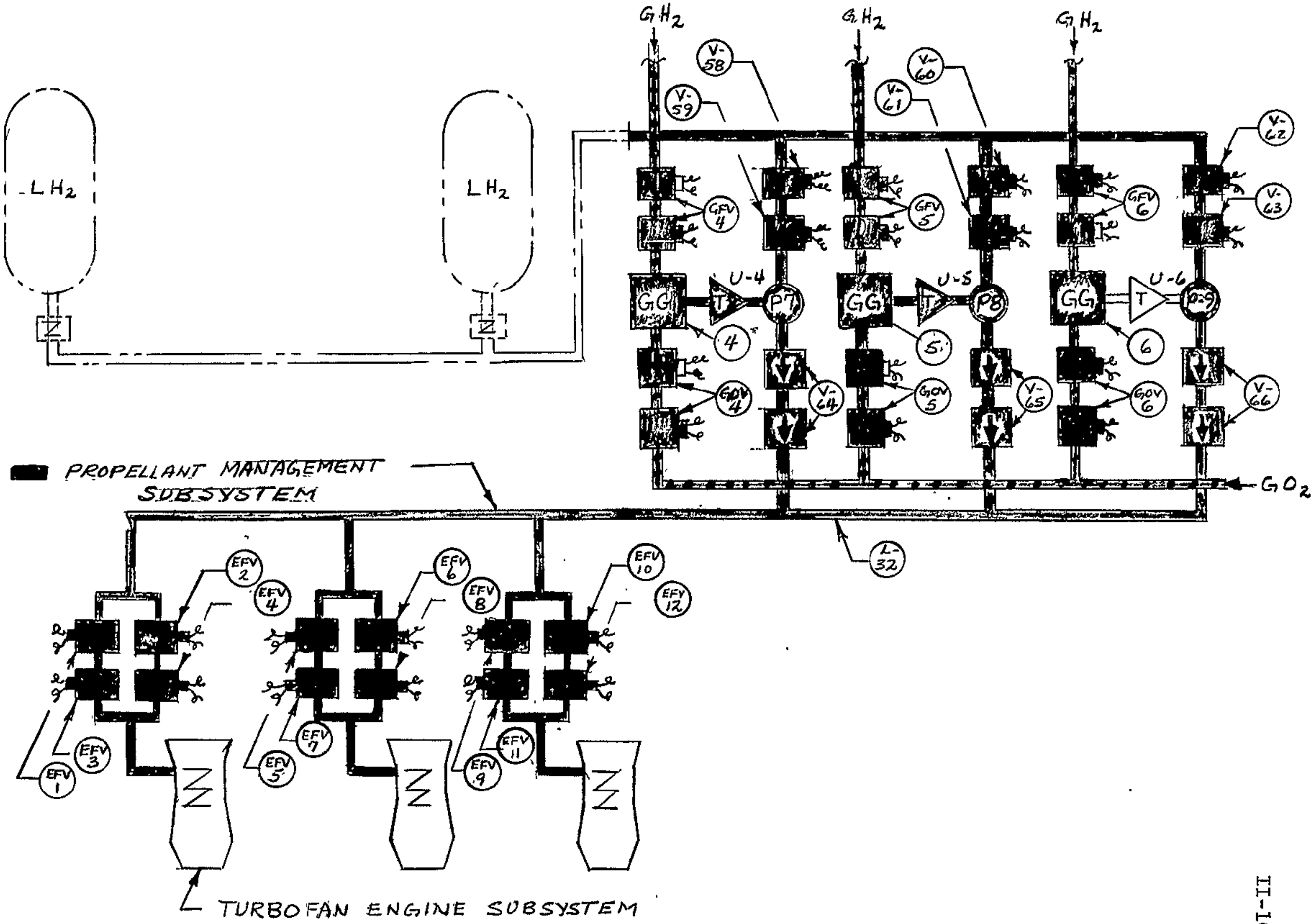


Figure II-42 Orbiter Airbreathing System Schematic

b. <u>Propellant Management Subsystem</u> - For both ferry and flight missions, LH_2 is pumped from the on-orbit LH_2 tanks to the three turbofan engines. The turbopump assembly is driven by a gas generator assembly which uses O_2 and H_2 supplied from the APS accumulators. The following assemblies and components are defined for this subsystem:

- 6.2.1 Fuel Feed Assembly
  - 6.2.1.1 Series-Parallel Solenoid Operated Valve Package
  - 6.2.1.2 Transfer Line
- 6.2.2 Turbo Pump Assembly
  - 6.2.2.1 Pump
  - 6.2.2.2 Series Solenoid Operated Valve Package
  - 6.2.2.3 Turbine
  - 6.2.2.4 Series Check Valve
- 6.2.3 Gas Generator Assembly
  - 6.2.3.1 Gas Generator
  - 6.2.3.2 H_2 Series Solenoid Operated Valve Package
  - 6.2.3.3 O_2 Series Solenoid Operated Valve Package

D. ELECTRONICS

1. General Description

The DRM electronics systems are similar for the booster and orbiter. As shown in Figure II-43, each system is composed of the following major elements:

a. Central Computer Complex for centralized data management and vehicle control.
b. Dedicated Peripheral Computers for high-iteration calculations and specialized processing.
c. Displays and Controls
d. Recorders
e. Data Bus

Only those characteristics of the electronics systems pertinent to the propulsion systems/electronics systems interface, to the estimating of data traffic over this interface and to the estimating of propulsion systems contribution to central computer processing loads were included in the model. Main and airbreathing engine controllers are discussed as part of the electronics systems, as dedicated peripheral computers, for the purposes of this study. Pertinent characteristics of each of the major elements of the DRM electronics systems are discussed in the following paragraphs.

2. Central Computer Complex

The Central Computer Complex (CCC) consists of four central computers, four data bus control units, and a mass memory. Each computer consists of a core memory, a central processor, and an input/output section to interface with the data bus control unit. The data bus control units interface the central computers with four sets of vehicle data busses. The processing rate of the CCC is equal to that of a single computer, i.e., the computers provide quadruply redundant processing capability, with no division or sharing of processing load between them. For simplicity in estimating processing loads, it was assumed that all processing required for propulsion systems functions would be executed at an average rate of 2 microseconds per program instruction (the equivalent of 1 add time for a reasonably modern computer).

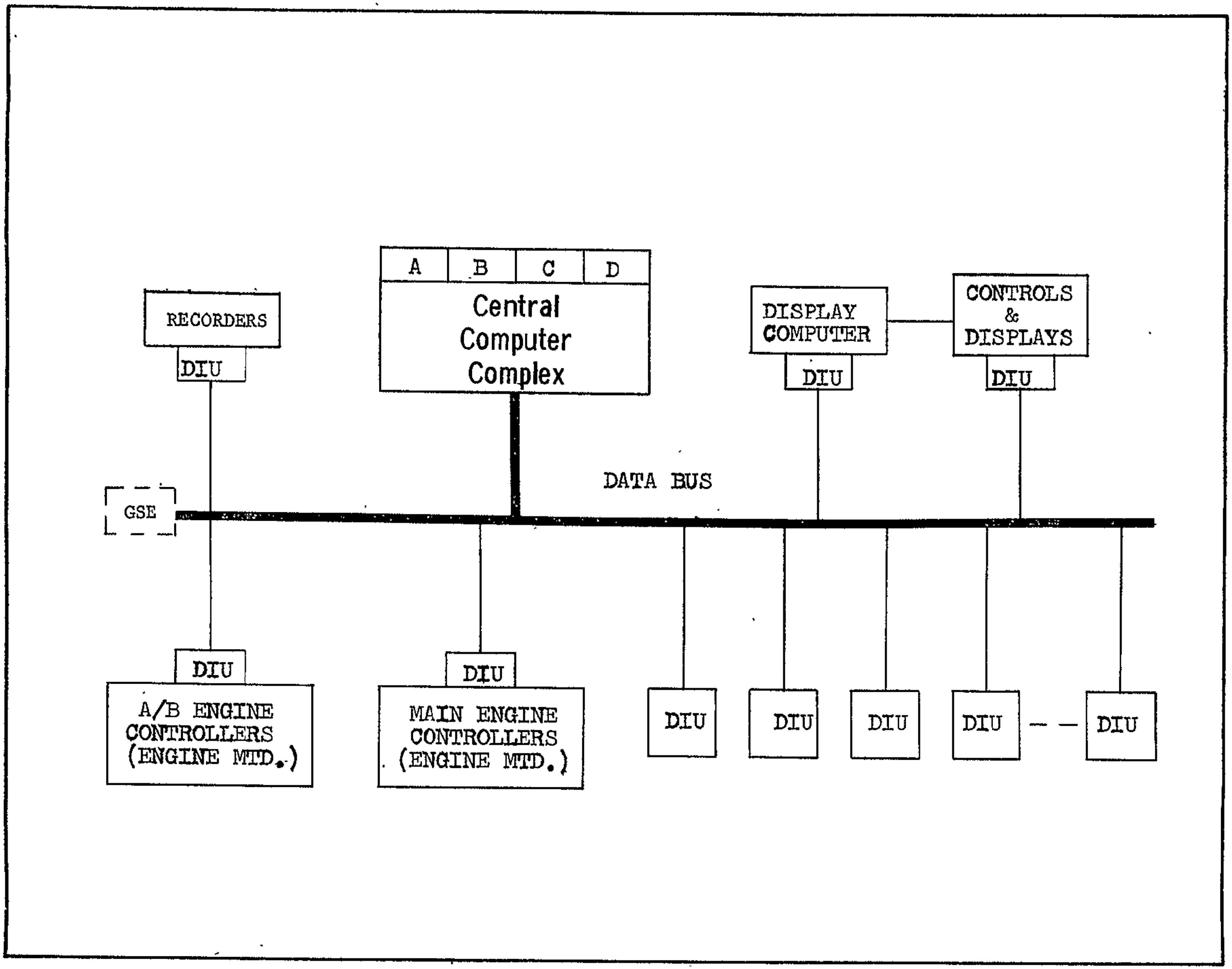


Figure II-43 DRM Electronics System

Central computer input/output processing is based on the following:

a. Each command sent out on the data bus is recirculated (returned to the CCC) by the receiving device and verified by the central computer for correctness of transmission and reception by the correct receiving device.

b. Any incoming data on the data bus, other than recirculated commands, will be the result of a data request issued by the CCC. The data request will not be recirculated, but the incoming data message resulting from the request will always include the address of the responding device. This address will be verified by the control computer to assure that the correct device responded.

c. Data will be transferred into and out of core on a cycle-steal basis.

d. An interrupt will be issued when a data transfer is complete.

e. No software is required to control the data bus.

With this scheme, 37 central computer program instructions are required to send and verify a command and 31 instructions are required to request and obtain a message from a remote device. These instructions are distributed in the computer software as follows:

	Issue Command and Verify	Issue Data Request and Retrieve Data
In Operating Program	5	5
In I/O Request Routine	12	13
In Interrupt Routine	20	13
Totals	37	31

Retrieval of information that is not regularly acquired and retained in a register (buffered) by a remote unit requires both the command and the data request input/output operations. The command instructs the remote unit to acquire the information. The remote unit accepts the command and recirculates it to the CCC for verification. Then, after an appropriate delay to allow the remote unit to acquire and format the requested information, the data request and retrieval operation is executed. Thus, 68 instructions (37 + 31) are required for the total input/output process.

In the case of information that is regularly scheduled (i.e., regularly sampled or computed and held in some storage device) by a remote unit, only the data request and retrieval operation need be executed. This type of information transfer requires 31 instructions.

To command an action to be taken by a remote device, without the device responding with information, requires only the command and verification operation (37 instructions).

It is recognized that this model imposes a heavy data traffic load on the data bus and a high processing load on the central computer in comparison to some other candidate concepts for data bus operation. However, it provides significant system flexibility by allowing any device on the data bus to be contacted by the central computer at any time. Also, it allows a simple system in terms of hardware required since devices on the data bus need only respond to their addresses and, except for the dedicated peripheral computers, require no data buffers, interleavers, or sequencers. Additionally, since addresses are verified on every transmission, error detection is enhanced.

3. Data Bus

A digital data bus system is used for all communication between the central computer complex and the vehicle subsystems. Digital interface units (DIUs) interface subsystems to the data bus. Separate forward and aft data busses are provided, each having quadruply redundant channels. All data flow is between the DIUs and the central computer complex (i.e., no direct communication is made between DIUs).

The data bus provides two-way transmission between the central computer and DIUs, with DIUs transmitting only when polled by the central computer. A data transmission rate of 10^6 bits per second is assumed. All messages are transmitted in 8-bit bytes plus one parity bit per byte. Messages from the central computer to DIUs contain 1 byte address, a 1 byte function code, a maximum of 7 information bytes, and a vertical parity byte. DIU to central computer messages carry the DIU address in the first byte, followed by up to 32 bytes of data and a vertical parity byte. These data bus transmission formats, along with explanatory notes are presented in Table II-7. Transmission is in biphase form (Manchester code). Communication operations over the data bus are as follows:

a. To command a digital interface unit to perform an action (such as closing a valve) a four byte command is sent, and recirculated back to the Central Computer Complex(CCC).

b. To obtain a measurement from a DIU (such as a line pressure), a four byte command is sent to the DIU and recirculated. After an appropriate time delay to allow the DIU to make the measurement, a three byte data request is sent to the DIU which returns data (typically in a four byte format) rather than recirculating the command.

c. To obtain the regularly scheduled engine controller information, a three byte command is sent to the engine controller DIU and the information is returned using as many bytes as necessary (within the format limitation) to return that particular set of information. The information sent from the engine controller is grouped by the frequency at which it is sent (for example, all data sent at a rate of 10 times per second is sent in one transmission).

d. Where a grouping of information is possible, this information will be available in one transmission rather than requiring separate transmissions. An example is the chamber pressure of the separation thrusters: one data request can obtain the chamber pressures of all separation thrusters controlled by any single DIU.

The data bus design reference model was formulated on the basis of obtaining maximum system flexibility with a minimum of remote hardware. These objectives are met by the baseline system at the expense of relatively high data bus rates.

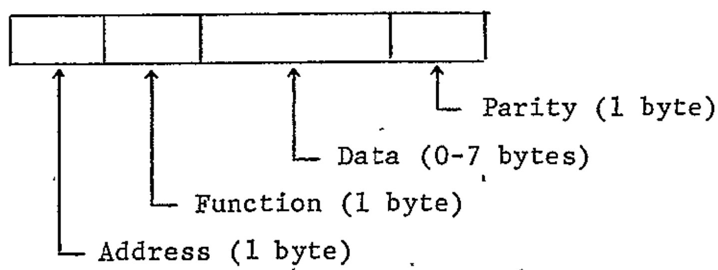
4. Dedicated Peripheral Computers

a. Engine Controllers - All engine controllers, both airbreathing and main engine, are general purpose, programmable digital data processors, engine mounted. Engine controllers will respond to control command from the central computer

TABLE II-7

DATA BUS FORMATS

CCC to DIU

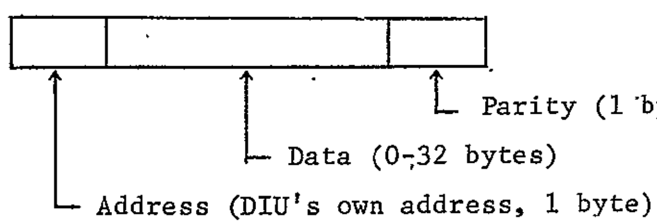


This format is sent to the DIU's for two reasons:

1) Command the DIU to some action (stimulate, perform a measurement, self check, etc.); in this case the message is recirculated back to the CCC in its entirity.

2) Request data (sent after a DIU has had time to make a measurement per a command); in this case the DIU returns a data message as shown below.

DIU to CCC



This is the format used by the DIU's to send measurement data to the CCC, and is also the format used to send information from an engine controller via a DIU.

NOTES: Each byte is nine bits long; 8 bits data, 1 bit parity.

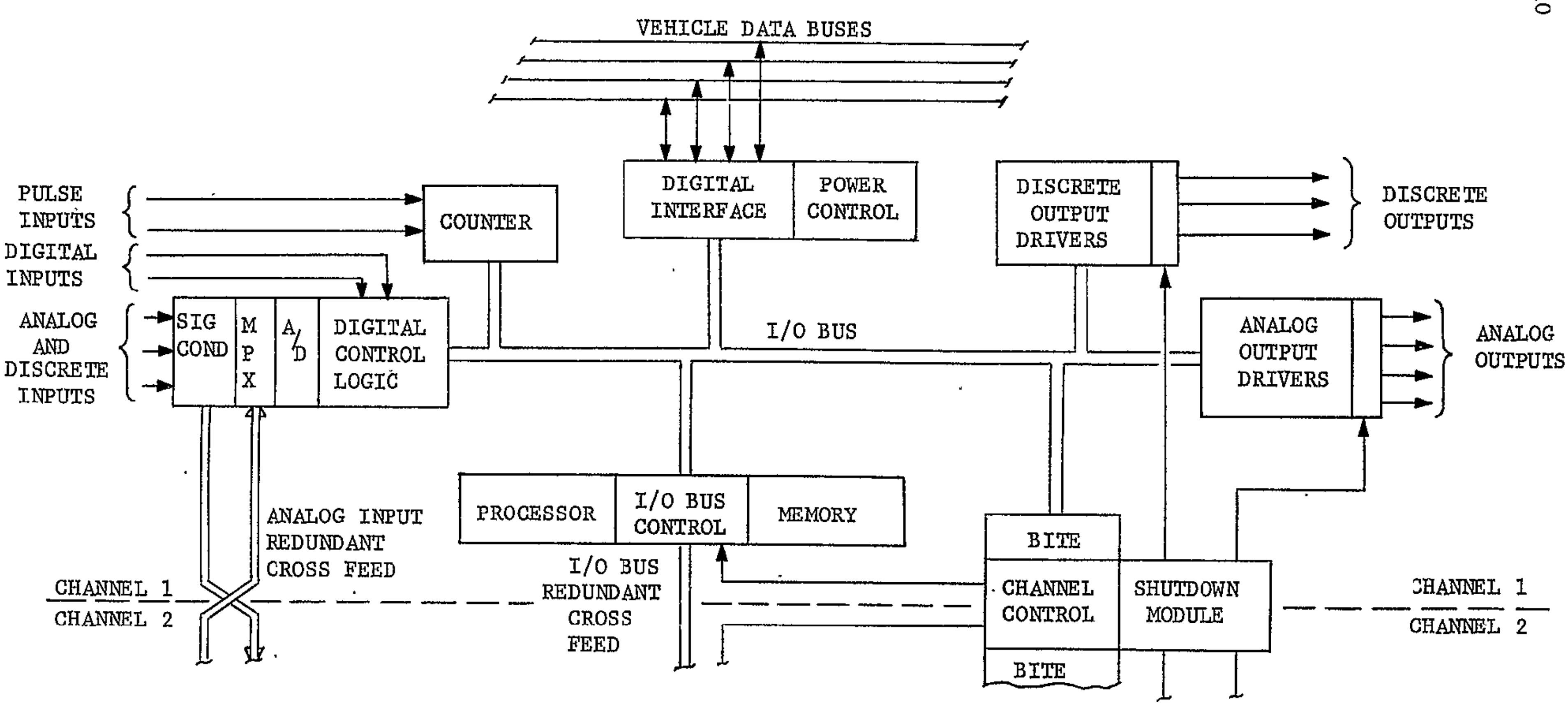
A DIU cannot initiate a transmission. It must receive a message from the CCC (of the top format above) which it will respond to with the data it has to transmit.

complex and will be responsible for direct control of engine operation, monitoring of engine performance, and formulation of status information for reporting to the central computer complex. Engine controllers will control engine start and shutdown and will perform fault isolation, built-in-test, timing and control, self-test, and data quantity reduction for recording. In addition, the engine controllers will provide such engine instrumentation subsystem functions as distribution of sensor excitation power, measurement sequencing, and signal conversion.

The pertinent DRM characteristics are essentially the same for both the main engine and the airbreathing engine controllers. Differences between the two are associated with memory size, operational software, input/output module complement, analog multiplexing ratio, and power requirements -- all of which have negligible significance in this study. The DRM engine controller is shown in block diagram form in Figure II-44. This diagram is applicable to both main and airbreathing engine controllers.

The controller contains a dual redundant set of signal conditioning, data processing, vehicle data bus interface, output driver, power control logic, power conditioning, and Built-In Test Equipment (BITE) modules. This provides dual redundant operating channels. A 16-bit, parallel, bidirectional data bus interconnects the controller modules. Each module is addressable, allowing the processor to select the sequence and rate at which each I/O module is processed. This provides completely asynchronous operation which can arbitrarily be programmed to meet various I/O requirements resulting from engine or instrumentation configuration, or operations changes.

Cross-channel analog and digital bus interconnect schemes provide a multinode configuration, wherein modules of one channel can be automatically switched to the other channel to replace failed like modules. The Channel Control Unit is the selector which allows this reconfiguration after a failure has been isolated to a module. Failure detection and isolation is achieved with dedicated test circuitry (BITE), in conjunction with certain capabilities of the processor. BITE provides parity checks, input reference test voltages, and output "wraparound" checks (output routed to input). The processor



(CHANNEL 2 IS MIRROR IMAGE OF CHANNEL 1)

FIGURE II-44

DRM ENGINE CONTROLLER BLOCK DIAGRAM

performs input data checks, memory sum checks, and its own self-test. A contingency shutdown module provides engine shutdown capability, under control of the channel control unit, in the event that multiple failures have rendered the normal shutdown capabilities inoperable.

The power system in the controller receives redundant vehicle bus power, and conditions and distributes it within the controller and to the engine actuators, instrumentation, and igniters via the output modules.

The processor modules of the controllers are digital, programmable, general purpose, parallel data processors with multiplexed I/O. Data and instruction words are 16-bit. Execution times are 6 microseconds add, 21.5 microsecond multiply, and 4.5 microsecond I/O. One real time or data dependent interrupt level is provided. Memory access for I/O is on a cycle-steal basis.

The processing functions performed by the engine controllers are somewhat different for the main and airbreathing engine application, as are the control and measurement signal quantities and types to be handled. Hence, the software complements, memory size, and input/output conditioning requirements will be different for the two types of engines. These provisions are assumed to be sufficiently modular in nature to allow the same basic controller configuration to be used in both applications, with different complements of the engine type-peculiar modules as necessary. DRM processing functions for the two engine types are described below.

1) Main Engine Controller Processing Functions - The controller provides accurate thrust, mixture ratio and gimbal angle control, and aids in Pogo suppression. The control commands are issued to the engine components by the controller in response to commands from the vehicle. The processor calculates thrust from chamber pressure, using stored values for C_F and C^*. It calculates mixture ratio using flow, temperature and pressure data from engine measurements. It compares calculated values with commanded values of thrust and mixture ratio, and issues signals to the appropriate engine valves to null the errors.

In addition, it responds to commands for gimbal angle and issues appropriate signals to the gimbal actuator servo valves. Further, the processor provides start and shutdown sequences, in response to vehicle commands. Safe shutdown from any power level is required upon initiation of a shutdown command. The processor also performs subsystem readiness checks on command from the vehicle, and provides a readiness status signal; performs limit and rate checking against stored values on flight safety parameters, issuing shutdown commands as required; and performs engine sequence tests and start/stop sequence control based on stored sequence programs. The quantity of engine performance data to be displayed and/or recorded through the vehicle display and recording provisions will be reduced by the engine controller processor through use of sample averaging techniques.

2) Airbreathing Engine Controller Processing Function- The controller controls fuel flow to the engine power assembly burner in accordance with engine thrust level commands from the vehicle central computer. The processor accepts engine parameter measurements (such as fan inlet pressure and temperature and high pressure turbine pressure and temperature), calculates thrust, compares calculated values with commanded values, and issues signals to the appropriate engine fuel control actuators to null the error. The processor provides start and shutdown sequences in response to vehicle commands, evaluates the engine subsystem performance through gas path analysis, performs subsystem readiness checks on command from the vehicle, and provides condition and readiness status signals to the central computer. In addition, it performs limit and rate checking against stored values on flight safety parameters, issuing shutdown commands as required. As for the main engine, the airbreathing engine controller's processor has capability for reducing the quantity of engine performance data for display and recording through sample averaging techniques.

b. Other Peripheral Computers - The only other peripheral computer pertinent to the propulsion system is the display computer. This computer frees the engine controllers and the central computer complex from routine processing associated with crew displays. The display computer extracts parameters for display (from lists provided by the central computer complex), orders the information for display and transforms it to be compatible with display hardware. The display computer is assumed to provide sufficient core memory and processing speed, dedicated exclusively to display processing tasks, to accomodate all necessary propulsion system display requirements, as well as all other vehicle systems display requirements.

5. Displays and Controls

Display capability is provided in the form of alphanumeric text, pictorial presentations, discrete indicators, etc. Control of display modes and direction of information to appropriate displays is the responsibility of the display computer. For this study it was assumed that unlimited cathode ray tube, microviewer (under display computer control), meter-type, and indicator lamp displays are available. That is, display capability was not considered a constraint on the propulsion system checkout and monitoring task. An alphanumeric keyboard was assumed to be available for man-machine interface with the central computer complex.

6. Recording

Propulsion system data to be recorded is transferred to the central computer complex. A maintenance recorder provides storage of information for maintenance functions. All recording is under control of the central computer. It is assumed that sufficient recording capability is provided by the vehicle maintenance recorder to accomodate approximately 75 K bits per second of booster propulsion system data during a 170 second peak-demand period and approximately 15 K bits per second of orbiter propulsion system data during a 170 second peak-demand period.

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A. PROPULSION SUBSYSTEM REQUIREMENTS

The propulsion subsystem requirements are outlined in Figures III-1 through III-6. These subsystem requirements were derived from the design reference model propulsion system and mission by identifying the functional and performance requirements of each propulsion subsystem during each of the seventeen mission phases. This key element of the propulsion criteria for checkout and monitoring provides visibility to the following:

- Functions to be performed by each propulsion subsystem during each mission phase, together with general performance goals.
- State or condition of each propulsion subsystem during each mission phase.
- Functional interfaces between subsystems.
- Functional interfaces with ground operations systems.

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B. FAILURE MODE AND EFFECTS ANALYSIS

The objectives of the failure modes and effects analysis (FMEA) were to determine the potential propulsion failure modes and resulting effects on the subsystem, system, crew and mission, and establish the criticality of the failure; and identify candidate failure detection methods for each failure mode to aid in establishing propulsion system measurement requirements.

1. Ground Rules

A set of ground rules were established to provide guidelines for the failure mode and effects analysis. These ground rules identify the level to which the FMEA was to be performed, the failure mechanisms to be considered, hardware items to be excluded from the analysis, and areas which required detailed analysis:

1. The FMEA shall be conducted for the ground, ferry, and flight operations defined in Chapter II of this volume.
2. The FMEA shall be conducted on all propulsion assemblies and components as defined in Chapter II of this volume.
3. Failure mechanisms in critical components shall be identified.
4. Those failure modes and types as identified for the Saturn V Vehicle Components in MSFC Drawing No. 10M30797 shall be utilized as appropriate.
5. The following passive components shall be included due to the nature of the Space Shuttle vehicle and mission:

    (a) Lines that are designated as Line Replaceable Units (LRU's) or parts of LRU's.

    (b) Filters

    (c) Propellant tankage

6. Cycle and time sensitive components shall be identified and analyzed as to their failure modes and effects.

7. 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.

8. It is assumed that the proper electrical signal is always transmitted from the controller to the propulsion component requiring such a signal.

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

10. Structural members which perform no function other than providing structural integrity are excluded.

11. Failures of access doors, module covers, deployment mechanisms, and actuators used for deployment purposes shall be excluded. The orbiter main engine nozzle extension/retraction mechanism shall be included.

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

13. Leakage will be defined and treated as follows:

<u>Major Leakage</u> - Loss of fluid or gas in excess of functional system tolerances.

a. Major leakage will be considered past sealing surfaces (seats) of components which possess a capability of being open or closed.

b. External leakage will be considered at the upstream and downstream side of flanged and bolted components. It should be noted that rupture and other related structural failures of tubing and ducting shall not be considered.

Minor Leakage - Loss of discernible quantities of fluid or gas within the functional system tolerance.

a. Minor external leakage will be treated only as it effects the operation of that component under consideration. It is assumed that closed compartments are purged with inert gas as a normal safety precaution. In those cases where leakage could result in a failure to a component in a vented compartment, such failure modes will be identified.

b. Minor internal leakage past dynamic component seals will not be considered if the component is normally open during its operating mode.

14. Every redundant component shall be identified and the effect of the loss of total redundancy will be analyzed.

15. The following criticality categories shall be utilized for potential effect of component failure:

Category	Potential Effect of Failure
1	Loss of life of crew member(s) (ground or flight).
1S	Applies to Safety and Hazard Monitoring Systems. When required to function because of failure in the related primary operating system(s), potential effect of failure is loss of life of crew member(s).
2A	Immediate mission flight termination or unscheduled termination at the next planned earth landing area. (Can also include loss of primary mission objectives)
2B	Launch scrub.
	Launch delay or loss of secondary mission objectives.
4	None of the above.

2. Approach and Format

The FMEA was performed at the component level. All components were qualified for analysis according to the FMEA ground rules. A brief description of each component function within its assembly was documented. Potential single point failure and, where applicable, failure of total redundancy of each component during the most critical mission phase were studied in detail to determine the effect on subsystem, system, crew and mission. Each component failure mode was then ranked according to the probability of malfunction occurence. The criticality of the failure was categorized according to its effect upon the crew, vehicle, and mission for each of three major mission operations (ferry operation, ground operation, and flight operation, designated A, B and C respectively in the analysis sheets).

Major parts of certain selected components were identified. Potential failure mechanisms for such parts were studied to determine the effect on the component. The results of the FMEAs were then reviewed to insure that the failure modes for these selected components were identified.

Recommendations for methods of failure detection and fault isolation were documented together with recommendations for deletion or addition of redundancy, preventive maintenance, or additional measurements.

The FMEA analysis sheets are presented in Appendix B (Volume IV).

C. LINE REPLACEABLE UNITS

Among the several functions to be performed by the on-board checkout and monitoring system are inflight fault isolation of line-replaceable-units (LRUs) for timely maintenance, and verification purposes after LRU replacement. Therefore, the definition of the checkout systems is in part determined by the requirement to isolate faulty LRUs and check them out after replacement, consistent with mission time lines. This portion of the report defines an LRU, presents the LRU selection ground rules, and identifies the LRUs.

The procedures for LRU removal, replacement and retest in the Maintenance Phase were defined to accomplish the selection of LRUs, and to determine the checkout functions associated with LRU removal, replacement and retest. The procedures are presented in Appendix C, Volume IV of this report.

1. Definition

A line replaceable unit is defined as any component, series of components, assembly, or subsystem that can be replaced by a competent mechanic in the Space Shuttle maintenance area.

2. Ground Rules and Criteria

a. Replacement of an LRU shall not impact the Space Shuttle maintenance timeline. It is assumed that simultaneous replacement can be achieved;

b. Replacement shall not require removal of major operational hardware which is not a part of the LRU subsystem;

c. Connections for LRU removal shall be minimized;

d. Retest requirements shall necessitate only retest of the replaced LRU;

e. The functional status of each LRU shall be able to be verified and monitored, and shall not introduce uncertainty in calibration in excess of the specification performance limits;

f. An LRU may consist of a series or group of LRUs.

Interconnecting lines were not generally evaluated in this study. Only main engine interconnecting and attaching lines were considered.

Component groupings into modular packaged LRUs were used when possible. The approach used the following criteria:

a. Component grouping shall be used on redundant-like components. In general, complex components or components which are expected to operate at high cycle rates will not be grouped with simple components or components which are expected to operate at low cycle rates;

b. Component groupings which require hydraulic, pneumatic or electrical disassembly connections in excess of those required for a lower level of replacement will not be considered as LRU candidates;

c. Modules weighing more than 150 lb. will not be considered as LRU candidates unless:

   1) The module is located at an obvious access door;

   2) The module is external to the vehicle skinline,

   3) Replacement of lower level components, assemblies or subsystems would delay mission timelines.

The LRU identification resulting from these ground rules and criteria are presented in the following pages. For each propulsion system, all of the components are identified, and a criteria matrix resulting in LRU selection is presented. The top level LRUs are shown on schematics and have written descriptions; those LRUs which are contained within the top level LRUs are identified in the tabular listings.

An objective is to have all propulsion control sensors be LRUs. However, the control sensors are not defined in the LRU listings.

3. Booster Main Propulsion System

Table III-1 reflects all components within the Booster main propulsion system and presents the criteria matrix resulting in LRU selection. (Because of commonality, the orbiter main propulsion system components are also presented in this table). Top level LRU identification for the Booster main propulsion system is shown schematically in Figure III-7. These are followed by a brief description of the top-level LRUs. Those LRUs which are contained within the top-level LRUs are identified in the tabular listings.

Table III-1 Main Propulsion System LRUs

Ref. No.	Main Propulsion System Booster Item	Meets LRU Criteria				LRU	
		Time	Accessibility	Calibration	Verification	Yes	No
1.1	Engine Subsystem	X	X	X	X	X	
1.1.1.1	Low Pressure Fuel Turbopump	X	X	X	X	X	
1.1.1.2	High Pressure Fuel Turbopump	X	X	X	X	X	
1.1.1.3	Low Pressure Oxidizer Turbopump	X	X	X	X	X	
1.1.1.4	High Pressure Oxidizer Turbopump	X	X	X	X	X	
1.1.1.5	Fuel Preburner	X	X	X	X	X	
1.1.1.6	Oxidizer Preburner	X	X	X	X	X	
1.1.1.7	Hot Gas Manifold	NO	NO	X	X		X
1.1.1.8	Fuel Main Valve	X	X	X	X	X	
1.1.1.9	Oxidizer Main Valve	X	X	X	X	X	
1.1.1.10	Fuel Control Valve, Oxidizer Preburner	X	X	X	X	X	
1.1.1.11	Oxidizer Control Valve, Oxidizer Preburner	X	X	X	X	X	
1.1.1.12	Oxidizer Control Valve, Fuel Preburner	X	X	X	X	X	
1.1.1.14	Interconnect Artic. Lines	X	X	X	X	X	
1.1.1.15	Interconnect Lines	X	X	X	X	X	
1.1.1.16	Oxidizer Recirculation Select Valve	X	X	X	X	X	
1.1.1.17	Fuel Recirculation Select Valve	X	X	X	X	X	
1.1.1.18	Fuel Recirculation Control Valve	X	X	X	X	X	
1.1.1.19	Fuel Recirculation Regulator	X	X	X	X	X	
1.1.2.1	Main Injector	NO	NO	NO	X		X
1.1.2.2	Main Combustion Chamber	NO	NO	X	X		X
1.1.2.3	Booster Nozzle	X	X	X	X	X	
1.1.2.4	Gas Distribution Plate	NO	NO	X	X		X
1.1.2.5	Interconnect Lines	X	X	X	X	X	
1.1.3.1	Preburner and Main TCA Igniters	X	X	X	X	X	
1.1.3.2	Interconnect Lines	X	X	X	X	X	
1.1.4.1	Gimbal Block	NO	NO	X	X		X
1.1.4.2	Gimbal Actuator and Power Pack	X	X	X	X	X	
1.1.5.1	Engine Controller	X	X	X	X	X	
1.1.5.2	Ignition and Valve Control Harness	X	X	X	X	X	
1.1.5.3	Instrumentation Harness	X	X	X	X	X	
1.1.5.4	Sensors	X	X	X	X	X	
1.1.6.1	Fuel Tank Pressurant Check Valve	X	X	X	X	X	
1.1.6.2	Oxidizer Tank Pressurant Check Valve	X	X	X	X	X	
1.1.6.3	Oxidizer Heat Exchanger	X	X	X	X	X	
1.1.6.4	Interconnect Lines	X	X	X	X	X	
1.1.7.1	Purge Valves	X	X	X	X	X	
1.1.7.2	Interconnect Lines	X	X	X	X	X	

Table III-1 (Continued)

Ref. No.	Main Propulsion System Orbiter Item	Meets LRU Criteria: Time	Accessibility	Calibration	Verification	LRU: Yes	No
4.1	Engine Subsystem	X	X	X	X	X	
4.1.1.1	Low Pressure Fuel Turbopump	X	X	X	X	X	
4.1.1.2	High Pressure Fuel Turbopump	X	X	X	X	X	
4.1.1.3	Low Pressure Oxidizer Turbopump	X	X	X	X	X	
4.1.1.4	High Pressure Oxidizer Turbopump	X	X	X	X	X	
4.1.1.5	Fuel Preburner	X	X	X	X	X	
4.1.1.6	Oxidizer Preburner	X	X	X	X	X	
4.1.1.7	Hot Gas Manifold	NO	NO	X	X		X
4.1.1.8	Fuel Main Valve	X	X	X	X	X	
4.1.1.9	Oxidizer Main Valve	X	X	X	X	X	
4.1.1.10	Fuel Control Valve, Oxidizer Preburner	X	X	X	X	X	
4.1.1.11	Oxidizer Control Valve, Oxidizer Preburner	X	X	X	X	X	
4.1.1.12	Oxidizer Control Valve, Fuel Preburner	X	X	X	X	X	
4.1.1.14	Interconnect Artic. Lines	X	X	X	X	X	
4.1.1.15	Interconnect Lines	X	X	X	X	X	
4.1.1.16	Oxidizer Recirculation Select Valve	X	X	X	X	X	
4.1.1.17	Fuel Recirculation Select Valve	X	X	X	X	X	
4.1.1.18	Fuel Recirculation Control Valve	X	X	X	X	X	
4.1.1.19	Fuel Recirculation Regulator Valve	X	X	X	X	X	
4.1.2.1	Main Injector	NO	NO	NO	X		X
4.1.2.2	Main Combustion Chamber	NO	NO	X	X		X
4.1.2.3	Orbiter Nozzle	NO	NO	X	X		X
4.1.2.4	Gas Distribution Plate	NO	NO	X	X		X
4.1.2.5	Interconnect Lines	X	X	X	X	X	
4.1.3.1	Preburner and Main TCA Igniters	X	X	X	X	X	
4.1.3.2	Interconnect Lines	X	X	X	X	X	
4.1.4.1	Gimbal Block	NO	NO	X	X		X
4.1.4.2	Gimbal Actuator and Power Pack	X	X	X	X	X	
4.1.5.1	Engine Controller	X	X	X	X	X	
4.1.5.2	Ignition and Valve Control Harness	X	X	X	X	X	
4.1.5.3	Instrumentation Harness	X	X	X	X	X	
4.1.5.4	Sensors	X	X	X	X	X	
4.1.6.1	Fuel Tank Pressurant Check Valve	X	X	X	X	X	
4.1.6.2	Oxidizer Tank Pressurant Check Valve	X	X	X	X	X	
4.1.6.3	Oxidizer Heat Exchanger	X	X	X	X	X	
4.1.6.4	Interconnect Lines	X	X	X	X	X	
4.1.7.1	Purge Valves	X	X	X	X	X	
4.1.7.2	Interconnect Lines	X	X	X	X	X	
4.1.8.1	Extendible Nozzle	N/A	X	X	X	X	
4.1.8.2	Extendible Nozzle Coolant Valve	N/A	X	X	X	X	
4.1.8.3	Extendible Nozzle Deployment Kit	N/A	X	X	X	X	
4.1.8.4	Nozzle Coolant Line	N/A	X	X	X	X	

Table III-1 (Continued)

Ref. No.	Main Propulsion System - Booster & Orbiter Item	Meets LRU Criteria				LRU	
		Time	Accessibility	Calibration	Verification	Yes	No
1.0	Booster - Main Propulsion System						
1.2.1.1	Oxidizer Feed Line (L-1 through L-7)	X	X	X	X	X	
1.2.1.2	Oxidizer Prevalve (V-77 through V-83)	X	X	X	X	X	
1.2.2.2	Oxidizer Isolation Valve (V-1 and V-2)	X	X	X	X	X	
1.2.3.2	Oxidizer Vent Valve (V-3 through V-6)	X	X	X	X	X	
1.2.4.2	Oxidizer Fill Valve (V-7)	X	X	X	X	X	
1.2.4.3	Oxidizer Fill Coupling (C-1)	X	X	X	X	X	
1.2.5.1	Oxidizer Tank - Diffuser and Sump (T-1)	NO	NO	X	X		X
1.2.6.2	Helium Coupling (C-2)	X	X	X	X	X	
1.2.7.1	Fuel Feedline (L-13 through L-19)	X	X	X	X	X	
1.2.7.2	Fuel Isolation Valve (V-8 through V-14)	X	X	X	X	X	
1.2.8.2	Fuel Vent Coupling (V-15 through V-18)	X	X	X	X	X	
1.2.8.3	Fuel Vent Valve (V-15 through V-18)	X	X	X	X	X	
1.2.9.2	Fuel Fill Coupling (C-5)	X	X	X	X	X	
1.2.9.3	Fuel Fill Valve (V-19)	X	X	X	X	X	
1.2.10	Fuel Tank - Diffuser and Sump (T-2)	NO	NO	X	X		X
1.3.1.2	Oxidizer Pressure Control Orifice (O-1 and O-2)	X	X	X	X	X	
1.3.1.3	Oxidizer Pressure Control Valve (V-20 and V-21)	X	X	X	X	X	
1.3.1.4	Oxidizer Pressurant Filter (F-1)	X	X	X	X	X	
1.3.1.6	Fuel Pressure Control Orifice (O-3 and O-4)	X	X	X	X	X	
1.3.1.7	Fuel Pressure Control Valve (V-22 and V-23)	X	X	X	X	X	
1.3.1.8	Fuel Pressurant Filter (F-2)	X	X	X	X	X	
1.3.2.2	Helium Coupling - Oxidizer (C-6)	X	X	X	X	X	
1.3.2.4	Helium Coupling - Fuel (L-4)	X	X	X	X	X	
4.0	Orbiter - Main Propulsion System						
4.2.1.2	Oxidizer Isolation Valve (V-1 and V-2)	X	X	X	X	X	
4.2.2.2	Oxidizer Vent Valve (V-3 through V-6)	X	X	X	X	X	
4.2.3.2	Oxidizer Fill and Drain Valve (V-7)	X	X	X	X	X	
4.2.3.3	Oxidizer Fill and Drain Coupling (C-1)	X	X	X	X	X	
4.2.4.1	Oxidizer Tank (Diffuser & Sump) (T-1 & T-2)	NO	NO	X	X		X
4.2.5.2	Helium Coupling - Oxidizer (C-2)	X	X	X	X	X	
4.2.5.3	Helium Coupling - Fuel (C-8)	X	X	X	X	X	
4.2.6.2	Fuel Isolation Valve (V-8 and V-9)	X	X	X	X	X	
4.2.7.2	Fuel Tank Vent Coupling (C-3)	X	X	X	X	X	
4.2.7.3	Fuel Tank Vent Valve (V-10 through V-13)	X	X	X	X	X	
4.2.8.2	Fuel Fill and Drain Coupling (C-5)	X	X	X	X	X	
4.2.8.3	Fuel Fill and Drain Valve (V-14)	X	X	X	X	X	
4.2.9.1	Fuel Tank (Diffuser & Sump) (T-3)	NO	NO	X	X		X
4.3.1.2	Oxidizer Pressure Control Valve (V-19 and V-20)	X	X	X	X	X	
4.3.1.3	Oxidizer Pressure Control Orifice (O-3 and O-4)	X	X	X	X	X	
4.3.1.4	Oxidizer Pressurization Line Filter (F-2)	X	X	X	X	X	
4.3.1.6	Fuel Pressure Control Valve (V-21 and V-22)	X	X	X	X	X	
4.3.1.7	Fuel Pressure Control Control Orifice (O-5 and O-6)	X	X	X	X	X	
4.3.1.8	Fuel Pressurization Line Filter (F-3)	X	X	X	X	X	
4.3.2.2	Helium Coupling - Oxidizer (C-6)	X	X	X	X	X	
4.3.2.4	Helium Coupling - Fuel (C-4)	X	X	X	X	X	

Table III-1 (Concluded)

Table III-1 (concl)

Ref. No.	Main Propulsion System - Booster & Orbiter Item	Meets LRU Criteria				LRU	
		Time	Accessibility	Calibration	Verification	Yes	No
4.4.1.2	Oxidizer Isolation Valve (V-23)	X	X	X	X	X	
4.4.2.2	Oxidizer Tank Vent Valve (V-24, V-25)	X	X	X	X	X	
4.4.2.3	Oxidizer Vent Heat Exchanger (H-1)	NO	X	X	X		X
4.4.3.1	Oxidizer Tank (Diffuser & Sump) (T-4)	NO	NO	X	X		X
4.4.4.2	Fuel Isolation Valve (V-26, V-27)	X	X	X	X	X	
4.4.5.2	Fuel Tank Vent Valve (V-28 through V-31)	X	X	X	X	X	
4.4.5.3	Fuel Vent Line Heat Exchanger (H-2, H-3)	NO	X	X	X		X
4.4.5.4	Fuel Vent Coupling (C-11)	X	X	X	X	X	
4.4.6.1	Fuel Tank (Diffuser & Sump) (T-5 & T-6)	NO	NO	X	X		X
4.5.1.2	Oxidizer Tank Pressurization Line Filter (F-4)	X	X	X	X	X	
4.5.1.3	Oxidizer Pressurization Regulator (R-5 & R-7, R-6 & R-8)	X	X	X	X	X	
4.5.1.4	Oxidizer Pressurization Valve (V-32; V-33)	X	X	X	X	X	
4.5.1.6	Fuel Tank Pressurization Line Filter (F-5)	X	X	X	X	X	
4.5.1.7	Fuel Pressurization Regulator (R-9 & R-11, R-10 & R-12)	X	X	X	X	X	
4.5.1.8	Fuel Pressurization Valve (V-34 and V-35)	X	X	X	X	X	

3. Booster Main Propulsion System (Continued)

LRU (1) LO_2 Tank Vent Package

Each vent valve package is composed of four series — parallel vent valves and is used in two places. Each valve, in addition to being a pressure relief valve, is a pneumatically controlled normally closed valve, which incorporates a positive opening and closing feature.

LRU (2) LO_2 Tank Isolation Valve

There are two of these valves per boom and they are connected at the oxidizer tank sump and to the engine distribution ducts. These valves are 18 inches in diameter and are attached by means of bolted flanges which contain sealing devices.

LRU (3) Fuel Isolation Valve

There are seven of these valves per boom and they are connected to the engine suction ducts. These valves are 14 inches in diameter and are attached by means of bolted flanges which contain sealing devices. The estimated weight of each valve is 70 lb.

LRU (4) LO_2 Prevalve

There are seven of these valves per boom and they are connected to the engine suction ducts. These valves are 10 inches in diameter and are attached by means of bolted flanges which contain sealing devices. The estimated weight of each valve is 60 lb.

LRU (5) Fuel Fill Valve

There are two of these valves in each boom and they are connected to the LH_2 fill and drain ducts. The valve functions as an emergency shutoff valve during captive firing tests and is also used to prevent backflow during engine childown.

3. Booster Main Propulsion System (Continued)

LRU (6) Fuel Autogenous Line Filter

There are two of these components on the booster and these gas filters are installed in the GH_2 autogenous pressurization line. They contain a diffuser and a removeable filter element which should be replaced after each flight.

LRU (7) Oxidizer Autogenous Line Filter

There are two of these components on the booster and these gas filters are installed in the GO_2 autogenous pressurization line. They contain a diffuser and a removeable filter element which should be replaced after each flight.

LRU (8) Fuel Pressurant Control Valve Package

These valves are used to control the pressurant flow rate of the autogenous gas to the propellant tanks in the event the primary orifice does not provide adequate control. These are solenoid operated valves.

LRU (9) Oxidizer Pressurant Control Valve Package

These valves are used to control the pressurant flow rate of the autogenous gas to the propellant tanks in the event the primary orifice does not provide adequate control. These are solenoid operated valves.

LRU (10) Oxidizer Pressurant Control Orifice

This fixed orifice controls the pressurant flow rate into the propellant tanks in each boom. It is enclosed in a flanged joint for easy removal or replacement.

LRU (11) Fuel Pressurant Control Orifice

This fixed orifice controls the pressurant flow rate into the propellant tanks in each boom. It is enclosed in a flanged joint for easy removal or replacement.

3. Booster Main Propulsion System (Continued)

LRU (12) Fuel Vent Valve Package

Each vent valve package is composed of four series-parallel vent valves and is used in two places. Each valve, in addition to being a pressure relief valve, is a pneumatically controlled normally closed valve, which incorporates a positive opening and closing feature.

LRU (13), (19) Fuel and Oxidizer Fill Line Coupling

The airborne half of this coupling consists of a mating ring with sealing surfaces. This component will require routine replacement of the mating parts.

LRU (14) Fuel Vent Line Coupling

This disconnect coupling is the airborne half of the GH_2 tank dump system coupling. It is attached to the airborne vent line by means of a mating ring with sealing surfaces.

LRU (15) Fuel Tank Prepressurization Coupling

This disconnect coupling is utilized to provide a helium connection for GSE prepressurization service. It is maintained like the other LRU couplings.

LRU (16) LO_2 Recirculation Line Coupling

This disconnect coupling is utilized to provide for ground recirculation of propellants just prior to launch. It is maintained like the other couplings.

LRU (17) LO_2 Tank Prepressurization Coupling

This disconnect coupling is utilized to provide a helium connection for GSE prepressurization service. It is maintained like the other LRU couplings.

3. Booster Main Propulsion System (Continued)

LRU (18) LO_2 Fill Valve

There are two of these valves in each boom and they are connected to the LO_2 fill and drain ducts. The valve functions as an emergency shut-off valve during captive firing tests and is also used to prevent backflow during engine chill-down.

LRU (20) Main Engine Subsystem

The high pressure, turbopump engine subsystem as defined in the DRM is composed of many assemblies, some of which are time sensitive and may require periodic maintenance. In the event that certain components in the engine that are not LRUs should fail or after the engine life cycle is passed, then a complete engine subsystem would be installed. Since there would be a base heat-shield and close-out boot that would isolate part of this engine, access panels in the rear area of each boom should be provided. The estimated weight of one complete engine is 5,370 lb. Therefore, special GSE would be required for engine removal

LRU (21) LO_2 Feed Lines

There are seven of these 10-inch ducts that are connected at the tank sump end and at the inlet to the oxidizer prevalve at the engine end. They are vacuum jacketed ducts and contain an evacuation port, a thermocouple vacuum gauge connection and a burst disc.

LRU (22) LH_2 Feed Lines

There are seven of these 14-inch ducts that are connected at the tank sump end and at the inlet to the fuel prevalve at the engine end. They are vacuum jacketed ducts and contain an evacuation port, a thermocouple vacuum gauge connection, and a burst disc.

4. Orbiter Main Propulsion System

Table III- 1 reflects all components within this system and presents the criteria matrix resulting in LRU selection. Top level LRU identification for the main propulsion system is shown in Figure III-8.

The following is a brief description of the top-level LRUs. Those LRUs which are contained within the top-level LRUs are identified in the tabular listings.

LRU (1) , (12) LO_2 and Fuel Tank Vent Package

Each vent valve package is composed of four series -- parallel vent valves and is used in one place for each propellant tank. Each valve in addition to being a pressure relief valve, is a pneumatically controlled normally closed valve, which incorporates a positive opening and closing feature.

LRU (2) , (3) LO_2 and Fuel Isolation Valve

There are four of these valves for LH_2 and three valves for LO_2. They are connected at the tank sump and to the engine distribution ducts. These valves are 14 and 10 inches in diameter and are attached by means of bolted flanges which contain sealing devices.

LRU (4) , (5) On-Orbit LO_2 and Fuel Tank Vent Package

These vent valve packages each contain two series valves. There are two of these packages on the LH_2 tankage and one package on the LO_2 tankage. The vent gases on ducted through special line heat exchanges to lower the heat leak into the on-orbit tankage.

4. Orbiter Main Propulsion System (Continued)

LRU 9, 6 On-Orbit LO_2 and Fuel Tank Pressurant Filters

There are two of these components on the orbiter, one each installed in the GH_2 and GO_2 pressurant lines. They contain a diffuser and a removeable filter element which should be replaced after each flight.

LRU 10, 7 On-Orbit LO_2 and Fuel Tank Pressurant Control Regulator Package

There are four of these regulators in series -- parallel for each propellant system. This component is a pressure regulator which incorporates a relief valve.

LRU 11, 8 On-Orbit LO_2 and Fuel Tank Pressurant Shut-off Valve

There are two of these valves in parallel for each propellant system. This solenoid actuated valve contains a set of orifices that permits slow passage of gas through the valve and acts to prevent overpressurization of the pressurization line upstream of the valve.

LRU 13, 21 LO_2 and Fuel Tank Prepressurization Coupling

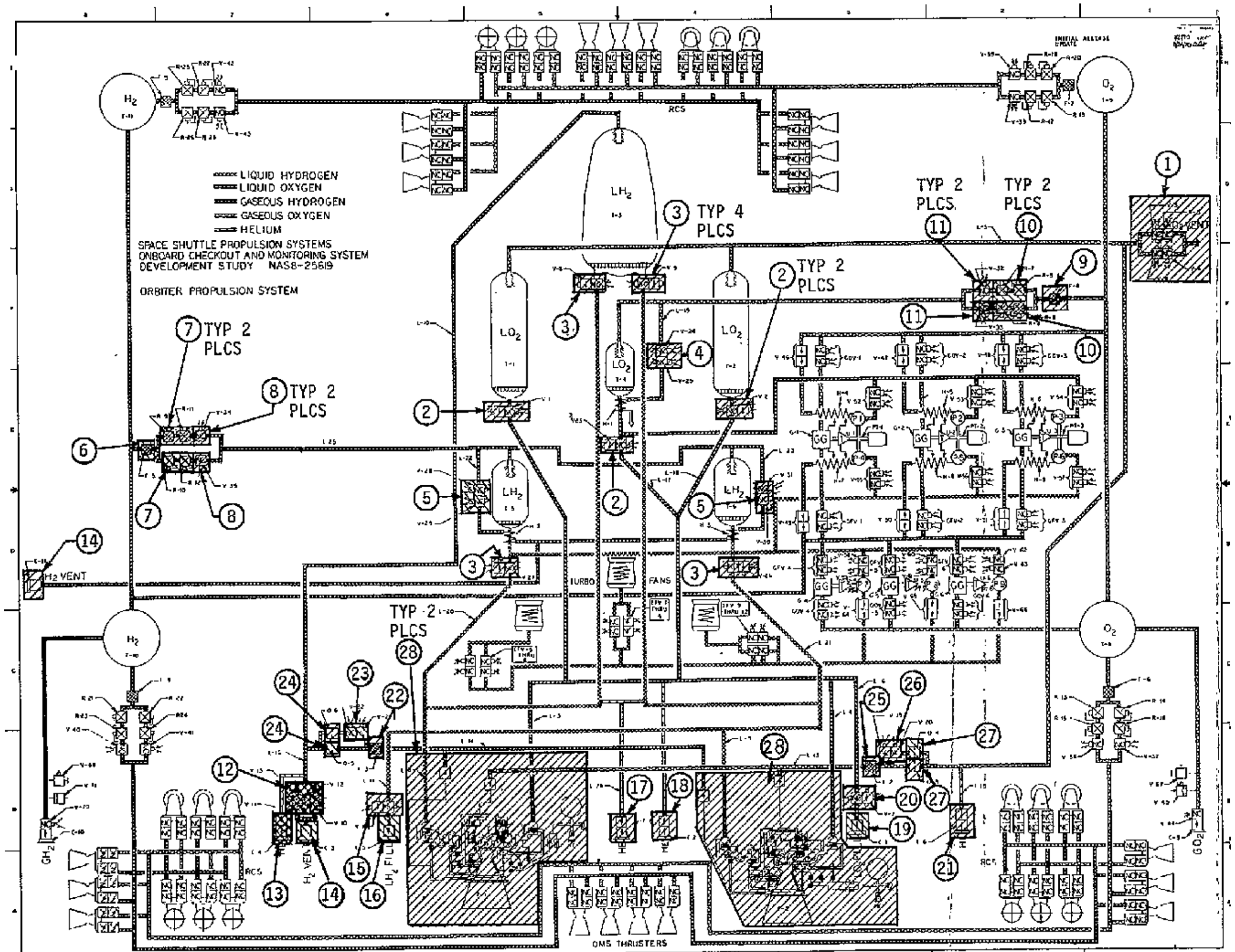
These disconnect couplings are utilized to provide a helium connection for GSE prepressurization service. They are maintained like the other LRU couplings.

LRU 14 Fuel Tank Vent Coupling

This disconnect coupling is the airborne half of the GH_2 tank dump system coupling. It is attached to the airborne vent line by means of a mating ring with sealing surfaces.

LRU 15, 20 LO_2 and Fuel Fill Valve

There are two of these valves in the orbiter and they are connected to the LH_2 and LO_2 fill and drain ducts. The valve functions as an emergency shutoff valve during captive firing tests and is also used to prevent backflow during engine chilldown.



ORBITER - MAIN PROPULSION SYSTEM

LINE REPLACEABLE UNITS (TOP LEVEL)

LRU NUMBER	DESCRIPTION
1	Main LO_2 Tank Vent Valve Package
2	LO_2 Isolation Valve
3	Fuel Isolation Valve
4	On-Orbit LO_2 Tank Vent Package
5	On-Orbit Fuel Tank Vent Package
6	On-Orbit Fuel Tank Pressurant Line Filter
7	On-Orbit Fuel Tank Pressurant Control Regulator Package
8	On-Orbit Fuel Tank Pressurant Shutoff Valve
9	On-Orbit LO_2 Tank Pressurant Line Filter
10	On-Orbit LO_2 Tank Pressurant Control Regulator Package
11	On-Orbit LO_2 Tank Pressurant Shutoff Valve
12	Fuel Tank Vent Valve Package
13	Fuel Tank Prepressurization Coupling
14	Fuel Tank Vent Coupling
15	Fuel Fill Valve
16	Fuel Fill Coupling
17	Fuel Recirculation Line Coupling
18	LO_2 Recirculation Line Coupling
19	LO_2 Fill Coupling
20	LO_2 Fill Valve
21	LO_2 Tank Prepressurization Coupling
22	Fuel Autogenous Line Filter
23	Fuel Pressurant Control Valve Package
24	Fuel Pressurant Control Orifice
25	Oxid Autogenous Line Filter
26	Oxid Pressurant Control Valve
27	Oxid Pressurant Control Orifice
28	Main Engine

Figure III-8 Orbiter Main Propulsion System LRUs

FOLDOUT FRAME 1

FOLDOUT FRAME

FOLDOUT FRAME 2

4. Orbiter Main Propulsion System (Continued)

LRU (16) , (19) LO_2 and Fuel Fill Coupling

The airborne half of these couplings consist of a mating ring with sealing surfaces. These components will require routine replacement of the mating parts.

LRU (17) , (18) LO_2 and Fuel Recirculation Line Coupling

These disconnect couplings are utilized to provide for ground recirculation of propellants just prior to launch. They are maintained like the other couplings.

LRU (22) , (25) LO_2 and Fuel Autogenous Line Filters

There are two of these components on the orbiter and these gas filters are installed in the GH_2 and GO_2 autogenous pressurization lines. They contain a diffuser and a removeable filter element which should be replaced after each flight.

LRU (23) , (26) Oxidizer and Fuel Pressurant Control Valve Package

These valves are used to control the pressurant flow rate of the autogenous gas to the propellant tanks in the event the primary orifice does not provide adequate control. These are solenoid operated valves.

LRU (24) , (27) Oxidizer and Fuel Pressurant Control Orifice

These fixed orifices control the pressurant flow rate into the propellant tanks. They are enclosed in a flanged joint for easy removal or replacement.

4. Orbiter Main Propulsion System (Continued)

LRU 28 Orbiter Main Engine

The high pressure, turbopump engine subsystem as defined in the DRM is composed of many assemblies, some of which are time sensitive and may require periodic maintenance. In the event that certain components in the engine that are not LRUs should fail or after the engine life cycle is passed, then a complete engine subsystem would be installed. Since there would be a base heat-shield and close-out boot that would isolate part of this engine, access panels in the rear area of each boom should be provided. The estimated weight of one complete engine is 5,370 lb. Therefore, special GSE would be required for engine removal. Additional ground equipment will be required for the extendable nozzle skirt on the orbiter engine.

5. Booster Auxiliary Propulsion System

Top level LRU identification for the APS is shown schematically in Figure III-9. Table III-2 reflects all components within this system and presents the criteria matrix resulting in LRU selection. The following is a brief description of the top-level LRUs. Those LRUs which are contained within the top-level LRUs are identified in the tabular listings.

LRU (1) RCS/Separation Engine Package

The RCS/Separation Engine Package consists of a thrust chamber assembly, ignition assembly and valve assembly. Under the ground rules established for determining a LRU, which states that the unit must be replaceable in the system with no change in system balance, and further, that the integrity of the replaced unit can be verified, the engine package will be removed as a single unit. The package includes the propellant valves, igniter assembly, and instrumentation, together with the thruster injector and chamber. The replacement of components on the package would be very difficult with the unit installed on the vehicle with the limitations of space and the inability to verify the component-to-vehicle-line-interface seal integrity once a component change had been made.

LRU (2)(3) GH_2 and GO_2 Filter

The oxygen and hydrogen gas filters are approximately eight inches long and are compatible with two to three inch lines and weigh approximately 3 pounds. The filter element is of the double weave wire cloth or etches disc type. The gas filters are brazed to the propellant distribution lines.

LRU (4)(5) GH_2 and GO_2 Solenoid Valve

The GH_2 solenoid valve is brazed to three inch propelland feed lines and weighs approximately 12 pounds. The GO_2 solenoid valve is brazed to three inch propelland feed lines and weighs approximately 10 pounds. Each solenoid valve has electrical connectors for electrical actuation and valve position instrumentation.

5. Booster Auxiliary Propulsion System (Continued)

LRU 6 GH_2 Check Valve Package

The GH_2 check valve package consists of two series redundant check valves welded to two inch propellant lines. The check valve package is brazed to two inch propellant lines in the Booster Hydrogen Conditioning Subsystem and Orbiter Propellant Conditioning Subsystem Gas Generator Assemblies. The check valve package is approximately 16 inches long and weighs approximately 1 pound.

LRU 7 Gas Generator GH_2 Propellant Valve Package

The gas generator GH_2 propellant valve package consists of two series redundant solenoid valves (main fuel valve and isolation valve) welded to two inch lines and weighs approximately 20 pounds. The valve package is brazed to two inch propellant lines in the Booster Hydrogen and Oxygen Conditioning Subsystems, Booster APU, and Orbiter Propellant Conditioning Subsystem Gas Generator Assemblies. Each solenoid valve has electrical actuation and valve position instrumentation connectors.

LRU 8 Gas Generator GO_2 Propellant Valve Package

The gas generator GO_2 propellant valve package consists of two series redundant solenoid valves (main oxidizer and isolation valve) welded to 1/2 inch lines and weighs approximately 15 pounds. The valve package is brazed to 1/2 inch propellant lines in the Booster Hydrogen and Oxygen Conditioning Subsystems, Booster APU, and Orbiter propellants conditioning subsystem gas generator assemblies. Each solenoid valve has electrical actuation and valve position instrumentation connectors.

LRU 9 LH_2 Check Valve Package

The LH_2 check valve package consists of two series redundant check valves welded to three inch propellant lines. The check valve package is brazed to three inch propellant lines in the Booster Hydrogen Conditioning Subsystem turbopump assembly. The check valve package is approximately 20 inches long and weighs approximately 2 pounds.

LRU 10 Turbopump

The booster turbopump consists of a LH_2 pump, turbine, gearbox, and lubrication system. The turbopump weighs approximately 250 pounds and flanges are provided on

5. Booster Auxiliary Propulsion System (Continued)

the turbine and pump for mounting to the vehicle structure. Three inch pump suction and discharge lines are brazed to the pump inlet and outlet. Electrical connectors are provided for pump and turbine speed and lubrication system temperature.

LRU (11) Turbopump Suction Valve Package

The turbopump suction valve package and LH_2 pump suction valve package consists of two series redundant solenoid valves (suction and isolation valves) welded to three inch and two inch lines respectively. The valve package weighs approximately 20 pounds. The valve package is brazed to pump suction lines in the Booster Hydrogen Conditioning and Orbiter Propellant Conditioning Subsystem turbopump assemblies. Each solenoid valve has electrical actuation and valve position instrumentation connectors.

LRU (12) Gas Generator/Heat Exchanger Package

The gas generator/heat exchanger package weighs approximately 50 pounds and has flanges for mounting to the turbine inlet duct. Mounting pads are also supplied for mounting to the vehicle structure. The heat exchanger inlet and outlet lines and gas generator propellant line connections are brazed. Electrical connectors are supplied for heat exchanger and gas generator pressure and temperature instrumentation and control.

LRU (13) LH_2 Solenoid Valve Package

The LH_2 Solenoid Valve Package consists of two series redundant solenoid valves (accumulator resupply valve and isolation valve) welded to three inch lines and weighs approximately 20 pounds. The valve package is brazed to three inch lines in the Booster Hydrogen Conditioning Subsystem turbopump assemblies. Each solenoid valve has electrical actuation and valve position instrumentation connectors.

LRU (14) Gas Generator

The gas generator weighs approximately 25 pounds and has flanges for mounting to the turbine inlet duct. Mounting pads are also aupplied for mounting to the vehicle structure. The gas generator GO_2 propellant inlet is brazed to 1/2 inch line and the GH_2 propellant inlet is brazed to 2 inch line. Electrical connectors are supplied for igniter power, igniter valve control, and pressure and temperature control.

5. Booster Auxiliary Propulsion System (Continued)

LRU (15) Compressor GO_2 Inlet Valve Package

The compressor GO_2 inlet valve package consists of two series redundant solenoid valves (GO_2 propellant valve and isolation valve) welded to one inch lines and weighs approximately 15 pounds. The valve package is brazed to one inch propellant lines in the Booster Oxygen Conditioning Subsystem turbocompressor assemblies. Each solenoid valve has electrical actuation and valve position instrumentation connectors.

LRU (16) Turbocompressors

The booster turbocompressor weighs approximately 200 pounds and has flanged inlets and outlets to permit mounting to the gas generator, overboard ducting, and GO_2 inlet and outlet lines. Mounting pads are also supplied for mounting to the vehicle structure. An electrical connector is supplied for turbine and compressor instrumentation.

LRU (17) GO_2 Check Valve Package

The GO_2 check valve package consists of two series redundant check valves welded to one inch (booster) or two inch (orbiter) propellant lines. The check valve package is brazed to propellant lines in the Booster Oxygen Conditioning and Orbiter Propellant Conditioning Subsystems. The check valve package is approximately 12 inches long and weighs approximately 1 pound.

LRU (18) Turbine

The turbine weighs approximately 85 pounds and has a flanged inlet and outlet to permit mounting to the gas generator and overboard dump ducting. Mounting pads are also supplied for mounting to the vehicle structure. An electrical connector is supplied for turbine instrumentation.

LRU (19) GO_2 Manual Valve

The GO_2 manual valve is brazed to two inch propellant fill lines and weighs approximately 1 3/4 pounds.

LRU (20) GO_2 Relief Valve

The GO_2 relief valve is brazed to two inch propellant fill lines and weighs approximately 1 3/4 lbs.

5. Booster Auxiliary Propulsion System (Continued)

LRU 21 GO_2 Quick Disconnect/Solenoid Valve Package

The quick-disconnect/solenoid valve package consists of a quick-disconnect coupling in series with a solenoid valve. The components are welded to two inch lines and weighs approximately 12 pounds. The package is brazed to propellant fill lines in the propellant fill assemblies. Each solenoid valve has electrical connectors for electrical actuation. Mounting flanges are supplied on the quick-disconnect coupling for bolting to the vehicle structure.

LRU 22 GH_2 Manual Valve

The GH_2 Manual Valve is brazed to a three inch propellant fill line and weighs approximately 2 pounds.

LRU 23 GH_2 Relief Valve

The GH_2 Relief Valve is brazed to a three inch propellant fill line and weighs approximately 2 pounds.

LRU 24 GH_2 Quick Disconnect/Solenoid Valve Package

The LRU package is similar to LRU 21. The components are welded to three inch lines and the assembly weighs approximately 15 pounds.

LRU 25, 26 GO_2/GH_2 Regulator Package

The regulator package consists of two series redundant regulators. The regulators are welded to two to three inch connecting lines. Threaded connectors are provided downstream of each regulator for 1/4 inch sensing lines. The regulator package is brazed to two or three inch propellant lines in the Propellant Management Subsystem accumulator assemblies. Each regulator is supplied with electrical connectors for actuation and instrumentation. Each package weighs approximately 40 pounds and is supplied with mounting pads for bolting to the vehicle structure.

Table III-2 Auxiliary Propulsion System LRUs

Ref. No.	Auxiliary Propulsion System - Booster Item	Meet LRU Criteria				LRU	
		Time	Accessibility	Calibration	Verification	Yes	No
2.2.1.1	Accumulator Tank (T-4 through T-11)	NO	NO	X	X		X
2.2.1.2	Filter (F-4 through F-11)	X	X	X	X	X	
2.2.1.3	Regulator (R-5 through R-36)	X	X	X	X	X	
2.2.1.4	Solenoid Valve (V-29 through V-44)	X	X	X	X	X	
2.2.2.1	Quick Disconnect Coupling (C-8, C-9)	X	X	X	X	X	
2.2.2.2	Solenoid Valve (V-79, V-80)	X	X	X	X	X	
2.2.2.3	Relief Valve (V-25, V-27)	X	X	X	X	X	
2.2.2.4	Manual Valve (V-26, V-28)	X	X	X	X	X	
2.3.1.1	Turbine (U-1 through U-3)	X	X	X	X	X	
2.3.1.2	Power Train (PT-1 through PT-3)	X	X	X	X	X	
2.3.1.3	Pump (P-1 through P-3)	X	X	X	X	X	
2.3.1.4	LH_2 Solenoid Valve (V-90, V-91, V-92, V-93, V-94, V-63)	X	X	X	X	X	
2.3.1.5	LH_2 Check Valve (V-64 through V-69)	X	X	X	X	X	
2.3.1.6	GH_2 Accumulator Resupply Subassembly						
2.3.1.6.1	Heat Exchanger (H-1 through H-3)	X	NO	X	X		X
2.3.1.6.2	LH_2 Solenoid Valve (V-45 through V-50)	X	X	X	X	X	
2.3.2.1	Gas Generator (G-1 through G-3)	X	X	X	X	X	
2.3.2.2	Heat Exchanger (H-4 through H-6)	X	X	X	X	X	
2.3.2.3	GH_2 Solenoid Valve (GFV-1 through GFV-3)	X	X	X	X	X	
2.3.2.4	GO_2 Solenoid Valve (GOV-1 through GOV-3)	X	X	X	X	X	
2.3.2.5	GH_2 Check Valve (V-51 through V-53, V-95 through V-97)	X	X	X	X	X	
2.4.1.1	Turbine (U-4 through U-6)	X	X	X	X	X	
2.4.1.2	Power Train (PT-4 through PT-6)	X	X	X	X	X	
2.4.1.3	Compressor (CV-1 through CV-3)	X	X	X	X	X	
2.4.1.4	GO_2 Check Valve (V-54 through V-56, V-85 through V-87)	X	X	X	X	X	
2.4.1.5	GO_2 Solenoid Valve (V-57 through V-62)	X	X	X	X	X	
2.4.2.1	Gas Generator (G-4 through G-6)	X	X	X	X	X	
2.4.2.2	GO_2 Solenoid Valve (GOV-4 through GOV-6)	X	X	X	X	X	
2.4.2.3	GH_2 Solenoid Valve (GFV-4 through GFV-6)	X	X	X	X	X	
2.6.1.1	Gas Generator (G-7 through G-9)	X	X	X	X	X	
2.6.1.2	Turbine (X-1 through X-3)	X	X	X	X	X	
2.6.1.3	Power Train (PT-1 through PT-3)	X	X	X	X	X	
2.6.1.4	GH_2 Solenoid Valve (GFV-7 through GFV-9)	X	X	X	X	X	
2.6.1.5	GO_2 Solenoid Valve (GOV-7 through GOV-9)	X	X	X	X	X	

Table III-2 (Concluded)

Ref No.	Auxiliary Propulsion System - Booster and Orbiter Item	Meets LRU Criteria Time	Accessibility	Calibration	Verification	LRU Yes	No
2.1, 5.1	RCS Engine Subsystem	X	X	X	X	X	
2.1.1, 5.1.1	Thrust Chamber Assembly	X	NO*	X	NO		X
2.1.2, 5.1.2	Ignition Assembly	X	NO*	X	NO		X
2.1.3, 5.1.3	Valve Assembly	X	NO*	X	NO		X
2.5	APS Separation Engine Subsystem	X	X	X	X	X	
2.5.1	Thrust Chamber Assembly	X	NO*	X	X		X
2.5.2	Ignition Assembly	X	NO*	X	X		X
2.5.3	Valve Assembly	X	NO*	X	X		X
5.4	OMS Engine Subsystem	X	X	X	X	X	
5.4.1	Thrust Chamber Assembly	X	NO*	X	X		X
5.4.2	Ignition Assembly	X	NO*	X	X		X
5.4.3	Valve Assembly	X	NO*	X	X		X

*The components on the thrusters will, in all probability, be inaccessible; the thruster interfaces will be designed such that each thruster is readily replaceable, however.

Ref. No.	Auxiliary Propulsion System - Orbiter Item	Meets LRU Criteria Time	Accessibility	Calibration	Verification	LRU Yes	No
5.2.1.1	Accumulator Tank (T-8 through T-11)	NO	NO	X	X		X
5.2.1.2	Filter (F-6 through F-9)	X	X	X	X	X	
5.2.1.3	Regulator (R-13 through R-28)	X	X	X	X	X	
5.2.1.4	Solenoid Valve (V-36 through V-43)	X	X	X	X	X	
5.2.2.1	Quick Disconnect Coupling (C-9, C-10)	X	X	X	X	X	
5.2.2.2	Solenoid Valve (V-44, V-70)	X	X	X	X	X	
5.2.2.3	Relief Valve (V-45, V-71)	X	X	X	X	X	
5.2.2.4	Manual Valve (V-67, V-68)	X	X	X	X	X	
5.3.1.1	Gas Generator (G-1 through G-3)	X	X	X	X	X	
5.3.1.2	Heat Exchanger (H-4 through H-9)	X	X	X	X	X	
5.3.1.3	GO_2 Solenoid Valve (GOV-1 through GOV-3)	X	X	X	X	X	
5.3.1.4	GH_2 Solenoid Valve (GFV-1 through GFV-3)	X	X	X	X	X	
5.3.1.5	GO_2 Check Valve (V-46 through V-48)	X	X	X	X	X	
5.3.1.6	GH_2 Check Valve (V-49 through V-51, V-80 through V-85)	X	X	X	X	X	
5.3.2.1	Turbine (U-1 through U-3)	X	X	X	X	X	
5.3.2.2	Power Train (PT-1 through PT-3)	X	X	X	X	X	
5.3.2.3	Pump (P-1 through P-6)	X	X	X	X	X	
5.3.2.4	LO_2 Solenoid Valve (V-52 through V-54)	X	X	X	X	X	
5.3.2.5	LH_2 Solenoid Valve (V-55 through V-57)	X	X	X	X	X	

6. Orbiter Auxiliary Propulsion System

Table III-2 reflects all components within this system and presents the criteria matrix resulting in LRU selection. Top level LRU identification for the APS is shown schematically in Figure III-10.

The following is a brief description of the top-level LRUs. Those LRUs which are contained within the top-level LRUs are identified in the tabular listings.

LRU (1) RCS/OMS Engine Package

The definitions, removal, replacement and retest, procedures are similar to those defined for LRU (1) of the Booster Auxiliary Propulsion System.

LRU (2)(3) GH_2 and GO_2 Filter

The definitions, removal, replacement and retest procedures are similar to those defined for LRU (2), (3) of the Booster Auxiliary Propulsion System.

LRU (4)(5) GH_2 and GO_2 Solenoid Valve

The definitions, removal, replacement and retest procedures are similar to those defined for LRU (4), (5) of the Booster Auxiliary Propulsion System.

LRU (6) GH_2 Check Valve Package

The definitions, removal, replacement and retest procedures are similar to those defined for LRU (6) of the Booster Auxiliary Propulsion System.

LRU (7) Gas Generator GH_2 Propellant Valve Package

The definitions, removal, replacement and retest procedures are similar to those defined for LRU (7) of the Booster Auxiliary Propulsion System.

LRU (8) Gas Generator GO_2 Propellant Valve Package

The definitions, removal, replacement and retest procedures are similar to those defined for LRU (8) of the Booster Auxiliary Propulsion System.

LRU (9) LH_2 Pump

The orbiter LH_2 pump weighs approximately 40 pounds and is bolted to the gear box housing of the turbopump assembly on the Propellant Conditioning Subsystem and the vehicle structure. Two inch pump suction and discharge lines are brazed to the pump inlet and outlet. Electrical connectors are provided for pump speed instrumentation.

6. Orbiter Auxiliary Propulsion System (Continued)

LRU (10) LO_2 Pump

The Orbiter LO_2 Pump weighs approximately 40 pounds and is bolted to the gearbox housing of the turbopump assembly on the Propellant Conditioning Subsystem and the vehicle structure. Two inch pump suction and discharge lines are brazed to the pump inlet and outlet. Electrical connectors are provided for pump speed instrumentation.

LRU (11) LO_2 Heat Exchanger

The LO_2 heat exchanger weighs approximately 23 pounds and has flanges for mounting to the turbine exhaust and overboard ducting. The heat exchanger inlet and outlet lines are brazed to 1/2 inch LO_2 lines. Electrical connectors are supplied for heat exchanger pressure and temperature instrumentation.

LRU (12) LH_2 Heat Exchanger

The LH_2 heat exchanger weighs approximately 23 pounds and has flanges for mounting to the turbine exhaust and overboard ducting. The heat exchanger inlet and outlet lines are brazed to two inch LH_2 lines. Electrical connectors are supplied for heat exchanger pressure and temperature instrumentation.

LRU (13) Power Train Unit

The power train unit weighs approximately 125 pounds and has flanges for mounting of LH_2 and LO_2 pumps. Mounting pads are supplied for bolting to structural members. The lubrication system and electrical harness connector are mounted to the gearbox housing. Spline connectors are used to connect the power shafts to the APU and turbine of the Orbiter Propellant Conditioning subsystem.

LRU (14) Gas Generator

The definitions, removal, replacement and retest procedures are similar to those defined for LRU (14) of the Booster Auxiliary Propulsion System.

LRU (15) Turbine

The definitions, removal, replacement and retest procedures are similar to those defined for LRU (18) of the Booster Auxiliary Propulsion System.

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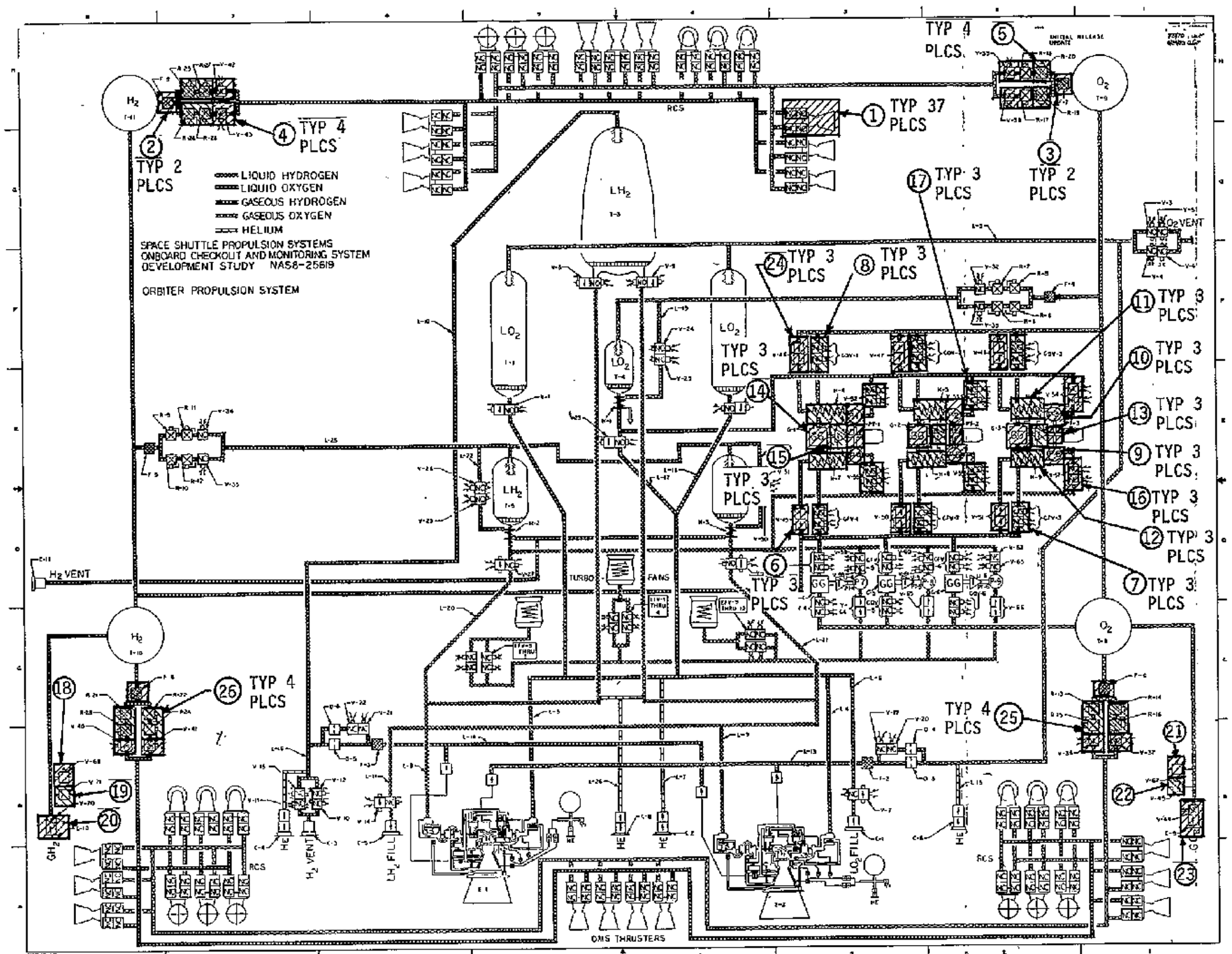

ORBITER AUXILIARY PROPULSION SYSTEM

LINE REPLACEABLE UNITS (TOP LEVEL)

LRU NUMBER	DESCRIPTION
1	RCS/OMS Engine Package
2	GH_2 Filter
3	GO_2 Filter
4	GH_2 Solenoid Valve
5	GO_2 Solenoid Valve
6	GH_2 Check Valve Package
7	Gas Generator GH_2 Propellant Valve Package
8	Gas Generator GO_2 Propellant Valve Package
9	LH_2 Pump
10	LO_2 Pump
11	LO_2 Heat Exchanger
12	LH_2 Heat Exchanger
13	Power Train Unit
14	Gas Generator
15	Turbine
16	LH_2 Pump Suction Valve Package
17	LO_2 Pump Suction Valve Package
18	GH_2 Manual Valve
19	GH_2 Relief Valve
20	GH_2 Quick Disconnect/Solenoid Valve Package
21	GO_2 Manual Valve
22	GO_2 Relief Valve
23	GO_2 Quick Disconnect/Solenoid Valve Package
24	GO_2 Check Valve Package
25	GO_2 Regulator Package
26	GH_2 Regulator Package

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Figure III-10

FOLDOUT FRAME 1

FOLDOUT FRAME 2

6. Orbiter Auxiliary Propulsion System (Continued)

LRU 16 LH_2 Pump Suction Valve Package

The definitions, removal, replacement and retest procedures are similar to those defined for LRU 11 of the Booster Auxiliary Propulsion System.

LRU 17 LO_2 Pump Suction Valve Package

The LO_2 pump suction valve package consists of two series redundant solenoid valves (suction and isolation) welded to two inch lines. The valve package weighs approximately 20 pounds. The valve package is brazed to pump suction lines in the Orbiter Propellant Conditioning Subsystem turbopump assemblies. Each solenoid valve has electrical actuation and valve position instrumentation connectors.

LRU 18 GH_2 Manual Valve

The definitions, removal, replacement and retest procedures are similar to those defined for LRU 22 of the Booster Auxiliary Propulsion System.

LRU 19 GH_2 Relief Valve

The definitions, removal, replacement and retest procedures are similar to those defined for LRU 23 of the Booster Auxiliary Propulsion System.

LRU 20 GH_2 Quick Disconnect/Solenoid Valve Package

The definitions, removal, replacement and retest procedures are similar to those defined for LRU 24 of the Booster Auxiliary Propulsion System.

LRU 21 GO_2 Manual Valve

The definitions, removal, replacement and retest procedures are similar to those defined for LRU 19 of the Booster Auxiliary Propulsion System.

LRU 22 GO_2 Relief Valve

The definitions, removal, replacement, and retest procedures are similar to those defined for LRU 20 of the Booster Auxiliary Propulsion System.

6. Orbiter Auxiliary Propulsion System (Continued)

LRU 23 GO_2 Quick Disconnect/Solenoid Valve Package

The definitions, removal, replacement and retest procedures are similar to those defined for LRU 21 of the Booster Auxiliary Propulsion System.

LRU 24 / 25 GO_2/GH_2 Regulator Package

The definitions, removal, replacement and retest procedures are similar to those defined for LRU 24 / 25 of the Booster Auxiliary Propulsion System.

7. Booster Airbreathing System

Table III-3 reflects all components within this system and presents the criteria matrix resulting in LRU selection. Top level LRU identification for the system is shown schematically in Figure III-11.

The following is a brief description of the top-level LRUs. Those LRUs which are contained within the top-level LRUs are identified in the tabular listings.

LRU (1) Turbofan Engine Subsystem

The turbofan engine subsystem as previously defined is composed on several assemblies (refer to Section IIC) some of which are time sensitive and may require periodic maintenance. Should a failure occur or periodic maintenance be required in the engine power assembly, it is probable that a complete new turbofan engine subsystem would be installed; however, turbofan engine LRUs are shown in Figure III-12. Since each of the seven turbofan engine subsystems is contained in its own wing compartment one subsystem can be removed with minimum effect on the other six subsystems. The estimated weight of one complete turbofan engine subsystem is 2200 lb. Therefore, ground support handling equipment would be required for engine removal.

LRU (2) Turbofan Inlet Valve Package

The valve package is composed of four series -- parallel solenoid valves and is used seven places. The package is fabricated with welded connections between the tubing and the solenoid valves. The welded assembly is installed into the vehicle with brazed sleeves. The tubing and valve inlet/outlet sizes are estimated at 0.5 in. O.D. The estimated weight of the package is 25 lb.

7. Booster Airbreathing System (Continued)

LRU (3) Cruise Tank Fuel Distribution Valve Package

The valve package consists of four series-parallel solenoid valves, joined with welded connections between the tubing and the solenoid valves. The welded assembly is installed into the vehicle with brazed sleeves. The tubing and valve inlet/outlet sizes are estimated at 4 in. O.D. The estimated weight of the package is 50 lb.

LRU (4) Cruise Tank Vent Valve Package

The valve package is composed of four series-parallel solenoid valves. The package is fabricated with welded connections between the tubing and the solenoid valves. The welded assembly is installed into the vehicle with brazed sleeves. The tubing and valve inlet/outlet sizes are estimated at 5 in. O.D. The estimated weight of the package is 60 lb.

LRU (5) Cruise Tank Vent Disconnect Coupling

This device is the airborne half of the GH_2 cruise tank GSE dumping system coupling. It is attached to the airborne vent transfer line by means of a bolted flange containing a sealing mechanism. The vent line tubing and corresponding attachment to the coupling are estimated at 5 in. O.D. The estimated airborne coupling weight is 20 lb.

LRU (6) Cruise Tank Fill Valve

This LRU has an estimated inlet/outlet size adaptable to 6-in. O.D. transfer lines. The valve is installed into the vehicle with bolted flanges which contain sealing devices. The estimated weight of the LRU is 30 lb.

LRU (7) Cruise Tank Fill Coupling

The coupling is the airborne half for the LH_2 cruise tanks GSE fill and drain system. The coupling is attached to the estimated 6-in. O.D. transfer lines by means of bolted flanges which contain sealing devices. The estimated weight of the airborne coupling is 25.

7. Booster Airbreathing System (Continued)

LRU (8) Cruise Tank Pressurization Regulator Package

The LRU package is composed of two regulators in series. The regulators and tubing are connected by welded joints. The regulator downstream sensing mechanism is connected to the downstream tubing with threaded plumbing tubing connections. The sensing line is estimated as ¼-in. O.D. tubing. The regulator inlet/outlet is sized for an estimated 2-in. O.D. tubing. The package is installed in the vehicle with brazed sleeves. The LRU estimated weight is 40 lb.

LRU (9) Cruise Tank Pressurization Valve Package

The LRU consists of two parallel mounted solenoid operated valves. The valves are installed in the vehicle with brazed sleeves. The valve inlet/outlet configuration is an estimated 2 in. O.D. tubing. The estimated LRU weight is 15 lb.

LRU (10) Pressurization Filter

The LRU is a single filter. The filter is installed into the vehicle with brazed sleeves. The inlet/outlet filter configuration is 2-in. O.D. tubing. The estimated LRU weight is 3 lb.

7. Booster Airbreathing System (Continued)

Turbofan Engine Subsystem

LRU (1) Engine Power Assembly

The Engine Power Assembly is composed of rotating machinery which is critical from an alignment and installation viewpoint. This criticality precludes in-place replacement of specific hardware. Replacement of failed hardware or periodic maintenance is best achieved through removal and replacement of the complete Turbofan Engine Subsystem. The removal, replacement and retest requirements for the Turbofan Engine Subsystem are as defined for LRU (1) of part a.

LRU (2) Fuel Control Assembly

The Fuel Control Assembly will be split into two modular packages which are mounted either directly on the Engine Power Assembly or on the engine compartment structure. One of the modular packages is the Electronic Controller, which will be mounted on the structure. The LRU description for the Electronic Controller is given below. The other modular package is composed of the fuel inlet valve, pump, and other hardware which supply GH_2 to the engine burner (refer to Figure III-12). These hardware will be modular mounted on the Engine Power Assembly. Because of the critical nature of the latter hardware and the dependence of proper operation of one component on the output of another component, it is assumed that failure of one component will necessitate "bench" recalibration of some other component at the time the failed component is replaced. Therefore, failure of any component in this modular package will require replacement of the entire package. Since the Electronic Controller depends upon component calibration data the Electronic Controller will be replaced anytime the modular component package is replaced. Thus, a totally "bench" calibrated Fuel Control System will be on board the vehicle at all times. The estimated weight of the modular component package is 150 lb.

7. Booster Airbreathing System (Continued)

LRU (3) Electronic Controller

As indicated above the Electronic Controller is structure-mounted in the engine compartment. The controller will be mounted in such a manner as to isolate it from the extraneous inputs that would impair or preclude function. An Electronic Controller failure will require that the replacement part be programmed with the acceptance test and calibration data that is unique to the Fuel Control Assembly and/or the Engine Power Assembly components. The estimated weight of the Electronic Controller is 80 lb.

LRU (4) Scavenge Pump

Five Scavenge Pumps are used. The pumps are modular mounted and when one pump fails the entire module is replaced. Six connections are broken for module replacement. The assembly is welded and the welded assembly is mounted to the Engine Power Assembly with brazed sleeves. The weight of the module is estimated at 40 lb.

LRU (5) Oil Boost Pump

The Oil Boost Pump is mounted to the Engine Power Assembly and plumbing connections are made with brazed sleeves. The estimated weight of the Oil Boost Pump is 10 lb.

LRU (6) Oil Pressure Pump

The Oil Pressure Boost Pump is mounted to the Engine Power Assembly and plumbing connections are made with brazed sleeves. The estimated weight of the Oil Pressure Pump is 10 lb.

LRU (7) Oil Strainer

Five Oil Strainers are used and are mounted external to the Engine Power Assembly. Each oil strainer has removal and replacement capability. The oil strainers are installed in the plumbing lines with threaded connectors. The estimated weight of each strainer is 1/2 lb.

7. Booster Airbreathing System (Continued)

LRU (8) Boost Pump Relief Valve

The Boost Pump Relief Valve is mounted on the Engine Power Assembly and plumbing connections are made with brazed sleeves. The estimated weight of the valve is 1 lb.

LRU (9) Boost Pump Regulating Valve

The Boost Pump Regulating Valve is mounted on the Engine Power Assembly and plumbing connections are made with brazed sleeves. The estimated weight of the valve is 1 lb.

LRU (10) Main Pressure Regulating Valve

The Main Pressure Regulating Valve is mounted on the Engine Power Assembly and plumbing connections are made with brazed sleeves. The estimated weight of the valve is 1 lb.

LRU (11) Zero "G" Tube Pressure System

This system does not exist on the Booster Turbofan Engine Subsystem.

LRU (12) Ignition Exciter

The Ignition Exciter is mounted on the Engine Power Assembly. Electrical connections are made with quick connect couplings. The estimated weight of the Exciter is 2 lb.

LRU (13) Ignition Compositor

The Ignition Compositor is mounted on the Ignition Exciter. Electrical connections are made with quick connect couplings. The estimated weight of the Compositor is 1/2 lb.

LRU (14) Ignition Plug

The Ignition Plug is mounted directly on the burner of the Engine Power Assembly. Electrical connections are made with quick connect couplings. The estimated weight of the Plug is 1/2 lb.

7. Booster Airbreathing System (Concluded)

LRU (15) Solid Start Cartridge

The Solid Start Cartridge is mounted in the Engine Power Assembly on the external structure of the high pressure turbine. Electrical connections are made with quick connect couplings. The estimated weight of the Cartridge is 2 lb.

Table III-3 Booster Airbreathing System LRUs

Ref. No.	Airbreatning Propulsion-Booster Item	Meets LRU Criteria				LRU	
		Time	Accessibility	Calibration	Verification	Yes	No
3.1	Engine Power Assembly	X	X	X	X	X	
3.1.1.1	Fan						X
3.1.1.2	Low Pressure Compressor	X	X	NO	NO		X
3.1.1.3	High Pressure Compressor	X	X	NO	NO		X
3.1.1.4	Burner	X	X	NO	NO		X
3.1.1.5	High Pressure Turbine	X	X	NO	NO		X
3.1.1.6	Low Pressure Turbine	X	X	NO	NO		X
3.1.2	Fuel Control Assembly	X	X	X	X	X	
3.1.2.1	Inlet Shutoff Valve						X
3.1.2.2	Variable Displacement Vane Pump	X	X	NO	NO		X
3.1.2.3	Cooldown and Pressure Relief Valve	X	X	NO	NO		X
3.1.2.4	Fuel Heater	X	X	NO	NO		X
3.1.2.5	Flowmeter	X	X	NO	NO		X
3.1.2.6	Shutoff and Dump Valve	X	X	NO	NO		X
3.1.2.7	Electronic Controller	X	X	X	X	X	
3.1.3.1	Scavenge Pumps	X	X	X	X	X	
3.1.3.2	Oil Boost Pumps	X	X	X	X	X	
3.1.3.3	Oil Strainers	X	X	X	X	X	
3.1.3.4	Boost Pumps Relief Valve	X	X	X	X	X	
3.1.3.5	Boost Pump Regulating Valve	X	X	X	X	X	
3.1.3.6	Main Pressure Regulating Valve	X	X	X	X	X	
3.1.4.1	Solid Start Cartridge	X	X	X	X	X	
3.1.5.1	Igniter Plug	X	X	X	X	X	
3.1.5.2	Ignition Compositer	X	X	X	X	X	
3.1.5.3	Ignition Exciter	X	X	X	X	X	
3.2.1.1	Inlet Pressurization Diffuser	NO	NO	NO	NO		X
3.2.1.2	Hemisphere Segments	NO	NO	NO	NO		X
3.2.1.5	Mounting Brackets	NO	NO	NO	NO		X
3.2.2.2	Series-Parallel Solenoid Valve Package	X	X	X	X	X	
3.2.3.2	Series-Parallel Solenoid Valve Package	X	X	X	X	X	
3.2.4.2	Series-Parallel Valve Package	X	X	X	X	X	
3.2.4.3	Quick Disconnect Coupling	X	X	X	X	X	
3.2.5.1	Quick Disconnect Coupling	X	X	X	X	X	
3.2.5.3	Solenoid Operated Valve with Integral Relief Provision	X	X	X	X	X	
3.3.1.2	Series-Parallel Regulator Package	X	X	X	X	X	
3.3.1.3	Parallel Solenoid Valve Package	X	X	X	X	X	
3.3.1.4	Filter	X	X	X	X	X	

BOOSTER AIRBREATHING SYSTEM

LINE REPLACEABLE UNITS (TOP LEVEL)

LRU NUMBER	DESCRIPTION
1	Turbofan Engine Subsystem
2	Turbofan Inlet Valve Package
3	Cruise Tank Fuel Distribution Valve Package
4	Cruise Tank Vent Valve Package
5	Cruise Tank Vent Disconnect Coupling
6	Cruise Tank Fill Valve
7	Cruise Tank Fill Coupling
8	Cruise Tank Pressurization Regulator Package
9	Cruise Tank Pressurization Valve Package
10	Pressurization Filter

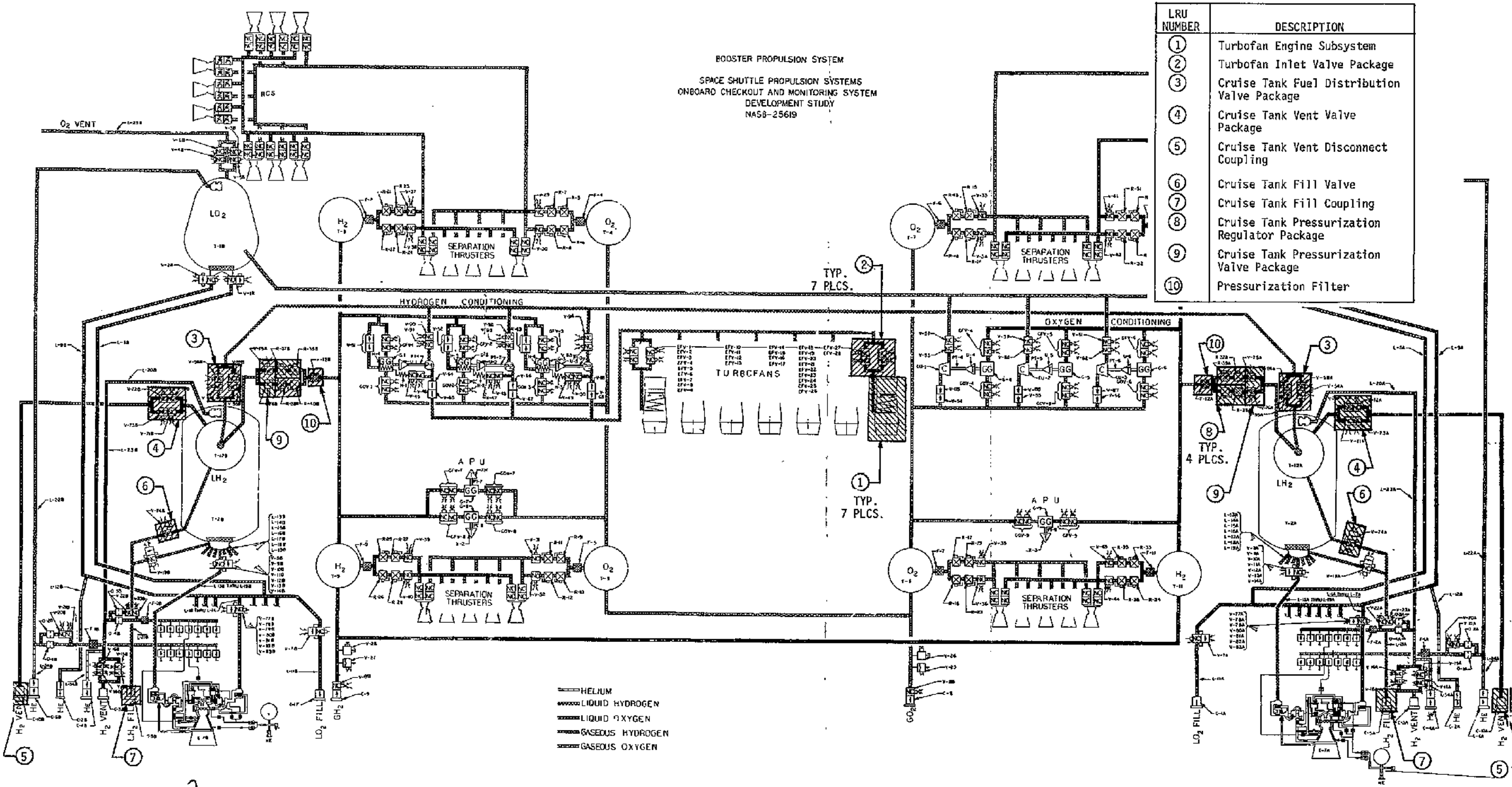
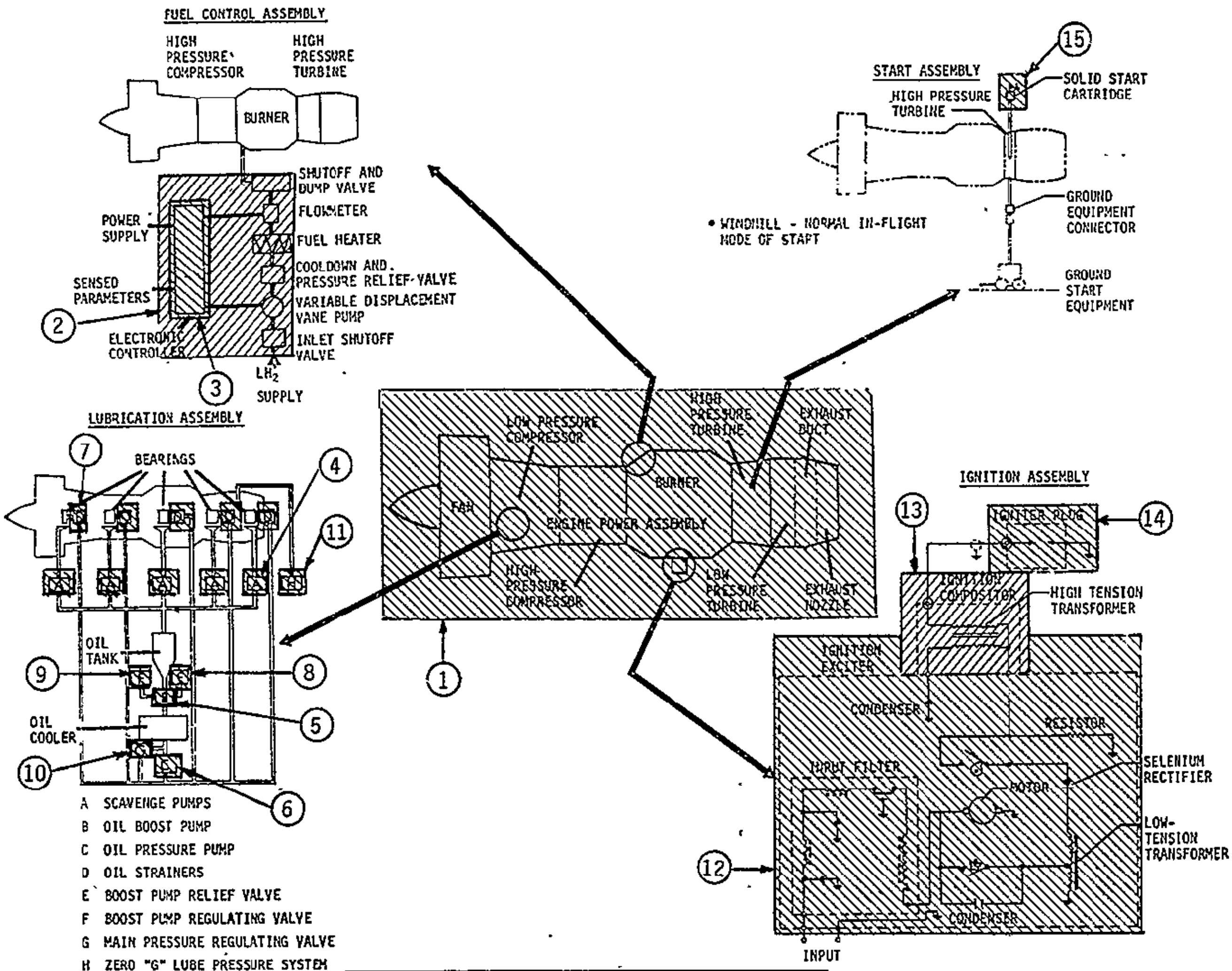


Figure III-11

FOLDOUT FRAME 1

FOLDOUT FRAME 2



LRU NUMBER	DESCRIPTION
1	Engine Power Assembly
2	Fuel Control Assembly
3	Electronic Controller
4	Scavenge Pump
5	Oil Boost Pump
6	Oil Pressure Pump
7	Oil Strainer
8	Boost Pump Relief Valve
9	Boost Pump Regulating Valve
10	Main Pressure Regulating Valve
11	Zero-g Lube Pressure System*
12	Ignition Exciter
13	Ignition Compositor
14	Igniter Plug
15	Solid Start Cartridge

*Applicable to orbiter only.

Figure III-12

8. Orbiter Airbreathing System

Table III-4 reflects all components within this system and presents the criteria matrix resulting in LRU selection. Line Replaceable Unit (LRU) identification for the system is shown schematically in Figure III-12.

The following is a brief description of the top-level LRUs. Those LRUs which are contained within the top-level LRUs are identified in the tabular listings.

LRU (1) Turbofan Engine Subsystem

The removal, replacement and retest requirement description is the same as that described for the Booster Airbreathing System. Refer to paragraph a., LRU (1).

LRU (2) Fuel Feed Valve Package

The valve package is composed on four series -- parallel solenoid valves and is used seven places. The package is fabricated with welded connections between the tubing and the solenoid valves. The welded assembly is installed in the system with brazed sleeves. The tubing and valve inlet/outlet sizes are estimated at 1/2-inch O.D. The estimated weight of the valve package is 25 lb. The removal, replacement and retest requirements are similar to those described for the Booster Airbreathing System, LRU (2) Turbofan Engine Inlet Valve Package.

LRU (3) GH_2 Valve Package

The LRU package is composed of two solenoid valves in series. The valves and tubing are connected by welded joints. The valve inlet/outlet is sized for an estimated 1 inch O.D. tubing. The package is installed in the system with brazed sleeves. The LRU estimated weight is 20 lbs.

8. Orbiter Airbreathing System (Continued)

LRU (4) Gas Generator Assembly

The Gas Generator Assembly is assumed to be mounted to structure and attached by bolted flanges to the Turbopump inlet duct. The Gas Generator Assembly includes a spark type ignition system, as well as GH_2 and GO_2 inlet ports. An overboard vent system is assumed to be included as part of the Turbopump assembly. The inlet/outlet gas connections are tubing welded to the Gas Generator Assembly. The gas valves are installed on the tubing with brazed sleeves. The estimated weight of the Gas Generator Assembly is 23 lb.

LRU (5) GO_2 Valve Package

The LRU package is composed of two solenoid valves in series. The valves and tubing are connected by welded joints. The valve inlet/outlet is sized for an estimated 1 inch O.D. tubing. The package is installed in the system with brazed sleeves. The LRU estimated weight is 20 lb. The removal, replacement and retest requirements are similar to LRU (3)

LRU (6) LH_2 Valve Package

The LH_2 Valve Package consists of two solenoid valves in series. The valves and tubing are connected by welded joints. The valve inlet/outlet is sized for an estimated 1/2 inch O.D. tubing. The package is installed in the system with brazed sleeves. The estimated weight is 13 lb.

LRU (7) Turbopump Assembly

The Turbopump Assembly is assumed to be mounted to structure and attached by bolted flanges to the Gas Generator Assembly outlet duct. The suction and discharge sides of the pump consist of tubing which is an integral part of the pump. The mating hardware is connected to the tubing with brazed sleeves. The estimated weight of the Turbopump Assembly is 30 lb.

8. Orbiter Airbreathing System (Continued)

LRU (8) Check Valve Package

The LRU is composed of two Check Valves in series. The valves and tubing are connected by welded joints. The valve inlet/outlet is sized for an estimated 1/2 inch O.D. tubing. The package is installed in the system with brazed sleeves. The estimated weight is 10 lb.

Turbofan Engine Subsystem

The LRUs for the Orbiter Turbofan Engine Subsystem are the same as those described for the Booster Turbofan Engine Subsystem except for the Zero-G lube oil pressure system which is described below. Refer to section b. of the Booster Airbreathing System for other Turbofan Engine Subsystem LRU descriptions and removal, replacement and retest requirements.

LRU (11) Zero-G Lube Pressure System

This LRU consists of a small gas storage vessel, a regulator which has vent capability, and a solenoid valve located at the tie-in point to the Lube Oil system. These components are modular mounted external to the Engine Power Assembly. A failure of any component requires replacement of the entire module. Modular mounted components are connected by welded tubing and the module is installed in the system with brazed sleeves. The estimated weight of the module is 25 lb.

Table III-4 Orbiter Airbreathing System LRUs

Ref. No.	Airbreathing Propulsion-Orbiter Item	Meets LRU Criteria: Time	Accessibility	Calibration	Verification	LRU: Yes	No
6.1.1.1	Fan	X	X	NO	NO		X
6.1.1.2	Low Pressure Compressor	X	X	NO	NO		X
6.1.1.3	High Pressure Compressor	X	X	NO	NO		X
6.1.1.4	Burner	X	X	NO	NO		X
6.1.1.5	High Pressure Turbine	X	X	NO	NO		X
6.1.1.6	Low Pressure Turbine	X	X	NO	NO		X
6.1.2.1	Inlet Shutoff Valve	X	X	NO	NO		X
6.1.2.2	Variable Displacement Vane Pump	X	X	NO	NO		X
6.1.2.3	Cooldown and Pressure Relief Valve	X	X	NO	NO		X
6.1.2.4	Fuel Heater	X	X	NO	NO		X
6.1.2.5	Flowmeter	X	X	NO	NO		X
6.1.2.6	Shutoff and Dump Valve	X	X	NO	NO		X
6.1.2.7	Electronic Controller	X	X	X	X	X	
6.1.3.1	Scavenge Pumps	X	X	X	X	X	
6.1.3.2	Oil Boost Pumps	X	X	X	X	X	
6.1.3.3	Oil Strainers	X	X	X	X	X	
6.1.3.4	Boost Pump Relief Valve	X	X	X	X	X	
6.1.3.5	Boost Pump Regulating Valve	X	X	X	X	X	
6.1.3.6	Main Pressure Regulating Valve	X	X	X	X	X	
6.1.3.7	Zero "G" Pressure Supply System	X	X	X	X	X	
6.1.4.1	Solid Start Cartridge	X	X	X	X	X	
6.1.5.1	Igniter Plug	X	X	X	X	X	
6.1.5.2	Ignition Compositor	X	X	X	X	X	
6.1.5.3	Ignition Exciter	X	X	X	X	X	
6.2.1.1	Series-Parallel Solenoid Operated Valve Package	X	X	X	X	X	
6.2.2.1	Pump	X					X
6.2.2.2	Series Solenoid Operated Valve Package	X	X	X	X	X	
6.2.2.3	Turbine	X					X
6.2.2.4	Series Check Valves	X	X	X	X	X	
6.2.3.1	Gas Generator	X	X	NO	NO		X
6.2.3.2	H_2 Series Solenoid Operated Valve Package	X	X	X	X	X	
6.2.3.3	O_2 Series Solenoid Operated Valve Package	X	X	X	X	X	
6.1.1	Engine Power Assembly	X	X	X	X	X	
6.1.2	Fuel Control Assembly	X	X	X	X	X	
6.2.2	Turbopump Assembly	X	X	X	X	X	
6.2.3	Gas Generator Assembly	X	X	X	X	X	

ORBITER AIRBREATHING SYSTEM

LINE REPLACEABLE UNITS

LRU NUMBER	DESCRIPTION
1	Turbofan Engine Subsystem
2	Fuel Feed Valve Package
3	GH_2 Valve Package
4	Gas Generator Assembly
5	GO_2 Valve Package
6	LH_2 Valve Package
7	Turbopump Assembly
8	Check Valve Package

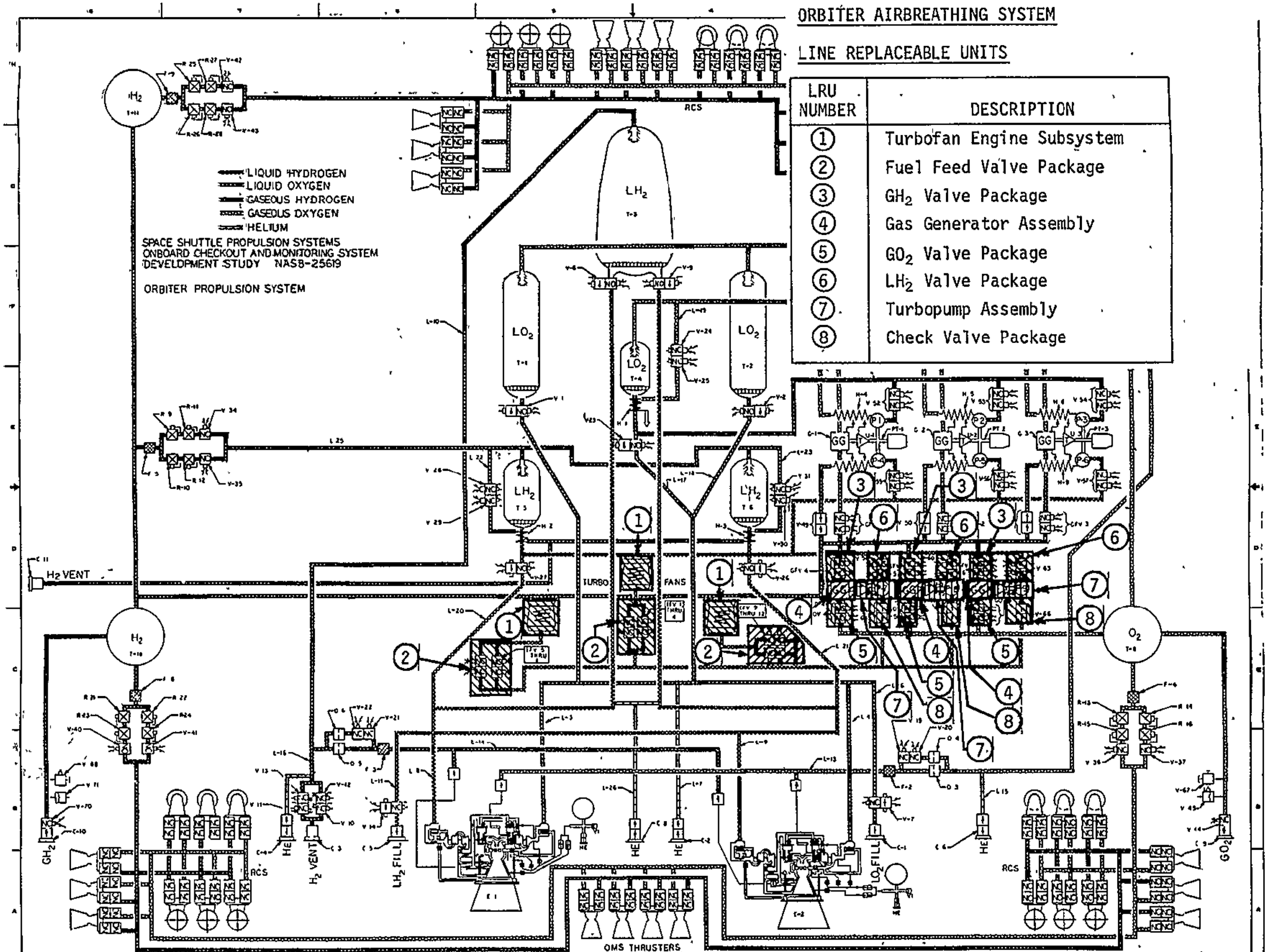


Figure III-13

D. CONTROL AND SEQUENCING

An early finding of the study was that the propulsion system control functions and the sequencing and logic interplay between these must be known in considerable detail before checkout and monitoring requirements could be completely established. This information was needed to determine what control actions were necessary in response to checkout and monitoring actions, and vice-versa. Analysis of checkout and monitoring requirements and subsequent estimates of data bus traffic and computer processing loads were dependent on this knowledge. Flow charts, similar to those used in computer programming, were found to be an effective way of developing and describing the control and sequencing criteria. These are presented in Figures III-14 through III-21.

Figures III-14 and III-15, which reflect the logic flow for the Booster Airbreathing System and the Orbiter Airbreathing System respectively, are presented at a system rather than subsystem level. This technique was selected since both control and checkout functions can be system integrated. The logic starts with pilot commands (i.e., engine start, engine shutdown and thrust control) and includes pilot warnings and feedbacks as required. The Booster Auxiliary Propulsion System logic diagrams shown in Figures III-16 through III-20 are presented at a subsystem level to more clearly present the control logic and sequencing required for subsystem operation.

Figure III-21 presents the logic flow applicable to the Booster Main Engine Subsystem. The logic presentation is similar to that described above for the Airbreathing Systems. In all cases, the logic starts with commands from the central computer and includes failure status feedback to the central computer.

Main Propulsion System component status during the various operating modes is shown by means of Position Status Lists. These are presented in Tables III-5 and III-6. These show the correct positions of the various valves, on/off status of controllers, and locked/unlocked status of actuators.

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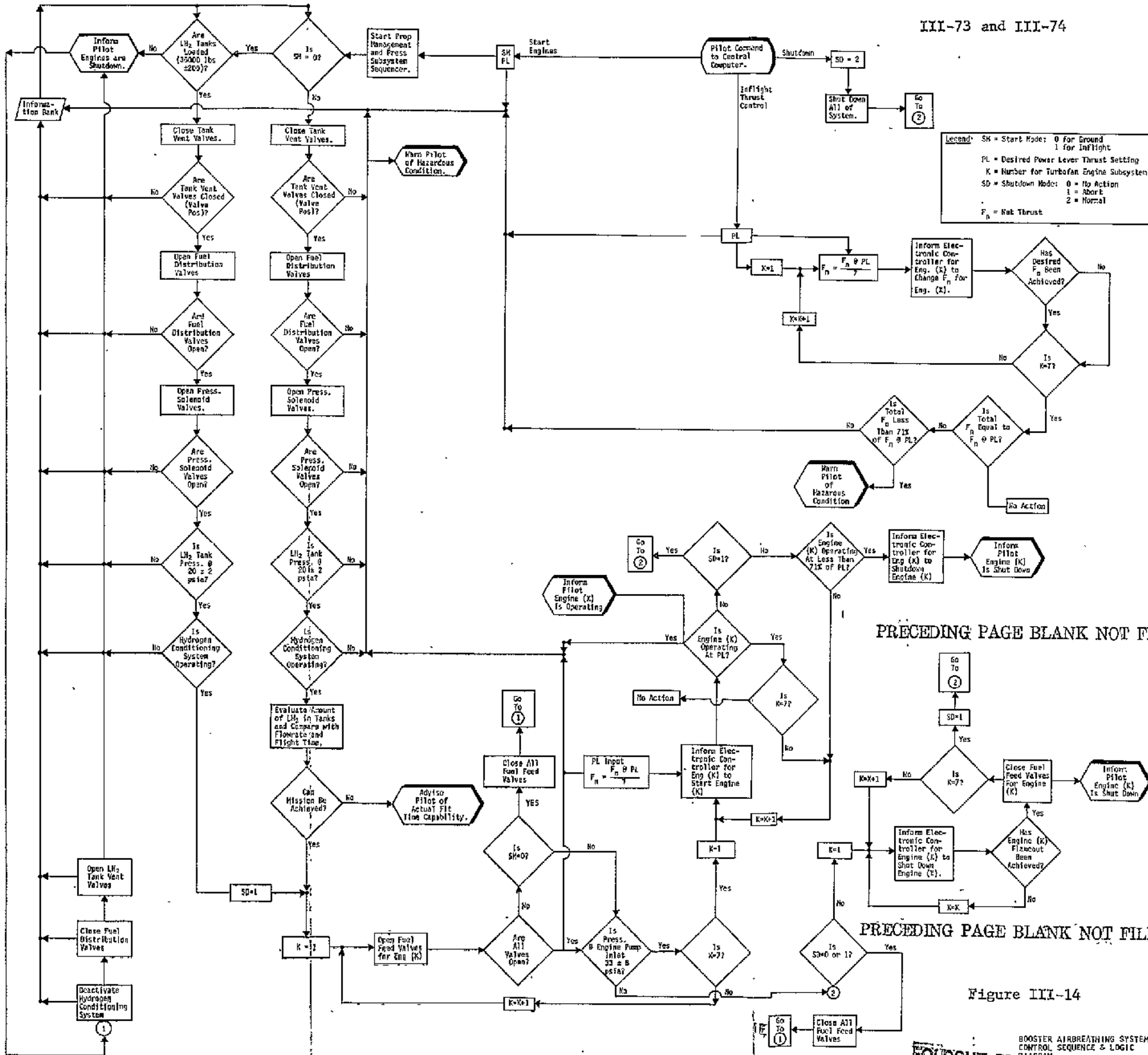

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Figure III-14

BOOSTER AIRBREATHING SYSTEM CONTROL SEQUENCE & LOGIC DIAGRAM

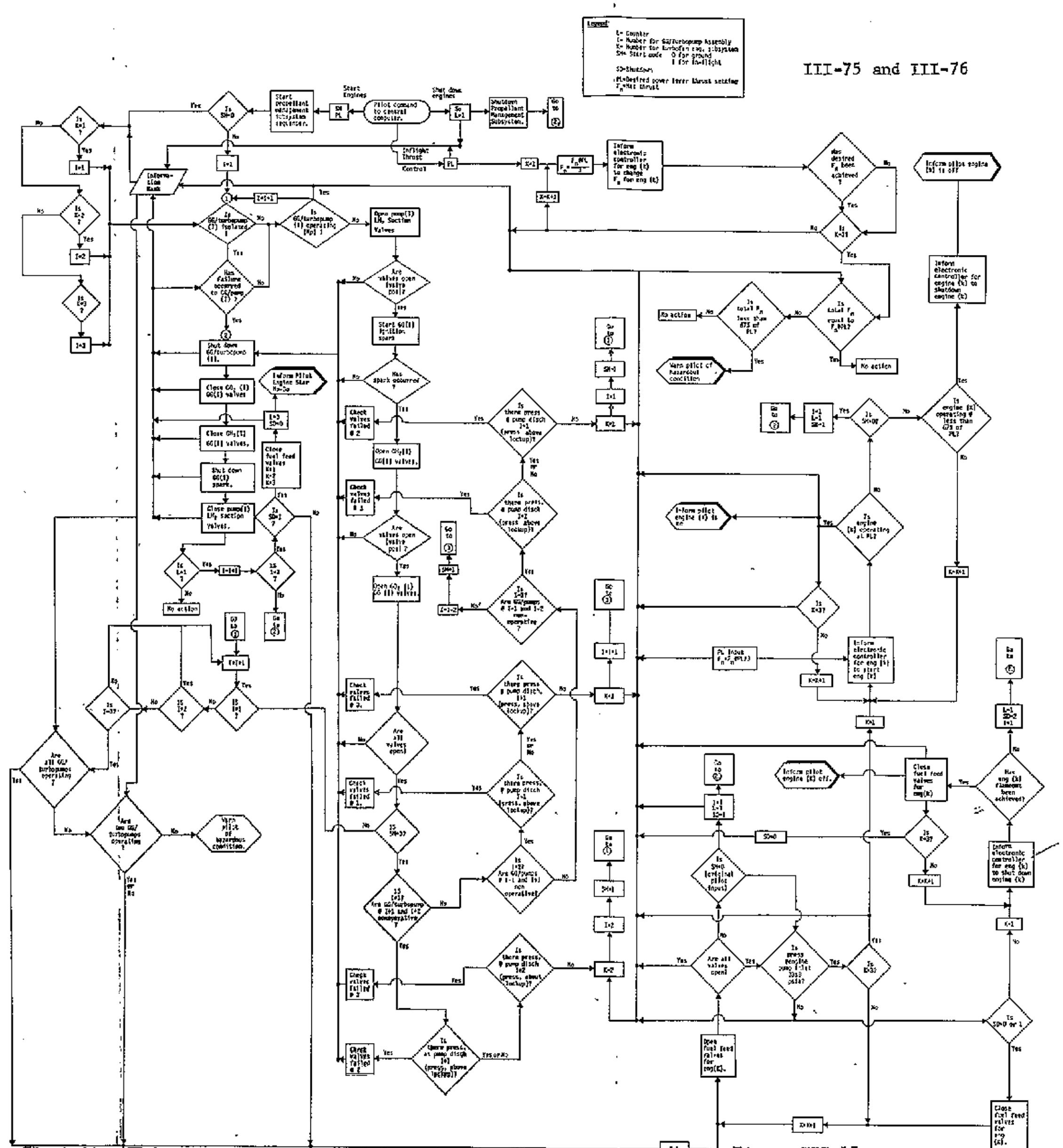
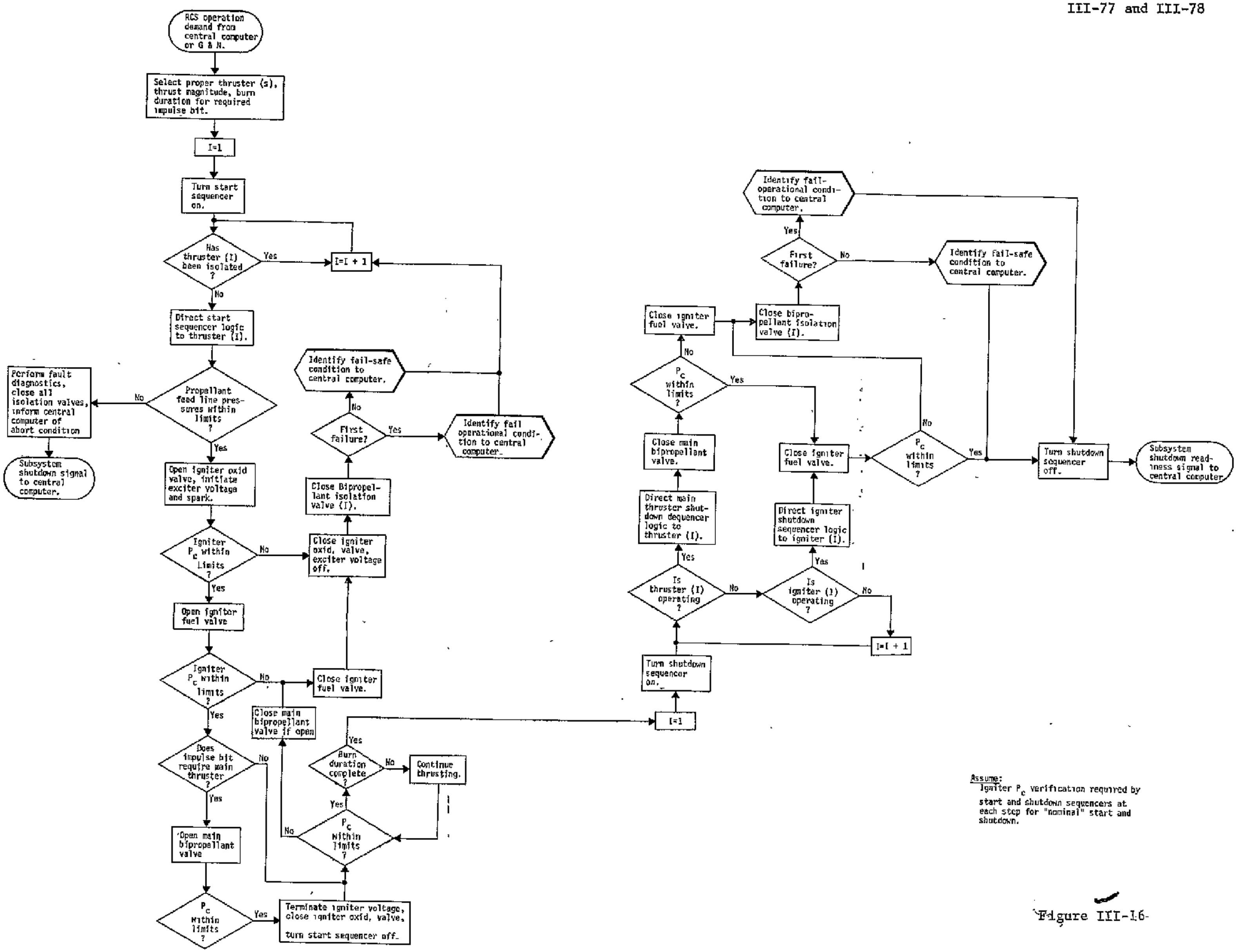


Figure III-15

ORBITER AIRBREATHING SYSTEM CONTROL SEQUENCE & LOGIC DIAGRAM

FOLDOUT FRAME

FOLDOUT FRAME



Assume:
Igniter P_c verification required by start and shutdown sequencers at each step for "nominal" start and shutdown.

Figure III-16

TYPICAL RCS CONTROL SEQUENCE AND LOGIC DIAGRAM

Assume:

1. All GGs are started before sequencing to accumulator resupply subassembly or LH_2 delivery systems
2. All GGs shutdown sequentially (nominally).
3. Central computer used to update identity of "first" GG/turbopump assembly to enable checkout of subsystem check valves.
4. Central computer logic exists to close all subsystem isolation valves upon approach.

Note: Bold arrows indicate logic coupling.

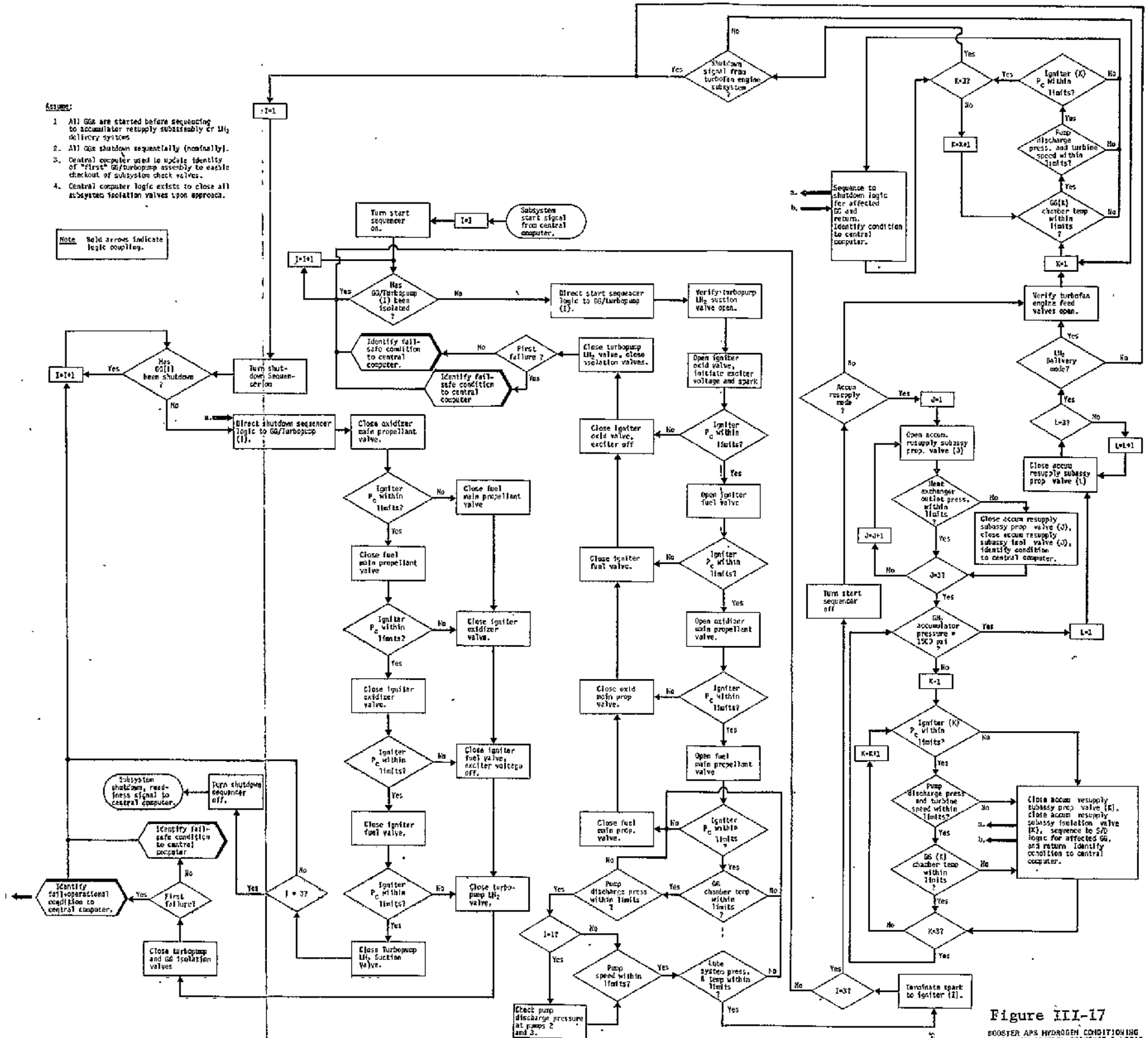


Figure III-17

BOOSTER APS HYDROGEN CONDITIONING SUBSYSTEM CONTROL SEQUENCE & LOGIC DIAGRAM

FOLDOUT FRAME 1

FOLDOUT FRAME 2

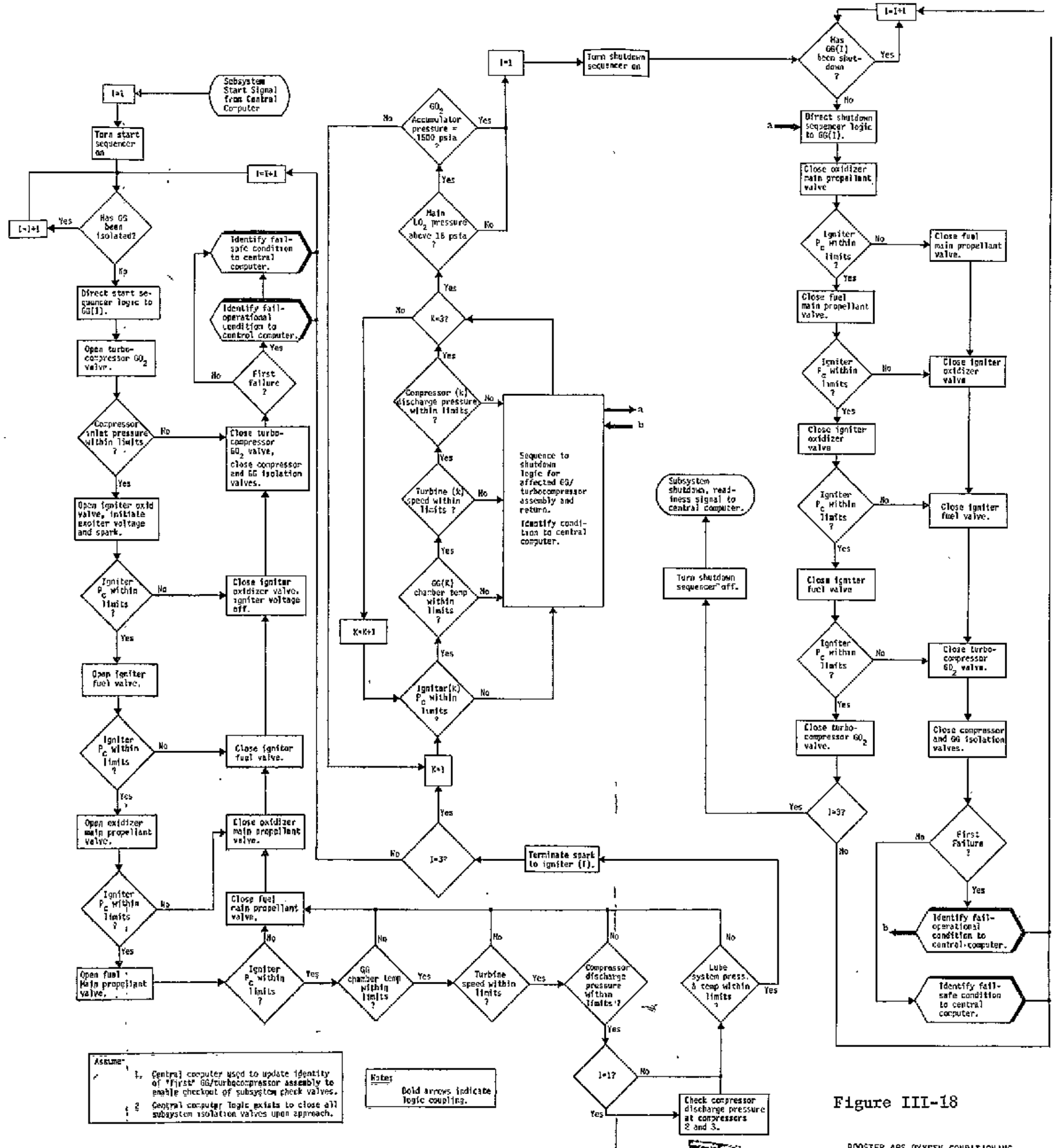


Figure III-18

BOOSTER APS OXYGEN CONDITIONING SUBSYSTEM CONTROL SEQUENCE & LOGIC DIAGRAM

FOLDOUT FRAME

FOLDOUT FRAME

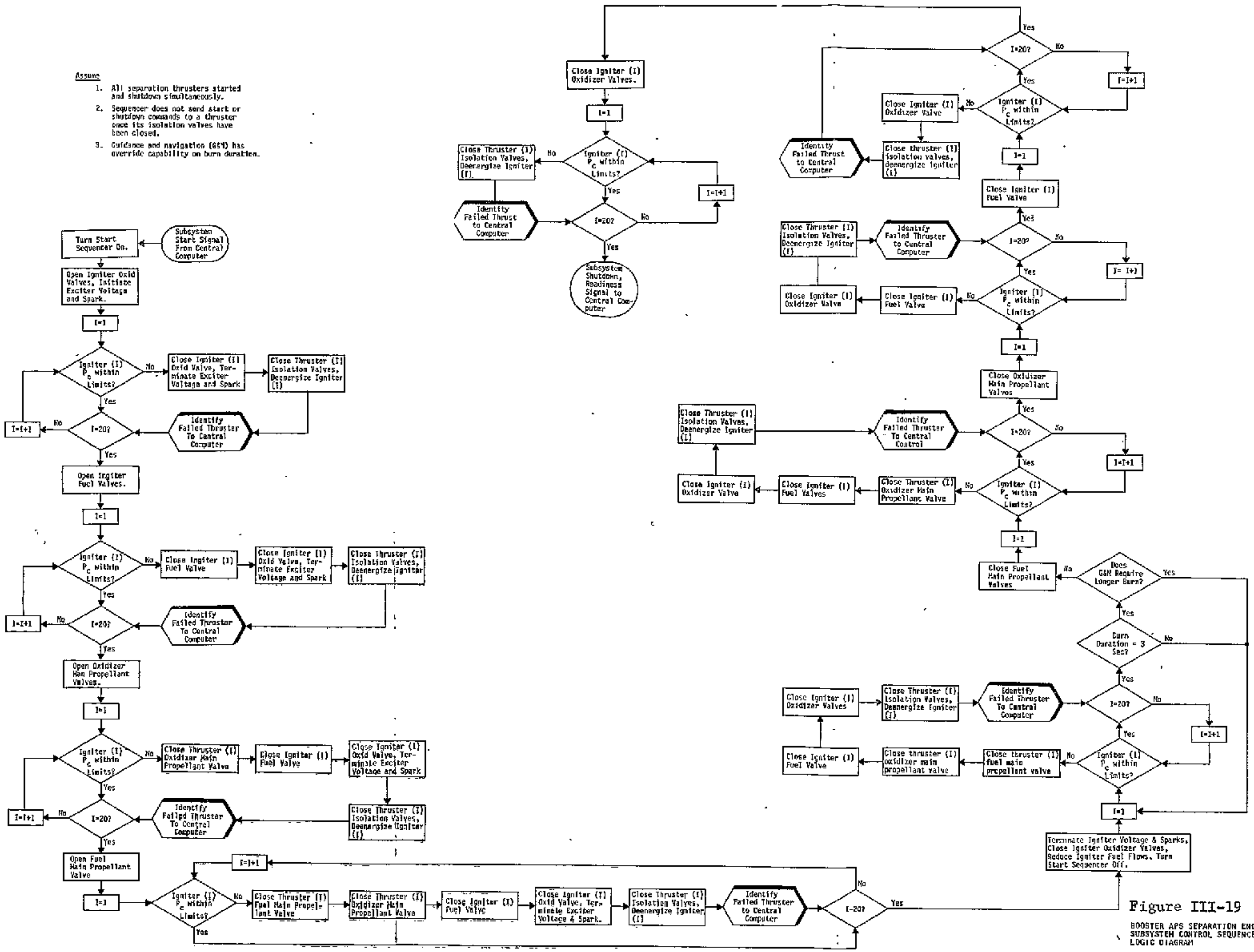


Figure III-19

BOOSTER APS SEPARATION ENG SUBSYSTEM CONTROL SEQUENCE LOGIC DIAGRAM

FOLDOUT FRAME 1

FOLDOUT FRAME 2

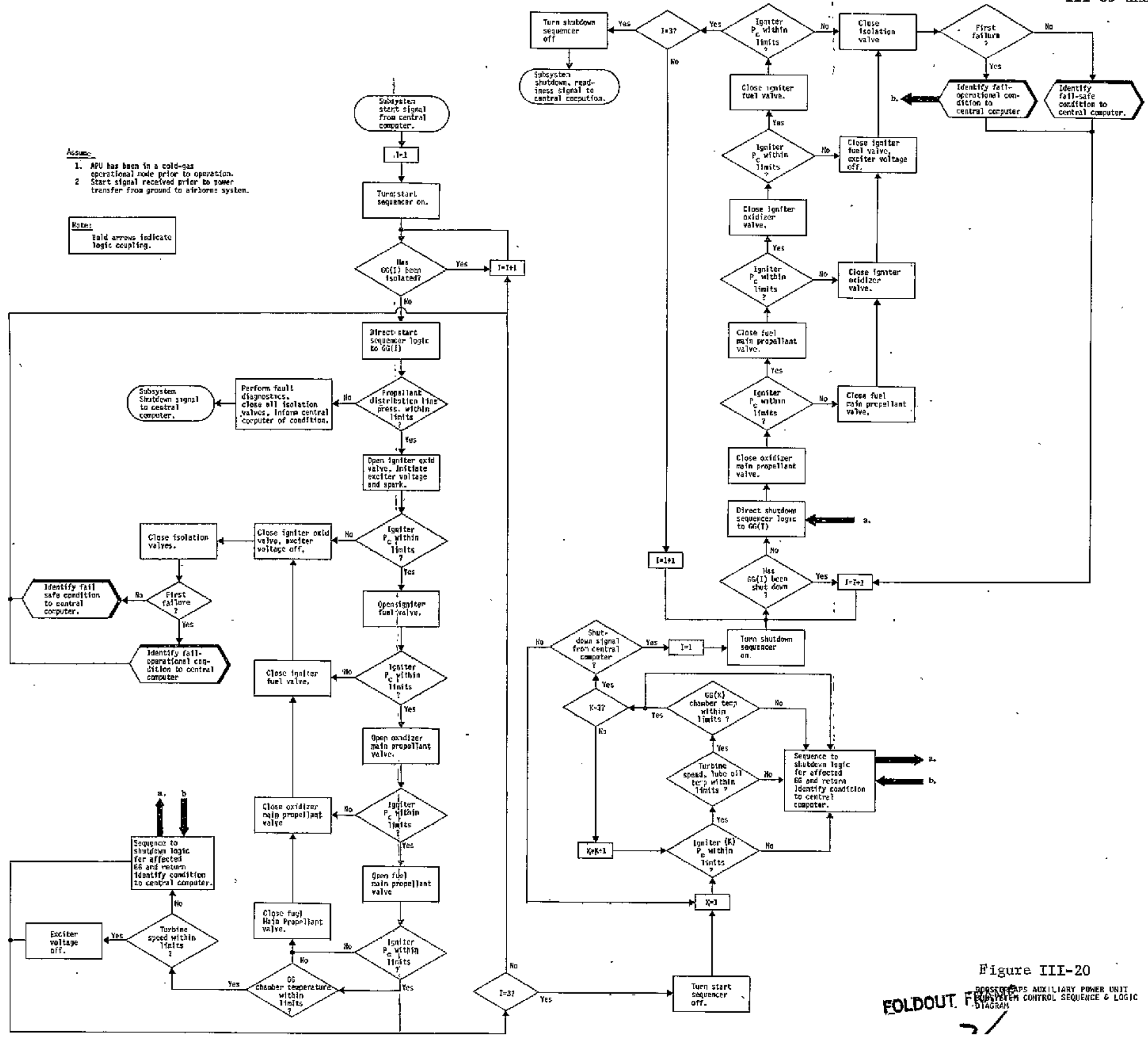


Figure III-20

BOOSTER/TAPS AUXILIARY POWER UNIT SUBSYSTEM CONTROL SEQUENCE & LOGIC DIAGRAM

FOLDOUT FRAME

FOLDOUT FRAME

	COMPONENT	SECURED FERRY	CHECK-OUT	PROP. LOAD	TANK PRESSURIZE	LAUNCH READY	START	OPERATION	SHUTDOWN	IN-FLIGHT SECURE	POSTFLIGHT PURGE	NORMAL STATE
MPMS	Ox. Prevalve (V-77 thru V-83)	► C	► 0	0	0	0	0	0	0	► C	► 0	0
	Ox. Isol. Valve (V-1, V-2)	► C	► 0	0	0	0	0	0	0	► C	► 0	0
	Ox. Vent Valve (V-3 thru V-6)	C	C	► 0	► C	C	C	C	C	C	► 0 ► C	C
	Ox. Fill Valve (V-7)	C	C	► 0	► C	C	C	C	C	C	► 0	► C
	Fuel Isol. Valve (V-8 thru V-14)	► C	► 0	0	0	0	0	0	0	► C	0	0
	Fuel Vent Valve (V-15 thru V-18)	C	C	► 0	► C	C	C	C	C	C	► 0 ► C	C
	Fuel Fill Valve (V-19)	C	C	► 0	► C	C	C	C	C	C	► 0	► C
	LOX. Fill Coupling (C-1)	C	C	► 0	0	► C	C	C	C	C	► 0	► C
	LOX. He (RECIR) Coupl. (C-2)	C	C	► 0	0	► C	C	C	C	C	► 0	► C
	H2 Vent Coupling (C-3)	C	C	► 0	0	► C	C	C	C	C	► 0	► C
	H2 Tank Pre-Press. Coup. (C-4)	C	C	► 0	0	► C	C	C	C	C	C	C
	LH2 Fill Coupling (C-5)	C	C	► 0	0	► C	C	C	C	C	► 0	► C
	Ox. Tank Pre-Press. Coup. (C-6)	C	C	► 0	0	► C	C	C	C	C	► 0	► C
MPS	Ox. Press. Cont. Valve (V-20, V-21)	C	C	C	C	C	C	► 0*	0	0	0	► C
	Fuel Press. Cont. Valve (V-22, V-23)	C	C	C	C	C	C	► 0*	0	0	0	► C
Engine	Controller	Off	► On	On	On	On	On	On	On	► Off	► On	► Off
	Actuators	Lock	Lock	Lock	Lock	Lock	Lock	► unLock**	unLock	► Lock	Lock	Lock
	Fuel Pump Recir. Sel. Valve	Turb.	Turb.	► Tank	Tank	Tank	► Turb.	Turb.	Turb.	► Tank	Tank	► Turb.
	Fuel Pump Recir. Cont. Valve	C	C	► 0	0	0	0	► Min.	Min.	► 0	0	► C
	Main Fuel Valve	C	C	C	C	C	► 0	0	► C (800PSIA)	C	C	C
	Ox. Pump Recirc. Sel. Valve	Turb.	Turb.	► Tank	Tank	Tank	► Turb.	Turb.	Turb.	► Tank	Tank	► Turb.
	TCOV	C	C	C	C	C	► 0	0	► C (800 PSIA)	C	C	C
	Fuel Preburn Ox. Shutoff Valve	C	C	C	C	C	► 0	0	► C	C	C	C
	Ox. Preburn Ox. Shutoff Valve	C	C	C	C	C	► 0	0	► C	C	C	C
	Igniter Ox. Valves	C	C	C	C	C	► 0	► C	C	C	C	C
	Fuel Ckt. He Purge Valve	C	C	C	C	► 0	► C	C	► 0(50 PSIA)	► C	► 0	► C
	Ox. Ckt. He Purge Valve	C	C	C	C	► 0	► C	C	► 0(50 PSIA)	► C	► 0	► C
	Pump Seal He Purge Valve	C	C	0	0	0	0	0	0	► C	► 0	► C
	Ox. Preburner Ox. Cont. Valve	Min.	Min	Min	Min	► Start	Start	► Run	► Min. ► 0	0	0	► Min
	Fuel Preburn. Ox. Cont. Valve	Min	Min	Min	Min	► Start	Start	► Run	► Min. ► 0	0	0	► Min
	Ox. Preburner Fuel Cont. Valve	Min	Min	Min	Min	► Start	Start	► Run	► Min. ► 0	0	0	► Min
	Ignition	E	E ► D	D	D	D	► E	► D(+.9 sec)	D	D	D	D

Legend: 0 = Open
C = Closed
E = Energized
D = De-energized

► = Change of State
* = FS + 150 Sec.
** = @90% P.C.

TABLE III-5

BOOSTER MAIN PROPULSION SYSTEM
POSITION STATUS LIST

FOLDOUT FRAME 1

FOLDOUT FRAME 2

	FERRY PRELOAD	FERRY LOAD	FERRY PRESS.	FERRY FLIGHT	SECURED	CHECKOUT	LAUNCH LOAD	LAUNCH PRESS.	LAUNCH READY	START	BURN	SHUTDOWN	ORBITAL	POSTFLIGHT PURGE
Ox. Isol. Valves (V-1, 2)	C	C	C	C	C	O	O	O	O	O	O	O	C	O
Ox. Vent Valves (V-3,4,5,6)	C	C	C	C	C	C	O	C	C	C	C	C	C	O
Ox. Fill and Drain Valves (V-7)	C	O	C	C	C	C	O	C	C	C	C	C	C	O
Fuel Isol. Valves (V-8,9)	C	C	C	C	C	O	O	O	O	O	O	O	C	O
Fuel Tank Vent Valves (V-10,11,12,13)	C	C	C	C	C	C	O	C	C	C	C	C	C	O
Fuel Fill and Drain Valve (V-14)	C	O	C	C	C	C	O	C	C	C	C	C	C	O
Ox. Press. Cont. Valves (V-19,20)	C	C	C	C	C	C	C	C	C	C	O	C	C	O
Fuel Press. Cont. Valves (V-21,22)	C	C	C	C	C	C	C	C	C	C	O	C	C	O
Ox. Isol. Valve (V-23)	C	O	C	C	C	O	O	C	C	C	C*	C	C	O
Ox. Vent Valves (V-24,25)	C	O	C O C	C	C	C	O	C O C	C	C	C	C	C O* C	O
Fuel Isol. Valves (V-26,27)	C	O	C	C	C	O	O	C	C	C	C*	C	C	O
Fuel Vent Valves (V-28,29,30,31)	C	O	C O C	C	C	C	O	C O C	C	C	C	C	C O* C	O
Oxid. Press. Valves (V-32,33)	C	C	O C O	O	C	C	C	O C O	O	O	O	O	O C* O	O
Fuel Press. Valves (V-34,35)	C	C	O C O	O	C	C	C	O C O	O	O	O	O	O C* O	O
Ox. Fill and Drain Coup. (C-1)	C O	O	O	C	C	C	O	O	C	C	C	C	C	O
Helium Coup. -Oxid. (C-2)	C O	O	O	C	C	C	O	O	C	C	C	C	C	O
Fuel Tank Vent Coup. (C-3)	C C	C	C	C	C	C	O	C	C	C	C	C	C	O
Helium Coupling-fuel (C-4)	C C	C	C	C	C	C	O	O	C	C	C	C	C	O
Fuel Fill Coupling (C-5)	C O	O	O	C	C	C	O	O	C	C	C	C	C	O
Helium Coup.-Oxid. (C-6)	C C	C	C	C	C	C	O	O	C	C	C	C	C	O
Helium Coup.-Fuel (C-8)	C O	O	O	C	C	C	O	O	C	C	C	C	C	O
Fuel Vent Coupling (C-11)	C O	O	O	C	C	C	O	O	C	C	C	C	C	O
Controller	OFF	OFF	OFF	OFF	OFF	ON	ON	ON	ON	ON	ON	ON	OFF	ON
Actuators	LOCK	LOCK	LOCK	LOCK	LOCK	LOCK	LOCK	LOCK	LOCK	LOCK	UNLOCK**	UNLOCK	LOCK	LOCK
Ignition	D	D	D	D	D	E D	D	D	D	E	D (+.9 sec)	D	D	D

Legend:
O = Open
C = Closed
E = Energized
D = De-energized
* = Conditional status
** = At 90% Pc

NOTE: Engine Conditions Are Same As For Booster.

TABLE III-6

ORBITER MAIN PROPULSION SYSTEM
POSITION STATUS LIST

FOLDOUT FRAME 1

FOLDOUT FRAME 2