2-p (mix)

CR - 128660
NTIS $20.00

Space Shuttle Program

MSC-03321

FINAL SUBMITTAL

(NASA-CR-128660) EXPENDABLE SECOND STAGE REUSABLE SPACE SHUTTLE BOOSTER. VOLUME 5: OPERATIONS AND RESOURCES Final Report, Phase B (North American Rockwell Corp.) 25 Jun. 1971 356 p CSCL 22B

N73-14871

Unclas
G3/31 50795

IBM GD AA H HONEYWELL

Phase B Final Report
Expendable Second Stage
Reusable Space Shuttle Booster
Volume V. Operations and Resources

Contract NAS9-10960, Exhibit B
DRL MSFC-DRL-221, DRL Line Item 6
DRD MA-078-U2
SD 71-140-5
25 June 1971

Space Division • North American Rockwell 12214 Lakewood Boulevard, Downey, California 90241

382

SD 71-140-5
(MSC-03321)

25 June 1971

PHASE B FINAL REPORT
EXPENDABLE SECOND STAGE
REUSABLE SPACE SHUTTLE BOOSTER

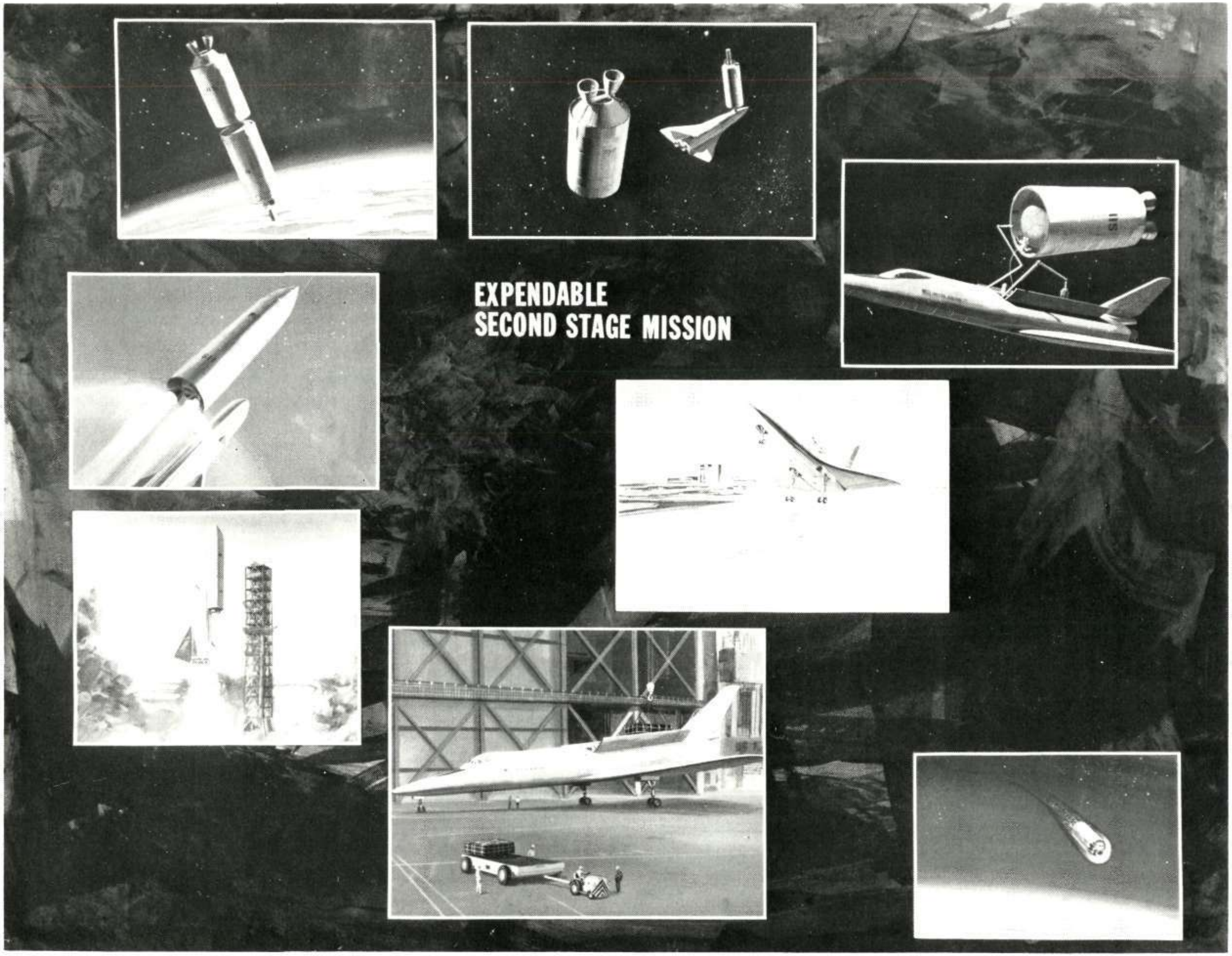
Volume V
Operations and Resources

Contract NAS9-10960, Exhibit B
DRL MSFC-DRL-221, DRL Line Item 6
DRD MA-078-U2

Approved by

for B. Hello
Vice President and General Manager
Space Shuttle Program

Space Division • North American Rockwell 12214 LAKEWOOD BOULEVARD • DOWNEY, CALIFORNIA 90241


EXPENDABLE
SECOND STAGE MISSION

FOREWORD

The Space Shuttle Phase B studies are directed toward the definition of an economical space transportation system. In addition to the missions which can be satisfied with the shuttle payload capability, the National Aeronautics and Space Administration has missions planned that require space vehicles to place payloads in excess of 100,000 pounds in earth orbit. To satisfy this requirement, a cost-effective multimission space shuttle system with large lift capability is needed. Such a system would utilize a reusable shuttle booster and an expendable second stage. The expendable second stage would be complementary to the space shuttle system and impose minimum impact on the reusable booster.

To assist the expendable second stage concept, a two-phase study was authorized by NASA. Phase A efforts, which ended in December 1970, concentrated on performance, configuration, and basic aerodynamic considerations. Basic trade studies were carried out on a relatively large number of configurations. At the conclusion of Phase A, the contractor proposed a single configuration. Phase B commenced on February 1, 1971 (per Technical Directive Number 503) based on the recommended system. Whereas a large number of payload configurations were considered in the initial phase, Phase B was begun with specific emphasis placed on three representative payload configurations. The entire Phase B activity has been directed toward handling the three representative payload configurations in the most acceptable manner. Results of this activity are reported in this 12-volume Phase B final report.

Volume I	Executive Summary	SD 71-140-1
Volume II	Technical Summary	SD 71-140-2
Volume III	Wind Tunnel Test Data	SD 71-140-3
Volume IV	Detail Mass Properties Data	SD 71-140-4
Volume V	Operations and Resources	SD 71-140-5
Volume VI	Interface Control Drawings	SD 71-140-6
Volume VII	Preliminary Design Drawings	SD 71-140-7
Volume VIII	Preliminary CEI Specification - Part 1	SD 71-140-8
Volume IX	Preliminary System Specification	SD 71-140-9
Volume X	Technology Requirements	SD 71-140-10
Volume XI	Cost and Schedule Estimates	SD 71-140-11
Volume XII	Design Data Book	SD 71-140-12

This volume contains information on ground and flight operations, manufacturing, facilities, and ground support equipment per requirements of Contract NAS9-10960, Exhibit B. In addition, data in the form of preliminary program acquisition plans for the conduct of Phase C (Design) and Phase D (Development and Operations) of the Expendable Second Stage on a Reusable Space Shuttle Booster and included in accordance with supplementary ESS support authorized by Contract NAS7-200, Task Authorization No. 5. The plans included herein are as follows:

Section 1	Operations Plan
Section 2	Facility Utilization and Manufacturing Plan
Section 3	Engineering and Development Plan
Section 4	Preliminary Test Plan
Section 5	Logistics and Maintenance Plan
Section 6	Program Management Plan

Each of the above sections have been prepared in the form of a plan and includes a description of the Scope and Purpose of the Plan. Each has its own Contents and Illustrations lists.

SECTION I

OPERATIONS PLAN

Preceding page blank

CONTENTS

Section		Page
1.0	INTRODUCTION	1-1
	1.1 PURPOSE	1-1
	1.2 SCOPE	1-1
	1.3 ESS OPERATIONAL FLOW PLAN	1-2
	1.3.1 Produce ESS Subsystem (FFBD 9.0)	1-2
	1.3.2 Support Facilities (FFBD 10.0)	1-2
	1.3.3 Training (FFBD 11.0)	1-2
	1.3.4 Test and Acceptance (FFBD 8.0)	1-2
	1.3.5 Maintenance Operations (FFBD 3.0)	1-2
	1.3.6 Operations Support (FFBD 4.0)	1-2
	1.3.7 Assembly and Launch (FFBD 2.0)	1-4
	1.3.8 Mission (FFBD 1.0)	1-4
	1.3.9 Mission Abort Operations (FFBD 5.0)	1-4
	1.3.10 Perform Ferry Mission (FFBD 6.0)	1-4
	1.4 TRADE STUDIES	1-4
	1.5 DEFINITIONS	1-5
	1.6 GROUND RULES AND ASSUMPTIONS	1-5
	1.7 REQUIREMENTS	1-6
	1.8 ESS MISSIONS	1-6
	1.9 OPERATIONS CONCEPTS	1-8
2.0	GROUND OPERATIONS	1-11
	2.1 LAUNCH OPERATIONS	1-11
	2.1.1 Receiving Inspection	1-12
	2.1.2 ESS Storage	1-13
	2.1.3 Pre-Mate Operations	1-14
	2.1.4 Booster Operations	1-14
	2.1.5 Transport ESS and Payload	1-16
	2.1.6 Vehicle Mating and Erecting Operation	1-17
	2.1.7 Transportation to the Pad	1-17
	2.1.8 Connection and Verification of Launcher and Pad Interfaces	1-18
	2.1.9 Final Checkout Operations	1-20
	2.1.10 Launch Countdown	1-23
	2.1.11 Pad Aborts	1-23

PRECEDING PAGE BLANK NOT FILMED

Section		Page

3.0	FLIGHT OPERATIONS	1-27
	3.1 MISSION OPERATIONS	1-27
	3.1.1 Mission Planning	1-27
	3.1.2 ESS Payloads	1-28
	3.2 MATED ASCENT	1-28
	3.2.1 Initial Ascent Maneuver	1-31
	3.2.2 Roll Maneuver	1-31
	3.2.3 Pitch Maneuver	1-31
	3.2.4 Ascent Guidance	1-31
	3.3 BOOSTER/ESS STAGING	1-32
	3.4 INITIAL EARTH ORBIT	1-36
	3.5 ESS ASCENT OPERATIONS	1-36
	3.5.1 Orbit and Phase Changes	1-36
	3.5.2 ESS Payload Separation	1-36
	3.6 ESS COMPONENT RECOVERY	1-37
	3.7 ESS DEORBIT	1-38
	3.8 ESS EARTH IMPACT	1-38
	3.9 MISSION ABORT OPERATIONS	1-43
	3.9.1 Booster/ESS Pad Abort	1-43
	3.9.2 Flight Abort	1-46
4.0	OPERATIONS SUPPORT	1-47
	4.1 FLIGHT OPERATIONS SUPPORT	1-47
	4.1.1 Meteorological Support	1-47
	4.1.2 Voice Communications	1-48
	4.1.3 Data Communications	1-48
	4.1.4 Coordination of Flight Support Elements	1-48
	4.1.5 Boost Monitoring	1-48
	4.1.6 Mission Support	1-49
	4.2 OPERATIONS MANAGEMENT SUPPORT	1-49
	4.2.1 Fleet Management and Planning Support	1-49
	4.2.2 Training and Development Support	1-50
	4.2.3 Mission Information Support	1-51
	4.2.4 Launch Support System	1-51
5.0	SAFETY CRITERIA	1-53
	5.1 SAFETY CRITICAL OPERATIONS	1-53
	5.1.1 Categories	1-53
	5.1.2 General Criteria	1-54
	5.1.3 Procedures for all Hazardous Operations	1-56
	5.1.4 Range Safety	1-56

Section | Page

5.2 PERSONNEL QUALIFICATION AND CERTIFICATION FOR HAZARDOUS OPERATIONS 1-56
5.2.1 Personnel Qualification and Certification Definition 1-56
5.2.2 Requirements 1-57

APPENDIXES
A. FUNCTIONAL FLOW DIAGRAMS 1-59
B. ESS/RSB OPERATIONS 1-75

Preceding page blank

ILLUSTRATIONS

Figure		Page
1-1	Top Level Functional Flow Diagram Expendable Second Stage/Reusable Space Shuttle Booster	1-3
1-2	Vehicle Orientation for Flight	1-7
1-3	Mission	1-8
1-4	ESS/Booster Launch Operations	1-11
1-5	Ground Operations Timeline	1-12
1-6	Booster/ESS/Payload Mating	1-15
1-7	ESS/Booster at Launch Pad	1-18
1-8	Simultaneous Propellant Loading Timeline	1-22
1-9	Countdown - Timeline	1-24
1-10	Space Station Mission Event Profile	1-30
1-11	RNS Mission Event Profile	1-30
1-12	Space Tug Mission Event Profile	1-30
1-13	ESS/Booster Separation Sequence	1-33
1-14	ESS/Booster Staging	1-34
1-15	ESS/Booster Staging With RNS Payload	1-35
1-16	Recovery Operations	1-39
1-17	Ship Distribution	1-41
1-18	ESS Debris Probability of Ship Impact	1-44
1-19	ESS Deorbit Impact Footprint	1-45

TABLES

Tables		Page
1	ESS Launch Pad Configuration Concept Evaluation	1-19
2	Ascent to Initial Earth Orbit	1-29

PRECEDING PAGE BLANK NOT FILMED

SECTION I. OPERATIONS PLAN

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this plan is to describe the expendable second stage (ESS) operations required to support the program objectives and mission requirements. The ESS augments the space shuttle booster by placing various NASA Space Transportation System payloads into earth orbit. This plan is compatible with the Operations Plan for Phase C/D, Volume I, Shuttle System (MSC-03310) (SD 71-103-1).

1.2 SCOPE

This plan describes the ESS operational requirements and activities derived from analysis of both ground and flight operations in conjunction with the space shuttle booster.

The operation plan encompasses those mission activities following completion of the flight qualification phase of the program. All necessary test and operational techniques will have been validated and all subsystems qualified prior to entering the operational phase.

The first two ESS vehicles will be accepted upon completion of post-static firing checkout (C/O) and all subsequent vehicles will be accepted upon completion of C/O at Seal Beach, at which time the operational cycle begins. Checkout at KSC will be conducted, the booster and ESS mated, the payload installed, vehicles moved to the launch pad, and preparation for launch countdown will be completed.

The operational cycle for the booster is basically defined in the Operations Plan (Booster), SD 71-103-3 except for ESS-peculiar operations. This is the installation and removal of the separation structure and flight software required by the ESS.

The flight phase begins with mated ascent, includes ESS payload separation, high value component recovery, and is completed at ESS deorbit. Abort operations are discussed in the summary as they affect ESS-booster operation.

The support operations required to plan and conduct missions are described in detail in those areas which support both the shuttle and the ESS. Safety criteria, as related to both shuttle and ESS, are presented.

1.3 ESS OPERATIONAL FLOW PLAN

The operation of the ESS shuttle booster system is depicted in Figure 1-1. This functional flow block diagram (FFBD) also describes the basic space shuttle program. The differences appear in lower level functions (see Appendix A).

1.3.1 Produce ESS Subsystem (FFBD 9.0)

The production of the ESS subsystem is covered in the Facilities Utilization and Manufacturing Plan (Section 2 of this volume).

1.3.2 Support Facilities (FFBD 10.0)

Support facilities is covered in the Facilities Utilization and Manufacturing Plan (Section 2 of this volume).

1.3.3 Training (FFBD 11.0)

Training is covered by the ESS Logistics and Maintenance Plan (Section 5 of this volume).

1.3.4 Test and Acceptance (FFBD 8.0)

Test and acceptance is covered in detail in the ESS Test Plan (Section 4 of this volume).

1.3.5 Maintenance Operations (FFBD 3.0)

Maintenance is covered in the ESS Logistics and Maintenance Plan (Section 5 of this volume).

1.3.6 Operations Support (FFBD 4.0)

Operations support includes the pre-mission, mission, and operations management functions and is covered in this plan. Mission operations include, but are not limited to:

Mission planning

Mission profiles

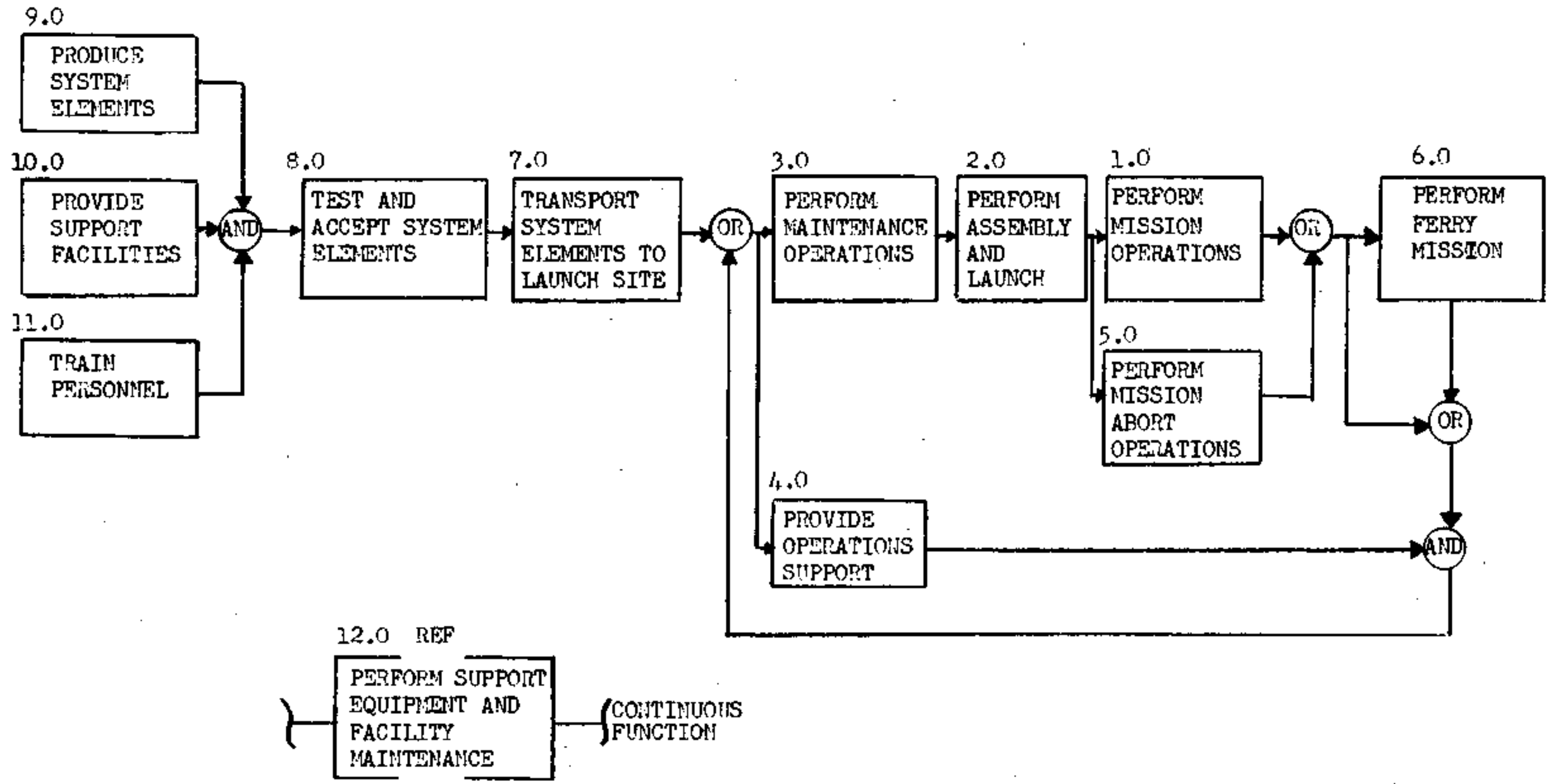


Figure 1-1. Top Level Functional Flow Diagram, Expendable Second Stage/Reusable Space Shuttle Booster

Data handling

Communications

1.3.7 Assembly and Launch (FFBD 2.0)

Assembly and launch is described in this plan and includes premate assembly installation, checkout, vehicle mating, erection, vehicle integration, payload erect and mate, final servicing, final checkout, propellant loading, launch countdown, and launch. The booster portion of this function is contained in the space shuttle operations plan, SD 71-103-3, except for the ESS-peculiar operations.

1.3.8 Mission (FFBD 1.0)

This function covers all activities from ESS-booster liftoff, mated ascent, ESS-booster separation, orbit, payload separation, component recovery, and deorbit and is covered in this plan. The mission function also includes booster reentry and flyback but these are not discussed herein (see Operations Plan, SD 71-103-3).

1.3.9 Mission Abort Operations (FFBD 5.0)

This function includes ESS-booster abort conditions from pad operations through launch, boost, booster separation, and deorbit, and is covered in this plan.

1.3.10 Perform Ferry Mission (FFBD 6.0)

The ferry mission is covered in the shuttle operations plan (SD 71-103-3) for Phase C/D. This function is not planned as a part of the normal ESS/RSB system operations; normally the booster is to return to the operational site after each launch of ESS.

1.4 TRADE STUDIES

The operational concepts and functional requirements described herein are based on the final results of the Phase B trade studies. Specific subsystem results may be found in the Volume II, Technical Summary, Appendix A.

1.5 DEFINITIONS

Terms used in the discussion of the ESS/space shuttle booster system operations concept are defined as follows.

Test	Examination of an item to ascertain that it meets specified requirements.
Checkout	An operation that measures performance with results specified beforehand, and compliance stated as acceptance criteria.
Data base	A compilation of data points of a family of parameters which is gathered under similar or relatable conditions and stored in a manner which permits extraction in varied groupings and formats.
Inspection	The examination, normally by visual or non-destructive test of system elements, subsystems, and equipment to determine conformance to established standards.
Test phase	That phase of the program ending at completion of static firing of the first vehicle.
Prelaunch	That phase of operations concerned with preparing the vehicle for launch (prelaunch checkout of the ESS/booster mating erection).

1.6 GROUND RULES AND ASSUMPTIONS

The operations plan is based on the following study assumptions:

A. The design reference mission(s) are established in the study control document with launch at Kennedy Space Center.

B. On the launch pad, the ESS will be located on the opposite side of the booster from the launch umbilical tower (LUT). ESS umbilical servicing and control will be by means of a fixed service tower located southwest of the flight vehicle. This service tower will not interfere with basic space shuttle operations.

C. ESS equipment recovery operations will be considered to improve cost effectiveness.

D. For ESS equipment recovery, ESS to orbiter hard docking shall be accomplished by a neuter docking system located on the ESS aft skirt at Position III (Figure 1-2).

E. The ESS-boosted payload shall not be separated from the ESS until the retrieval orbiter vehicle is near, unless the ESS components are not to be recovered.

F. A shuttle orbiter vehicle shall be assumed available in space within the 24-hour ESS lifetime for recovery of ESS modules. ESS-orbiter final docking will be accomplished by the orbiter manipulator equipment.

1.7 REQUIREMENTS

The study requirements from the study control document, as revised, are presented in Volume II, Technical Summary of this report, and they reflect criteria used in developing the operations of the ESS.

1.8 ESS MISSIONS

The Expendable Second Stage will be used in conjunction with a space shuttle booster in placing large payloads in low earth orbits. Three potential payload configurations were considered for detailed application in defining ESS Phase B design requirements.

Space Station (MDAC); 176,960 lb; 34 ft diameter by 111 ft long
Mission: 55° x 270 n mi

Reusable Nuclear Shuttle (RNS) 83,000 lb; 33 ft diameter by 170 ft long
Mission 31 1/2° x 260 n mi

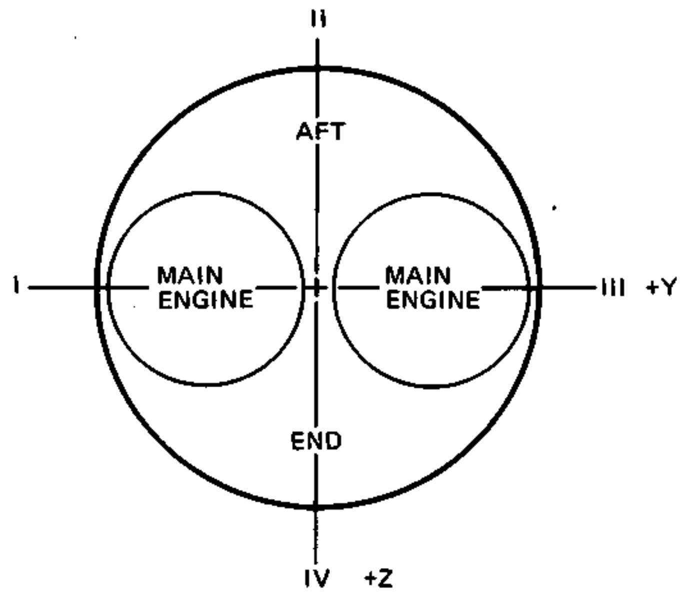


Figure 1-2. Vehicle Orientation for Flight

Space Tug; 107, 180 pounds; 15 ft diameter by 80 ft long
Mission: 28 1/2° x 100 n mi

The ESS is designed to provide for those payloads. The ESS is therefore designed for greater capability for some of the potential payloads and missions, but the single system provides flexibility in payloads and missions. Payload weight and orbit parameters for maximum capability of the system are discussed in Volume II.

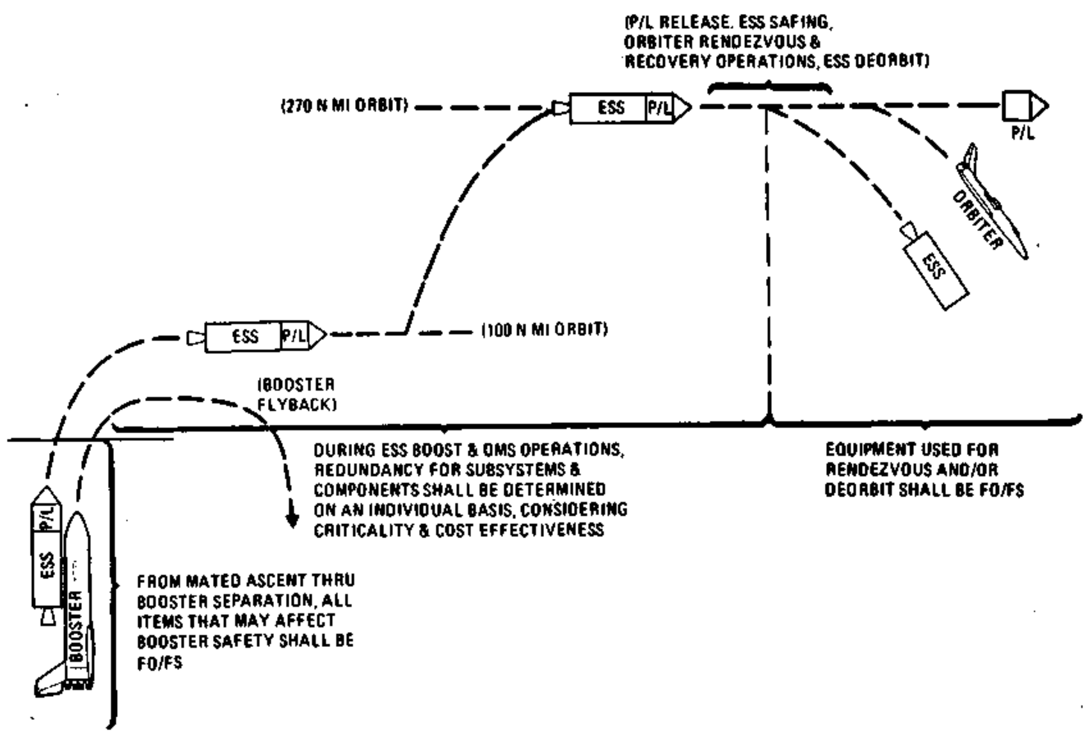


Figure 1-3. Mission Profile

1.9 OPERATIONS CONCEPTS

The operations concepts described here are based on final Phase B trade studies, the study requirements, and the ground rules and assumptions.

These concepts provide a framework for the ESS operational requirements. These requirements have been developed in conjunction with and are compatible with the Space Shuttle Program.

The space shuttle booster/ESS launch combination will be vertically positioned at launch. The ESS replaces the orbiter on the booster and similar launch-site checkout sequencing, overall operations philosophy, and launch pad positioning are utilized. The ESS prelaunch checkout will be based on the maximum effectiveness of the ESS on-board equipment. The payload will be larger and stacked above the ESS, rather than being internally stowed as with the orbiter.

When the first vehicle arrives at the operation site, it will be identified, inspected for damage, and mated to the booster in the horizontal position. The mated vehicles will then be subjected to the horizontal dynamic modal vibration test program. The vehicles will then be demated and their respective prelaunch and launch operations continued. The data from the dynamic test program will be used to verify flight control program parameters.

The prelaunch and launch operations will be similar to those successfully demonstrated on the Apollo/Saturn Program, but will require less time as a result of using the Space Shuttle subsystems and concepts.

The above operations and the test acceptance of ESS subsystems will be conducted by approved engineering and system safety procedures. Prior to the test of the first flight article, a test hazard analysis of the end-to-end test setup (facilities, GSE, booster, and ESS) will be conducted to identify hazards which could cause loss of life or damage to the vehicle. Prior to the conduct of the test, these identified hazards will be removed or controlled.

Based upon the hazard analysis, pre-established emergency shutdown and backup instructions will be identified in the test procedures for use in emergencies. Hazard analysis after the initial ESS will only be required where modifications could induce system hazards.

2.0 GROUND OPERATIONS

2.1 LAUNCH OPERATIONS

Launch operations in accordance with the NASA requirements, for the ESS/booster will be from Kennedy Space Center (KSC). It is planned that two ESS will be launched each year. Launch operations for the booster and ESS are illustrated in Figure 1-4.

The launch operation functions covered by the ESS Top FFBD's 3.0 and 2.0 are defined herein, commencing with receiving and inspection, and continuing through storage, installation of reusables, premate checkout, booster mate and interface verification, stack and erection, payload installation and verification, transport to pad, launch readiness checkout, and countdown. ESS impact on launch pad operations will be held to the minimum and will involve only those operations which, for design or safety reasons, cannot be accomplished in the low bay area and those operations necessary for launch preparation. Flight and ground crew exposure to hazardous conditions will be held to the minimum.

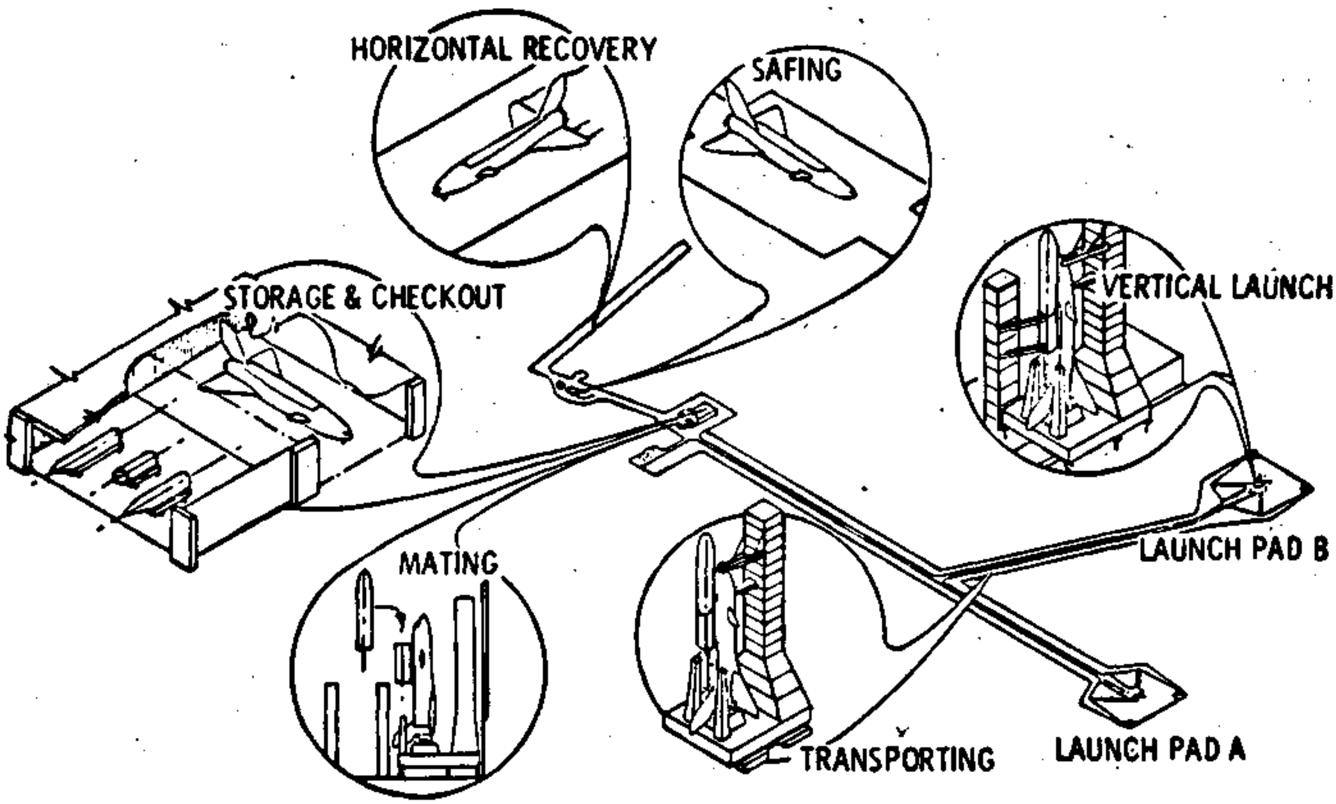


Figure 1-4. ESS/Booster Launch Operations

The vehicle will be maintained as nearly as practical in the flight configuration during all scheduled pad operations. The ESS processing timeline for the KSC launch operations to accomplish the functions to be discussed is shown in Figure 1-5.

2.1.1 Receiving Inspection

After arrival at KSC, the ESS is placed in the low bay of the Vertical Assembly Building. Receiving inspection of the ESS is performed for depackaging and identification and damage verification (ID&D) while the ESS is in the horizontal position on the transporter. The stage is also rotated on the transporter to verify that no equipment is detached.

The recovered and refurbished components can be installed at this point. The engines may be installed with the ESS in a horizontal position using equipment provided in the orbiter. The stage is then placed vertically on the ESS handling fixture — Saturn transporter. (Avionics installation may be delayed until the ESS is raised to the vertical position.)

The recovered ESS components will, after removal from the orbiter, be subjected to a receiving-inspection for ID&D. Those components will then be sent to the respective refurbishment site, and then returned for installation. Refurbishment of the engines is expected to be minor and accomplishable at the operations site.

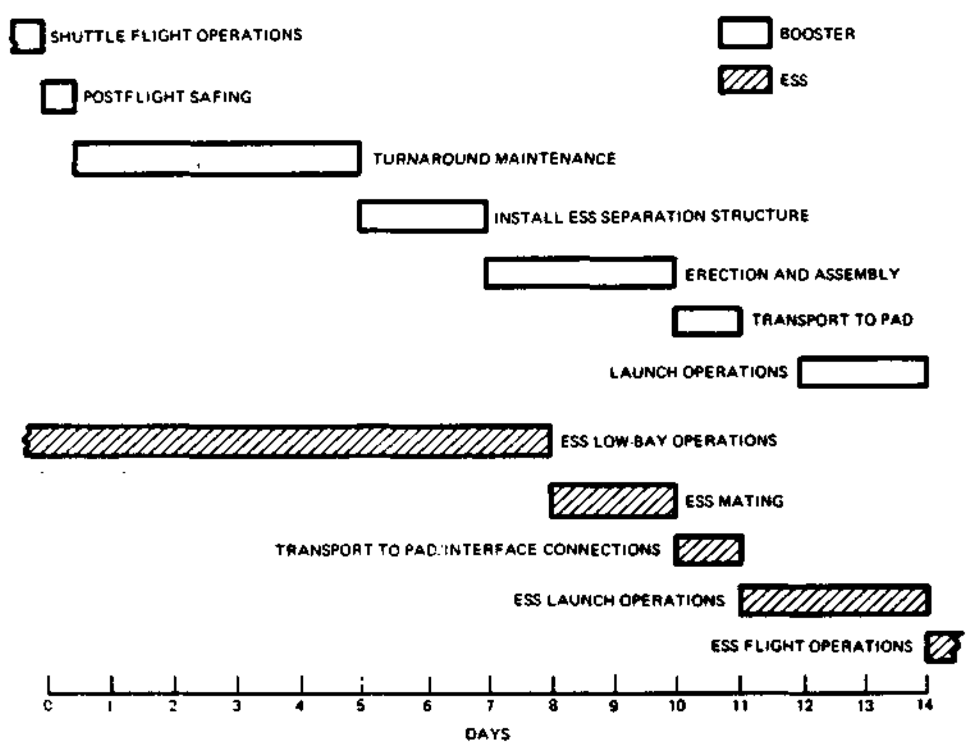


Figure 1-5. Ground Operations Timeline

2.1.2 ESS Storage

If the ESS is placed in storage, storage procedure encompasses pre-storage, storage, and post-storage maintenance and checkout.

Pre-storage. The configuration of a system element being placed into storage will be established prior to committing it to storage and will be maintained in accordance with applicable documentation. The pre-storage activities will include such activities as visual inspection of all accessible vehicle exterior surfaces, and the installation of protective covers and desiccants. All umbilical interfaces and access parts not required for storage monitoring purposes will be provided protective covers. Disconnected electrical interfaces on subsystems will be maintained and secured. Positive pressure will be applied to pressure subsystems and the subsystems secured.

The vehicle pressure systems will be provided specified blanket pressures and the moisture content of the atmosphere within the subsystems will be verified to be within acceptable limits. A listing of the vehicle valve positions for storage will be established and verified. All propulsion system thrust chamber exits will be provided desiccant and protective covers. An in-storage humidity level will be established for the thrust chamber internal environment, based upon design requirements. All subsystems that require blanket pressure during storage will be identified. Main propulsion system gimbal actuator midstroke locks will be installed and the hydraulic system will be inspected for leakage. Vacuum-jacketed lines on the vehicle will be backfilled with CO_2 to 0.25 to 0.5 psig positive pressure. With all pre-storage activities completed, the vehicle will be towed to the storage area.

Storage. The vehicle will be periodically monitored during storage for conformance to storage specification requirements. The controlled environmental system operation will be periodically checked. Temperature and humidity limits, with acceptable levels of variation, will be established and verified on a periodic basis for hazardous contaminants such as ozone and chlorides. Unacceptable contaminant levels will be corrected. Periodic visual inspections will be made of subsystem blanket pressures which also will be re-established if required. Throughout the storage period the vehicle will be grounded by cable to the storage area grounding grid.

Normally, vehicle checkouts and modifications will not be accomplished during vehicle storage. Accumulated tasks (modifications, soft goods replacement, etc.) will be reviewed with a view to possible early return of the stage from storage to a work flow status to minimize potential operations impact.

Post-Storage Maintenance and Checkout. Once a decision has been made to remove the vehicle from storage for utilization, storage functions will be completed and the vehicle will be transported to the VAB low-bay area. In addition to the normal checkout requirements to establish vehicle readiness for mating, additional inspections and checkouts will be required. Items will be replaced, refurbished, recalibrated, or retested in accordance with established procedures. Reuse components may be installed, if these are on the basic stage, and the stage prepared for checkout. Vehicle subsystems such as the hydraulic subsystem will be serviced to established standards. Vehicle protective covers and desiccants will be removed, and subsystem blanket pressures will be minimized. The gimbal actuator mid-stroke locks will be removed and vacuum levels re-established in vacuum-jacketed lines. A visual inspection of the vehicle exterior surfaces will be made and selected subsystem leak tests will be conducted.

A storage plan will be developed to define the extent of the preparation in storage, monitoring, and post-storage activities. This plan will be structured toward defining the work tasks as a function of the projected duration of storage.

2.1.3 Pre-Mate Operations

The ESS is connected, in the low bay area, with GSE provided for stage checkout. The stage checkout consists of a complete leak and functional test of the propulsion subsystems and of the avionics subsystems in the stage. This stage checkout is similar to the shuttle checkout, but is not as detailed as that performed for final checkout at Seal Beach; welds are not leak-checked and detailed component leak checks are minimized.

The ground and onboard checkout and fault isolation (COFI) subsystem will be exercised to check individual subsystems. Checkout of individual subsystems will be followed by a DMC and ground-computer-controlled integrated checkout. Data obtained from these tests will be evaluated to assure that each subsystem (including redundant paths) is performed satisfactorily to meet mission requirements.

2.1.4 Booster Operations

After completion of premate checkout, the flight program will be loaded into the on-board computer. Proper loading of the flight program will be verified utilizing onboard avionic equipment. Any storables, such as crew convenience items, that are required are loaded on board at this time. After completion of these tasks, the booster will be towed to the mating bay and placed in position for the hoisting operations.

The ESS/booster separation mechanism (different than that for the orbiter) will be installed and inspected to assure readiness. The booster to launcher mating surfaces will be readied for mate. The attach points will be inspected and all covers not required to maintain cleanliness will be removed.

After the above operations are completed, the booster is ready for mating with the ESS. The total operation of booster/ESS/payload mating is shown in Figure 1-6.

The lifting sling is not attached to the bridge crane, then positioned over the booster sling attach points. The sling is lowered and secured to the booster. Restraining line control of the vehicle will be maintained throughout the hoisting operation. The booster will be raised slowly until the landing gear clears the floor; lifting will be halted at this point. With electrical power and hydraulics supplied from the ground, the landing gear will be retracted and the landing gear doors closed. On-board controls will be used for this operation. Ground hydraulics and electrical power will be disconnected from the booster, and hoisting operations will then continue until the vertical position is attained.

Vertical lift is continued until clearance is sufficient to allow the LUT to be positioned beneath the suspended booster. By use of the overhead crane

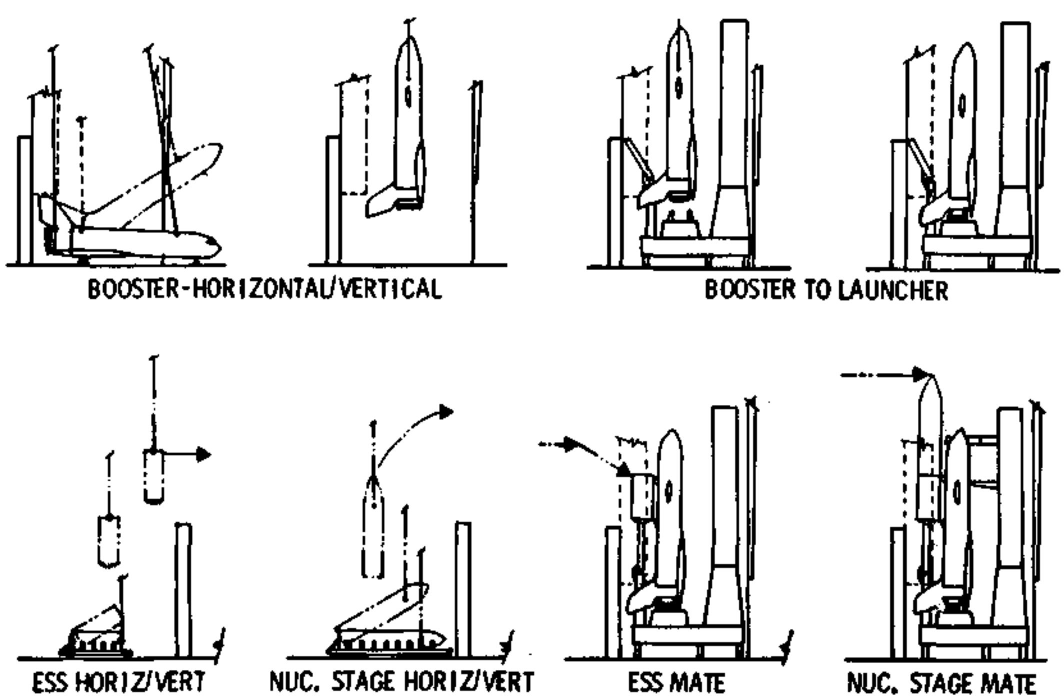


Figure 1-6. Booster/ESS/Payload Mating

and restraining lines, the booster is then lowered onto the mobile launcher. Mechanical launcher interfaces are verified and monitored throughout this operation. Launcher holddown mechanisms are attached to the vehicle and secured. All booster electrical power, hydraulic, pneumatic, and cryogenic launcher interfaces are connected and verified. Hoisting equipment and restraining lines are removed and stowed.

2.1.5 Transport ESS and Payload

After the booster is erected and verified on the LUT, the ESS is placed in a horizontal position and the ESS and payload transported horizontally on a dolly to the transfer isle adjacent to the mating bay.

Existing GSE will be used for hoisting, handling, and safety retention for accomplishing the ESS/booster mating operation.

Checkout in the mating area after mating will be limited to verification of the booster/ESS interfaces and the shuttle LUT interfaces where verification is non-hazardous.

The payload required for a specific mission (such as MDAC space station, space tug, and RNS) will be completely checked out and ready for flight prior to installation. The payload, upon completion of checkout, will be transported to the transfer aisle and erected ready for mate in a like manner as the ESS. Capability will exist during mating to support time-critical payload parameter monitoring.

Existing GSE will be used for hoisting, handling, and safety retention for accomplishing the ESS and payload mating operation.

Cables from the bridge cranes are attached and the ESS vehicle is rotated to the vertical in the Saturn transporter and erected, hoisted by crane, and transported to the mating bay where all mating surfaces are inspected and verified. The ESS is then lowered and mated to the booster ready for payload mating.

The payload and ESS mating interfaces are inspected and verified prior to final positioning and mate.

Mating the ESS and payload stages individually to the booster provides maximum clearance during transfer of the ESS and payload stages to the mating bay. If the ESS and nuclear stage payload were erected and mated prior to transfer, there would be only 20 feet (minimum overhead clearance area) available for hook-up, load bars, slings and clearance. However, two other payloads (space station — MDAC — and space tug) can be erected, mated to the ESS stage, and then transferred as one unit in a single lift to the mating bay.

2.1.6 Vehicle Mating and Erecting Operation

Vehicle erection and mating includes preparation for, and accomplishment of, mating of the booster, ESS, and payload. All activities are performed in a protected, enclosed area. Access work platforms will be utilized throughout the mating operation for visual verifications as well as in performance of tasks such as handling of erection slings, alignment operations, and interface verification.

Mating the ESS and ooster will not commence until after completion of checkout of each vehicle.

The ESS/booster/payload mate and interface verification is the only operation performed in the high bay area. No functional C/O will be accomplished in this area. Existing Saturn and space shuttle handling fixtures presently planned will be utilized to perform these operations in the most cost-effective manner.

Prior to transfer to the pad, all exterior access panels not required at the pad will be closed out for flight; all others will be installed. The mated payload, ESS, and booster is then ready for transfer to the pad on the mobile launcher. The launch pad, all servicing equipment, and GSE will have been verified prior to transfer of the mated vehicles.

2.1.7 Transportation to the Pad

The mated payload/ESS/booster on the mobile launcher will be transported from the VAB on the crawler.

The crawler will be manned by crawler personnel and safety observers. Constant communications will be maintained between all operations personnel during the transporting operation.

The crawler will proceed from the VAB to the launch pad via the crawler roadway. Only one of the two launch pads will be utilized for ESS launches. That pad will be outfitted to supply the needs of the ESS and payload, and still be compatible with space shuttle operations. Only one pad is required for ESS due to the low flight rate. After arrival at the launch pad, the mobile launcher will be positioned and lowered onto the pad. The launch pad will have been prepared to receive the mobile launcher and the payload/ESS/booster prior to their arrival at the launch pad. After the mobile launcher is lowered to the launch pad, the crawler transporter will be removed.

2.1.8 Connection and Verification of Launcher and Pad Interfaces

Launch pad operations consist of connecting and verifying the vehicles and pad interfaces, performing launch readiness checkout, and final preparation. Table 1-1 describes an evaluation conducted on the ESS launch pad configuration.

The pad-to-mobile-launcher electrical and fluid interfaces will be prepared for connecting by removing all covers and protective devices and performing visual verification of condition and alignment. Ancillary interfaces (e.g., water, communications, monitoring, warning, alarm) will be prepared in the same manner, and interfaces will be connected and verified. All fluid-gas systems interface connections will be verified by pressure testing. Warning and alarm and monitoring systems interfaces will be verified by condition simulations.

The umbilical swing arms will be connected to provide ESS access and service platforms, as shown in Figure 1-7.

Since the Phase B plan includes a fixed ESS servicing tower located on the launch pad, the umbilical will be hooked up initially there, and ESS/GSE interfaces will be verified on the pad. This will be accomplished by bringing up system pressure and leak checking the fluid lines and by command/ response verification for electrical cables.

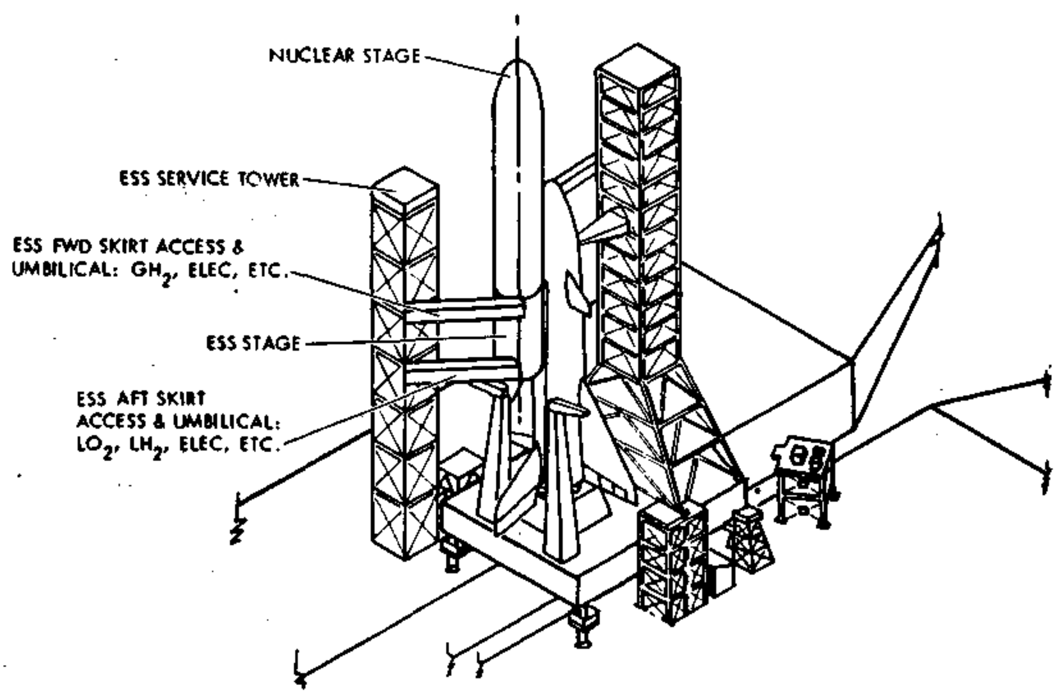


Figure 1-7. ESS/Booster at Launch Pad

Table 1-1. ESS Launch Pad Configuration Concept Evaluation

	ALTERNATE CONCEPT		
EVALUATION FACTORS	IA (LUT SWING ARMS)	IB (RISE-OFF PYLONS)	IC (PAD SERVICE TOWER)
TOTAL COST (STAGE II & FAC)	19.0	50.9	35.5
ADDED ENVIRONMENT EXPOSURE	NONE	NONE	1 DAY
DEVELOPMENT RISK	HIGHEST 3	2ND HIGHEST 2	LOWEST 1
SAFETY ASSESSMENT	LOWEST 3	2ND PREFERRED 2	PREFERRED 1
ESS DISCONNECT ASSESS.	LOWEST 3	2ND HIGHEST 2	HIGHEST 1
LIFT-OFF CLEARANCE	LOWEST 2	HIGHEST 1	HIGHEST 1
COMPATIBILITY WITH SHUTTLE BASELINE	2ND HIGHEST 2	LOWEST 3	HIGHEST 1

For the first vehicle, an umbilical swing arm test is planned. This will consist of connecting both the forward and aft umbilicals and then releasing them. After the swing arm test, the umbilicals will be reconnected and the ESS/GSE interface verified.

2.1.9 Final Checkout Operations

A launch readiness checkout will be performed after all ground support systems have been interfaced with the mobile launcher and ESS service tower and verified. The launch readiness checkout will consist of a data and control management subsystem (DCM) internal self-check on both the booster and ESS. The DCM will then be used to perform a systems check of the subsystems. This checkout will include a check of functional paths through the use of the COFI subsystem capability.

Integrated Checkout

Integrated C/O will be performed by the on-board systems and monitored by the control room in preparation for launch. These integrated checks are planned for the launch pad rather than for the high bay of the vertical assembly building, since with the fixed tower concept it would be necessary to provide additional GSE in the high bay. To avoid the expense of this GSE, all integrated booster/ESS checkout will be accomplished on the launch pad. Malfunctions occurring at the pad will be corrected on the pad, with that part of the checkout being performed again to assure that the vehicle is ready for continuing final checkout.

Checkout and servicing of the payload is undefined at this time and all payloads are assumed to be autonomous. Further definition of payload operations will be performed in the design phase. The logical approach is to perform as much payload checkout as possible prior to mating the payload to the ESS, then performing integrated checks and servicing on the launch pad. An extension of the ESS service tower and separate payload swing arm(s) can be provided and will be the responsibility of the payload contractor.

ESS Servicing Verification

Servicing the ESS will be accomplished within two hours. It is assumed that any payload servicing will also be conducted concurrently with ESS activities. The servicing consists primarily of loading tanking propellants and providing high pressure helium to pressurize the propellant tanks and stage pressure receivers. Various other operations are required such as providing purges, thermal conditioning gas, and valve actuation gas. Electrical power and control is ground supplied until shortly before liftoff when the vehicle power supply is switched on. All hydrogen vents are connected to the facility vent system and routed to a burn pond.

Each ESS will be subjected to a cryogenic countdown demonstration test. This test will be primarily for facility and GSE verification under cryogenic conditions and ground launch crew certification rather than ESS checkout, although it will result in added ESS verification. The test will consist of a simulated launch with the countdown terminated just prior to booster main propulsion ignition. After countdown, propellants will be detanked and a limited series of re-verification checks will be run. For subsequent vehicles, the countdown demonstration will be an integrated vehicle check with no cryogenics tanked.

Servicing Operations

Launch servicing operations begin with the loading of cryogenic propellants, LO_2, and LH_2. After propellants are loaded, the flight personnel are transported to the launch site and board the vehicle. Propellants are replenished until the final stages of countdown operation. Final system activation and countdown operations are performed. Both airborne and ground subsystems are continuously monitored for abort conditions that could occur during launch operations.

Propellant Loading

The launch pad area will be cleared of all personnel prior to loading propellants. Chilldown of transfer lines and shuttle tankage, venting, transfer of propellants, replenishment, and termination are accomplished by an automated system with contingency pause and revert capability. After chilldown, loading of LO_2 and LH_2 into the booster, ESS, and payload (if required) will begin.

Booster liquid-oxygen rapid load will be completed prior to initiating ESS rapid load; booster liquid-hydrogen rapid load will be completed prior to initiating ESS rapid load. ESS liquid-oxygen rapid load will be completed prior to initiating ESS liquid-hydrogen rapid load.

The first phase of the loading, after tank chilldown, is a "fine load" (low rate of flow) followed by "rapid load" (high rate of flow). Completion of propellant loading is accomplished with another fine-load sequence.

Airborne level-sensing transducers, in conjunction with the ground computer system and ground transducers, will control the entire automated loading sequence. Remote control and display capability will be used throughout the countdown to monitor propellant loading. The propellant loading timeline is shown in Figure 1-8.

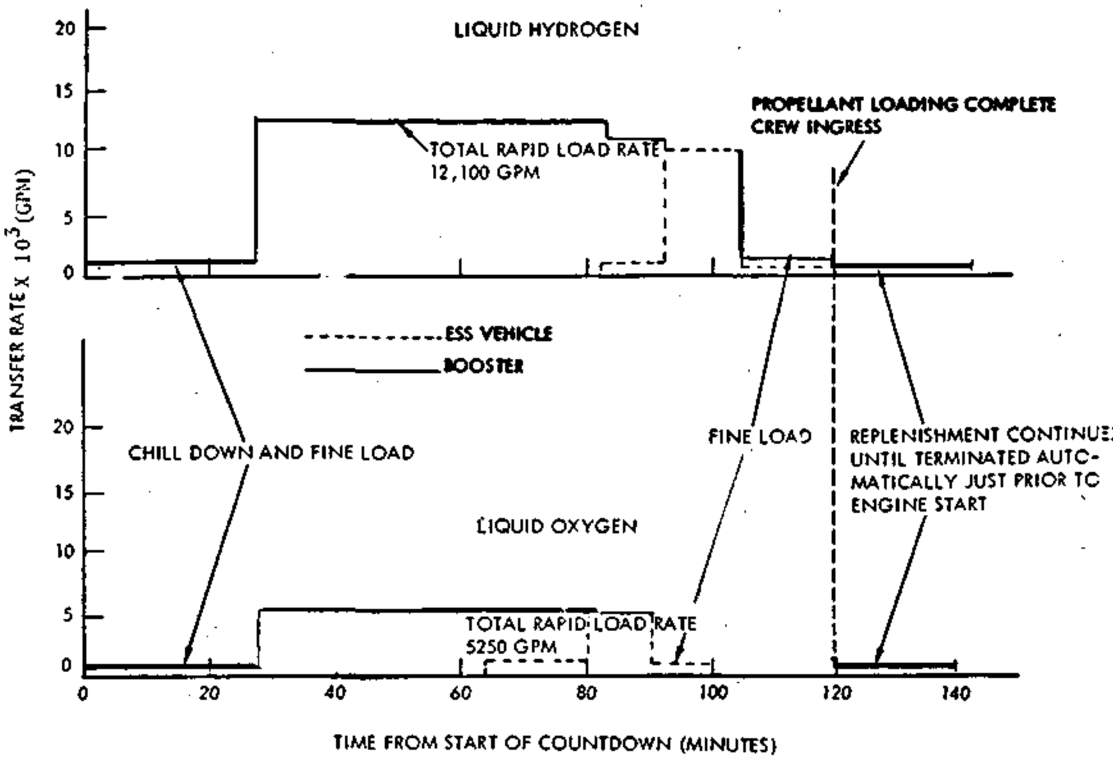


Figure 1-8. Simultaneous Propellant Loading Timeline

Propellant Replenishment. The topping mode (low flow rate) of the propellant loading control system will be used to replenish propellants lost in boiloff. The topping mode is continued throughout crew and passenger loading until time for pressurization. Termination of replenishment is an integral function of the automated terminal countdown.

Personnel Loading. The launch pad facility will have a rapid-lift elevator within the LUT to transport crew members and the closeout crew to the boarding platform access arms. It must be noted that the number of "up" passengers will generally be limited to six. The closeout crew will ensure that each flight crew member is secured and ready for launch. The access arm will be moved to a standby position just clear of the booster when the hatches are closed and the closeout crew has moved back into the LUT.

The launch vehicle design will incorporate emergency egress capabilities for the flight crew and other personnel during launch operations. This capability will be sustained as close to launch as possible. In addition, the launch facility will provide personnel safing areas to protect the crew, tower, and rescue team personnel from possible hazards.

2.1.10 Launch Countdown

The countdown will begin during the final checkout phase prior to propellant loading at T-5 hours. Countdown will consist of applying subsystem power, propellant loading, personnel boarding, final vehicle servicing, internal power subsystem activation, and additional tasks necessary to verify vehicle readiness for launch. The ESS/booster countdown timeline is presented in Figure 1-9.

With the completion of the crew boarding operations, the terminal countdown will be performed. The launch countdown checklist will be called up by the booster flight crew and displayed. Each function called out on the countdown checklist will be performed in sequence. This will include a verification that all systems are configured for launch. The GN&C subsystem will be verified for proper alignment of the inertial platform by initiating computer routine to sequence the inertial measurement unit (IMU) for alignment check. A preliminary confirmation that all supporting systems are in a GO condition will be made and electrical power will be transferred to vehicle internal power. The hydraulic system will be used to verify selected actuators. Airborne systems will be automatically scanned for proper configuration and readiness for launch. The range safety officer will verify that the range is clear for launch. The mission director will determine that all mission criteria have been satisfied and will issue the clearance to launch. The crew will then verify that the ready-for-launch summary is presented from all subsystems.

The launch program will be initiated by the flight crew. The launch sequence will progress automatically from this point to liftoff. During this sequence, the propellant replenishment will be terminated, the propellant tanks pressurized, the ground pneumatic system isolated, and the booster engines ignited. When an intermediate thrust level is reached, an evaluation of propulsion system performance will be made, a signal will be transmitted to release the vehicle stabilizing system, and the thrust level will be commanded to go to the normal power level. When the thrust-to-weight build-up is greater than 1.0, the shuttle achieves a free liftoff and rises from the launch pad, and simultaneously activates the liftoff signal.

2.1.11 Pad Aborts

Booster Abort

The pad abort (prelaunch) mode is confined to the period of crew loading. It terminates at vehicle liftoff. A decision to abort would include immediate shutdown of booster engines and crew egress. The booster crew egresses rapidly when crew safety is jeopardized, while remaining subsystems (other

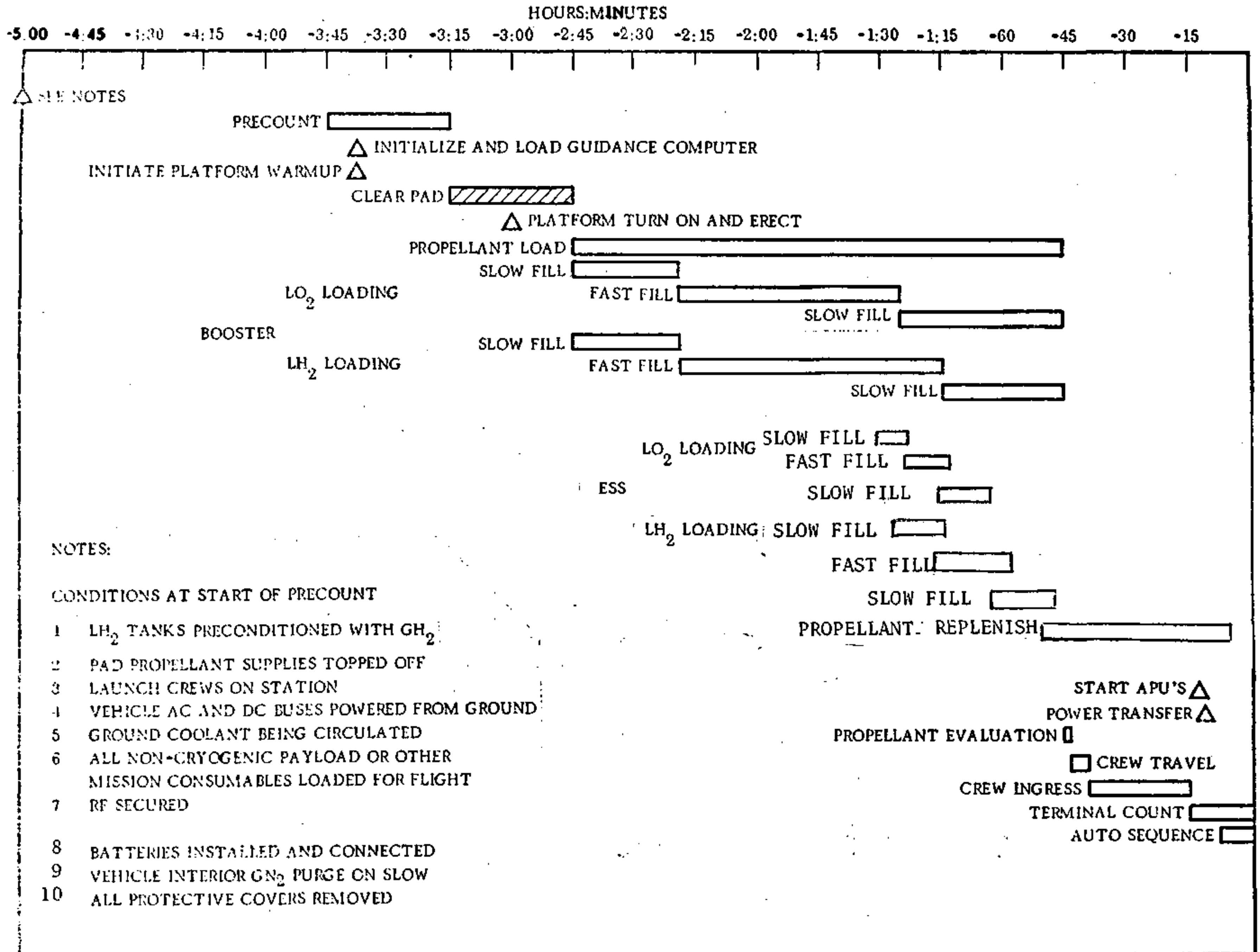


Figure 1-9. Countdown—Timeline

than the booster engines) are being deactivated. Critical systems are safed, and propellants are detanked if necessary. An inspection is performed, and any necessary maintenance and repairs. Correction of the abort condition is followed by a return to launch countdown or standby status.

ESS Abort

The period for possible ESS (prelaunch) abort is the same as that for booster abort. Subsystems are deactivated and safed. Propellants are detanked, and maintenance and repair are performed.

Preceding page blank

3.0 FLIGHT OPERATIONS

ESS flight operations comprise seven phases: mated ascent, ESS/booster staging, initial orbit insertion, mission operations, stationkeeping operations, ESS deorbit maneuvers, and ESS earth impact. All aspects of ESS flight operations are discussed here, commencing with mission planning, description of typical flight profiles, and concluding with ESS deorbit. These operational functions are defined by Functional Flow Block Diagrams 1.0 and 5.0, as shown in Figure 1-1.

3.1 MISSION OPERATIONS

3.1.1 Mission Planning

Mission planning encompasses the equipment and the services necessary to assure that the space vehicles are available for their scheduled launch and the associated mission support equipment and services are prepared to render assistance for successful completion of the mission. Primary tasks of the mission planning are:

A. To schedule all the activities and services related to each mission

B. To coordinate all activities and services

C. To monitor the various activities to ensure proper execution and the availability of the ESS, shuttle vehicle, and support equipment and services on a timely basis

D. To plan the mission launch time so the ESS mission life will require less than 24 hours. This also requires coordination with space shuttle flights to provide for the orbiter to rendezvous with the ESS for return of the ESS recoverable components.

In order to implement the planning effort, a mission plan will be prepared for each flight mission describing the mission objectives and requirements, vehicle configuration, assembly and launch schedule of the vehicles, support equipment and services requirements, mission trajectory and profile, and other pertinent flight and flight support requirements directly related to the mission. The flight trajectories, during mated ascent, are different for each of the defined payloads; thus, the software for

PRECEDING PAGE BLANK NOT FILMED

the Booster and the ESS require some minor changes to implement each mission.

3.1.2 ESS Payloads

Fourteen payload configurations were identified as candidates in Phase B for the ESS. Of that total, three were selected for more detailed performance, loads, and control analysis. These three payloads are:

Space station (MDAC), final orbit 270 x 270 nautical miles at 55° inclination

Space tug, final orbit 100 x 100 nautical miles at 28.5° inclination

Reusable nuclear shuttle (RNS), final orbit 260 x 260 nautical miles at 31.5° inclination

Variations in payload weights and final orbits have been incorporated into three different ascent trajectories shown in Table 1-2. Capability for one ESS main engine out at staging is also shown for the two lighter payloads. Typical mission event profiles for these three prime payloads are shown in Figures 1-10, 1-11, and 1-12. Optional final orbit near rendezvous capability will require additional mission time for phasing and final rendezvous braking burns. The ESS avionics subsystem will require extended capacity to accomplish close rendezvous and subsequent normal mission events within the 24-hour ESS lifetime.

3.2 MATED ASCENT

Mated ascent begins at liftoff of the space shuttle booster from the launch pad. The desired final orbit inclination angle can be achieved by launch directly into the desired plane. For inclinations greater than 28-1/2 degrees, the launch can be in either a northerly or in a southerly direction. For actual launch azimuths outside of the 44- to 100-degree KSC range limits, conditions of no-jettisonable flight hardware are imposed. For rendezvous missions the launch window will be controlled within a few minutes to minimize the inflight phasing time required with a 24-hour ESS lifetime.

The sequential phases for the mated boost initial ascent maneuver are a roll maneuver, a pitch maneuver, and an atmospheric load-relieving trajectory.

The powered-ascent trajectory of the space shuttle is pre-programmed with the trajectory and flight programs stored in the DCM. This requires a minor change of software in the booster. The guidance computation is based

Table 1-2. Ascent to Initial Earth Orbit (100 x 66 nautical miles)

Trajectory Characteristics \ Payload	Space Station	Space Tug	RNS
Booster burnout			
Duration, sec	249.8	234.3	228.5
Altitude, ft	281,749	264,562	259,343
Range, n mi	108.9	101.1	94.7
Load factor, g's	2.05	2.36	2.52
ESS burnout			
Duration, sec	248.5	184.8	163.9
Altitude, ft	399,984	400,032	400,016
Range, n mi	714.2	558.9	506.4
ESS burnout			
(one engine out at staging)	Capability not available		
Duration, sec		342.2	291.8
Altitude, ft		400,000	400,048
Range, n mi		927.9	807.4
Payload capability (with margin)	183,001	127,304 lb.	93,025 lb.

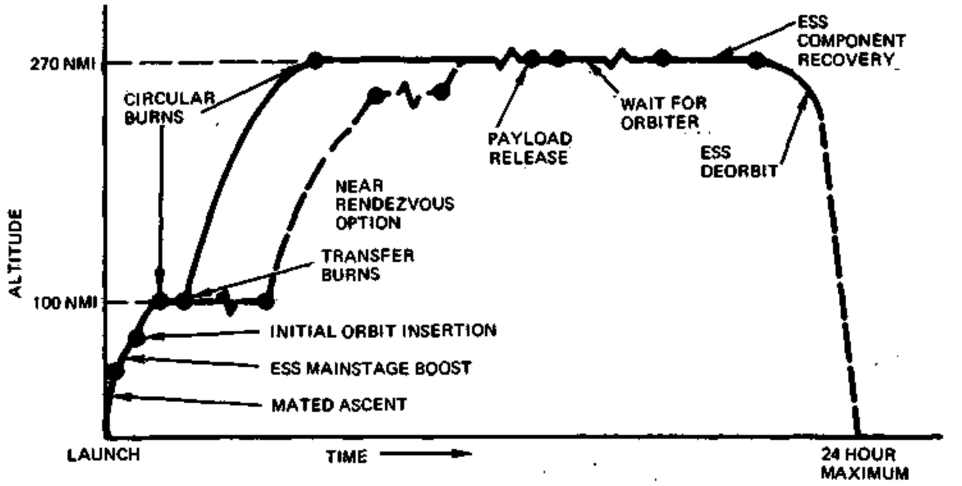


Figure 1-10. Space Station Mission Event Profile

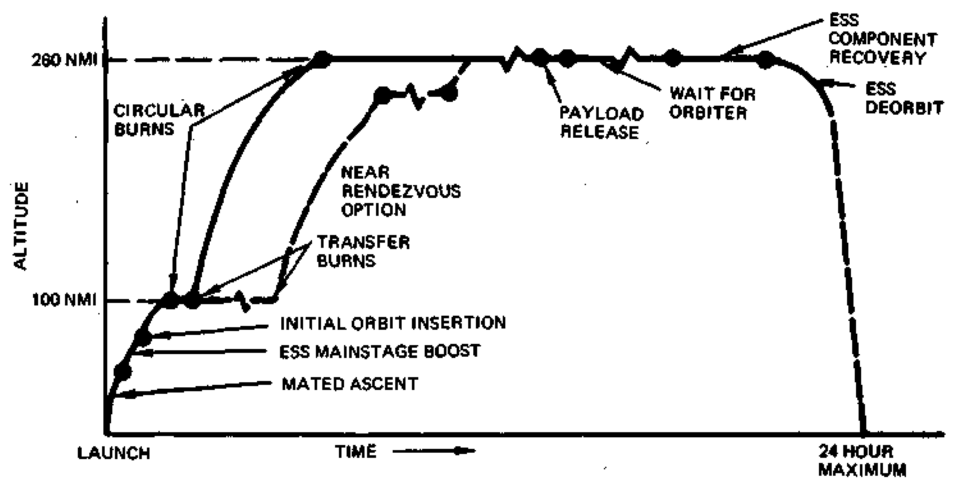


Figure 1-11. RNS Mission Event Profile

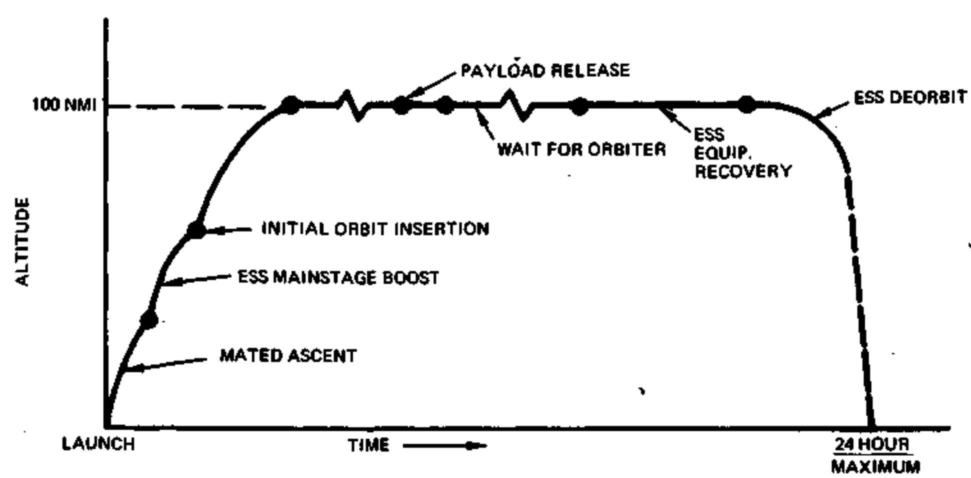


Figure 1-12. Space Tug Mission Event Profile

on the pre-programmed stored data and updated by velocity and attitude inputs from the IMU. Control of the flight during mated ascent trajectory is managed by the guidance, navigation, and flight control elements of the booster integrated avionics subsystem.

Ground Control will monitor both vehicle systems and the launch trajectory, verify on-board measurements, readings, and computations, and assist the crew in making "go/no-go" decisions only to the extent necessary to assure safe flight. Critical ESS measurement information will be displayed in the booster for crew control. The crew will have emergency controls for implementing aborts, ESS engine starts, and staging. Range safety will monitor the shuttle trajectory.

3.2.1 Initial Ascent Maneuver

At liftoff, the booster engine thrust vector control (TVC) will be activated by the DCM, and an auto-sequence pre-programmed maneuver will be commanded to provide for a vertical flight. At the same time, the booster crew will initiate the post liftoff checklist and TVC activation. Following liftoff, the space shuttle ESS vehicle will be aligned for vertical flight. Vertical flight will be maintained until the vehicle has risen approximately 100 feet above the tower.

3.2.2 Roll Maneuver

The vehicle roll maneuver is performed after clearing the tower to enable a pure pitch maneuver into the azimuth required for the desired initial orbit inclination.

3.2.3 Pitch Maneuver

Upon completion of the roll maneuver, the pitch program is initiated.

3.2.4 Ascent Guidance

The primary functions for ascent guidance are continuing the pitch program, regulating the thrust of the booster engines, and maintaining the roll and yaw attitude of the vehicle. The trajectory will minimize atmosphereic load effects for minimum load impact on the shuttle booster.

3.3 BOOSTER/ESS STAGING

The separation subsystem must provide safe separation capability during mated ascent, for both normal and abort-initiated conditions. The booster-ESS separation sequence is shown in Figure 1-13.

Following a nominal four-minute mated boost interval, the normal staging sequence will be initiated by activation of near-depletion sensors in the booster LO_2 tankage. Cross-monitoring of the booster and ESS engine thrust profiles will be continuous via hardware during the staging sequence for automatic monitoring and control.

The sequencing requirements are:

A. Booster propellant near-depletion sensors activated.

B. Initiate ESS main engines, start to minimum power level (MPL); initiate booster main engines cutback to MPL; maintain booster inertial attitude by engine TVC.

C. Initiate "start motion" linkage separation; initiate booster engine cutoff.

D. Initiate ESS engine thrust increase to normal power level.

E. Initiate final separation.

F. Arm ESS propellant dispersion system

The complete booster/ESS separation sequence will be controlled by the DCM in both vehicles. Any abnormal engine performance conditions on either ESS or booster will be compensated for by maintaining the predicted relative total thrust profiles. For example, if only one ESS main engine begins operation, the power level of that engine will be increased above MPL prior to initiating booster engine cutoff. (See Figure 1-14 for the thrust scheduling sequence.) Final separation releases the forward and aft ESS attachments near the ESS pivot ends as the upper stage is thrust upward by linkage motion.

To determine the characteristics of a normal booster/ESS separation a simulation program was run using the RNS as a typical payload. The results of this study are illustrated in Figure 1-15 which presents this data for three seconds after the first ESS motion.

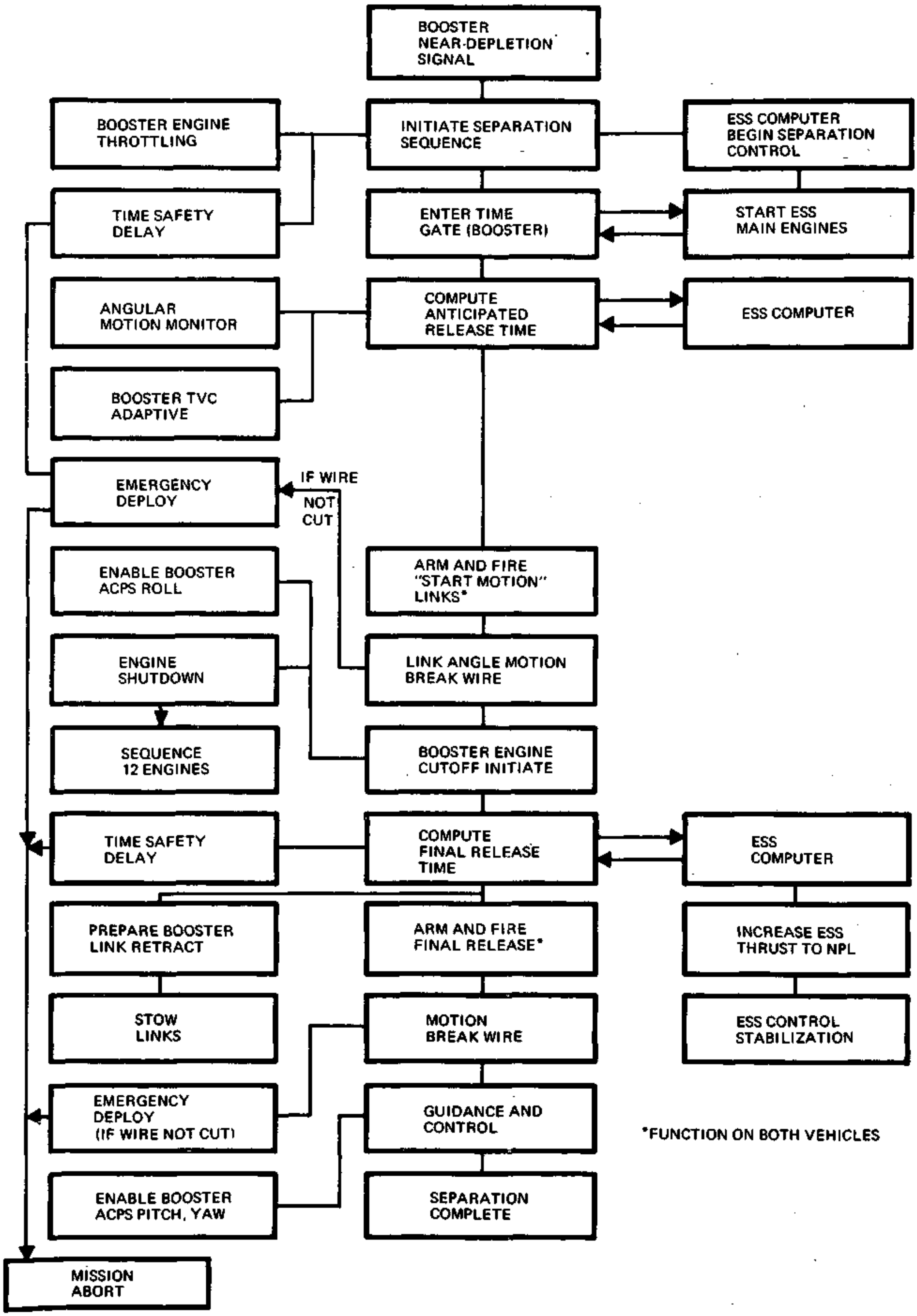


Figure 1-13. ESS/Booster Separation Sequence

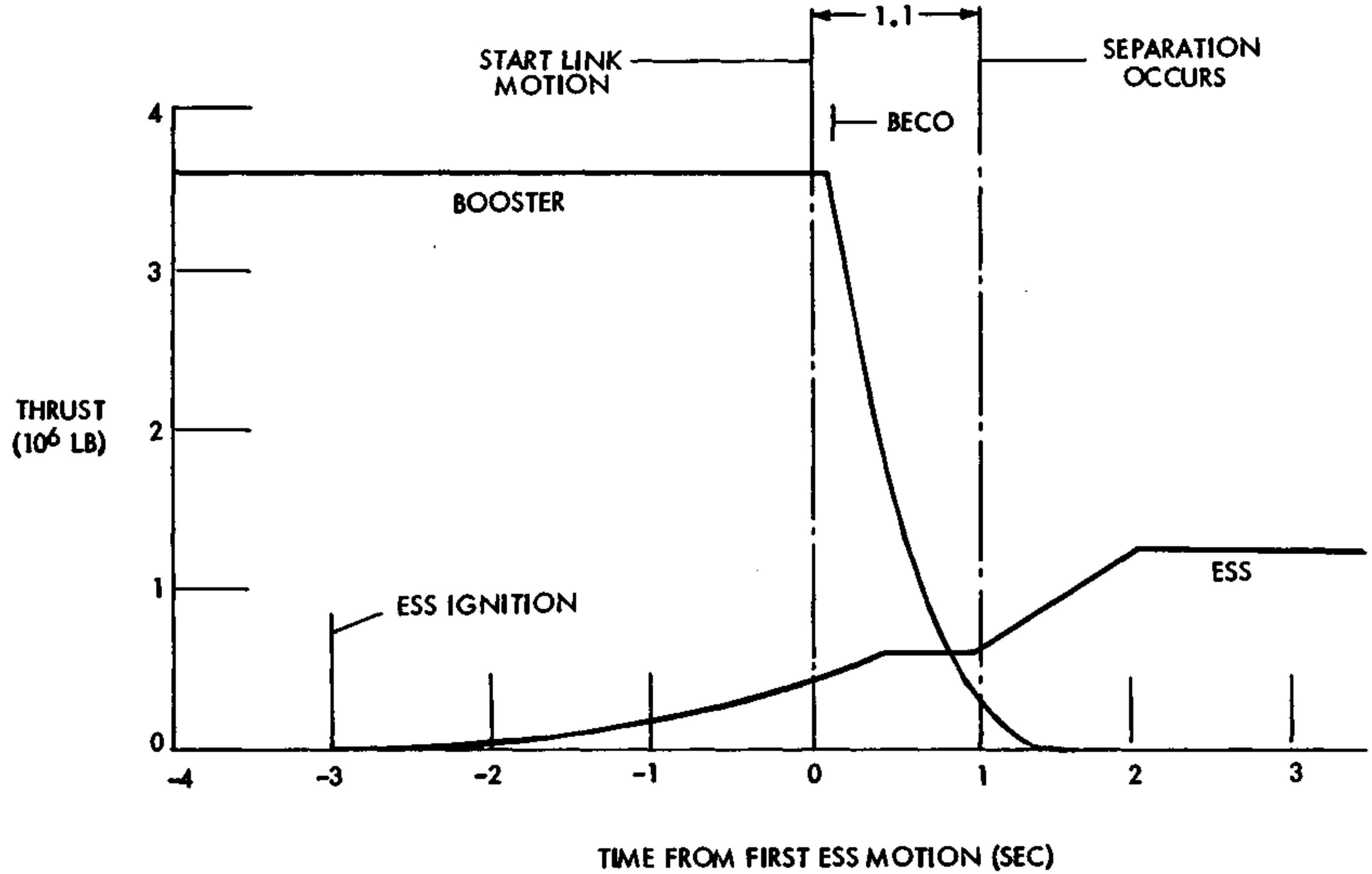


Figure 1-14. ESS/Booster Staging

PITCH RATES (INERTIAL)
(DEG/SEC)

TIME (SEC)	BOOSTER	ESS
-2	+1.65	+1.65
-1	+0.94	+0.94
0	+1.82	+1.82
1	-1.44	+0.08
2	-1.53	+1.87
3	-1.58	+1.71
4	-1.62	+ .87

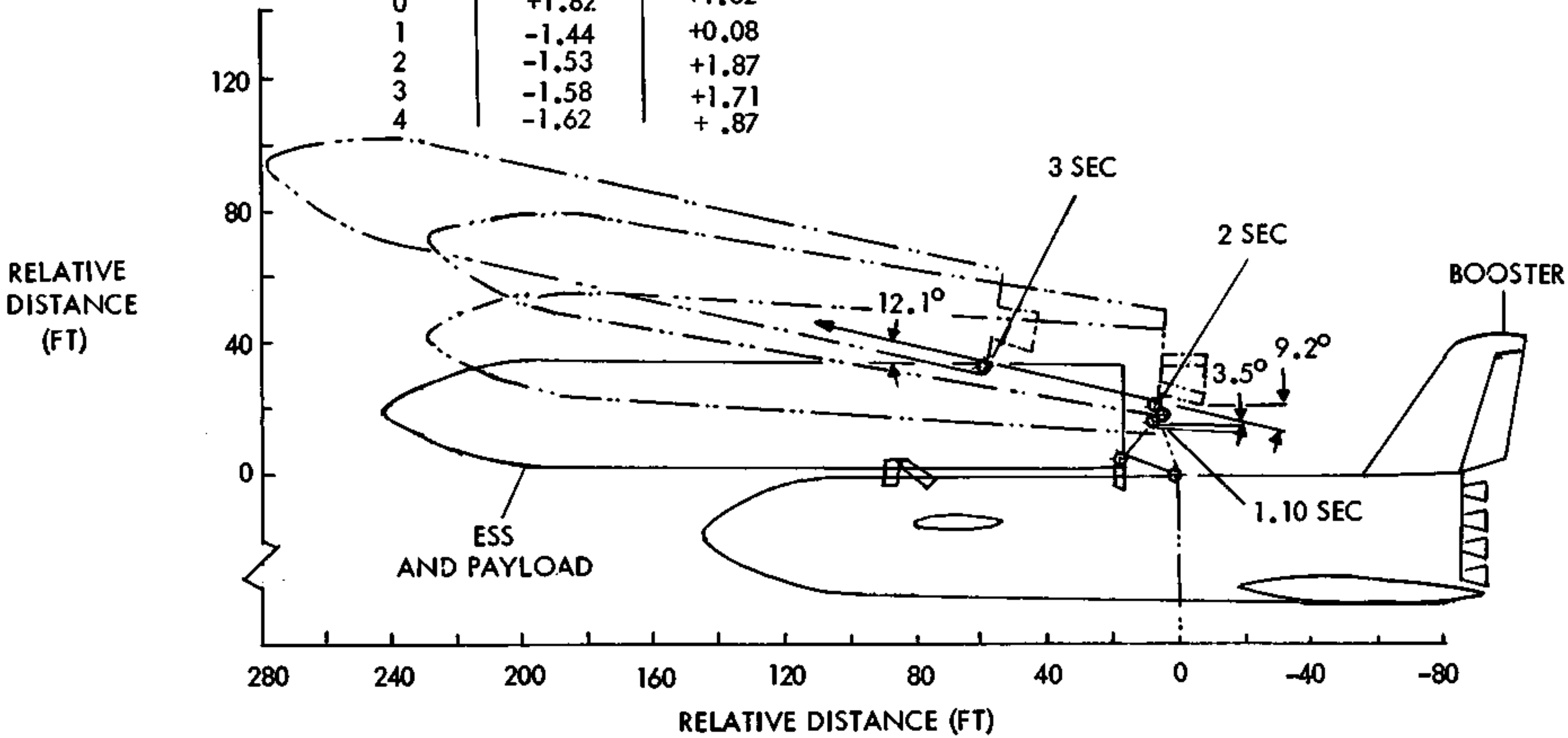


Figure 1-15. ESS/Booster Staging With RNS Payload

3.4 INITIAL EARTH ORBIT

The ESS main engines will inject the ESS and payload into a 100 x 66 nautical mile orbit. One-engine-out at staging will not prevent attainment of proper parking orbit conditions for lighter payloads. ESS engine cutoff will be effected by sensed velocity. Table 1-2 lists nominal trajectory characteristics. Following ESS mainstage cutoff, main propellant residuals will be dumped through the main engine valves; the propellant Dispersion System will be safed.

3.5 ESS ASCENT OPERATIONS

3.5.1 Orbit and Phase Changes

The ESS coasts in a 100 x 66 nautical mile orbit to the circularization burn at apogee. Missions without near-rendezvous requirements will employ from 100 nautical miles to final orbit an elliptical transfer burn and another circularization burn. The space tug payload activities will be confined to the payload release function.

Payloads to be delivered in a near-rendezvous final orbit with a passive target vehicle will utilize the 100-nautical-mile orbit for phasing corrections with respect to the higher target vehicle. The final ascent will incorporate a circularization maneuver in a 10-nautical-mile lower orbit before terminal phase rendezvous events leading to final 11 ± 10 nautical-mile accuracy with the target vehicle.

3.5.2 ESS Payload Separation

Upon achievement of the final mission orbit, the ESS and mated payload will perform stationkeeping maneuvers to maintain the desired orbit. Release of the payload will be sequenced in a compatible scheme with each payload's unique capabilities and mission objectives. A payload launched for independent functioning in orbit would be released by an ESS command and the ESS will then translate a safe distance to a safe orbit by use of the ACPS following separation. If the final orbit has been a close rendezvous with a target vehicle, the ESS ACPS will maintain the initial relative stationkeeping position with the passive target vehicle.

Transferral of the ESS payload to the target vehicle is outside the scope of this study, but the method probably would depend upon the availability of a manned space tug type of vehicle. For this study, payload separation will be accomplished either with a docked retrieval vehicle or through release of a passive payload with subsequent retrieval by a space tug. For either condition, the ESS payload separation could be sequenced by the retrieval vehicle's crew within the nominal ESS flight timeline. In the event that the orbiter vehicle, scheduled for recovery of ESS subsystem elements, should arrive before ESS payload separation, the orbiter docking will not be initiated until after completion of the ESS payload release.

3.6 ESS COMPONENT RECOVERY

Recovery at the main propulsion and avionics components will be accomplished in space after the ESS has completed payload separation. The recovery will be made by the space shuttle orbiter within the mission lifetime of 24 hours.

Provisions must be made in the ESS design to accomplish recovery - a neuter docking port and equipment separation devices. The docking port has been provided on the exterior of the ESS at Position III. This port is identical to the one on the space station and the same docking adapter is used. The engine separation is accomplished using separable bolts, the avionics by separable connections.

The basic operation is shown by Figure 1-16 and consists of the following ten steps:

1. The space shuttle orbiter performs near rendezvous with the ESS. The ESS must maintain proper attitude during this operation.

2. The space shuttle orbiter crew controls the removal of the space station docking adapter from the orbiter cargo bay using the manipulator arms.

3. A majority of the separable bolts attaching the engine to the ESS are fired. The feed ducts, engine fluid panel, engine electrical panel and thrust vector control system are severed.

4. The docking adapter is mated to the ESS docking port. The manipulator arms then mate the adapter (with ESS) to the orbiter docking port. Once the docking adapter is mated to the ESS, the ESS ACPS is deactivated.

5. The heat shield is opened, the manipulator arm tool changed (if required), and the manipulator arms attached to an ESS main engine at the handling point.

6. The gimbal block separable bolts are fired. The engine is now completely severed from the ESS.

7. The engine is removed and placed on a storage rack in the orbiter cargo bay.

8. The other ESS engine is removed and placed in the cargo bay.

9. After completion of engine removal, the avionics packages are removed and stored.

10. The ESS and orbiter remain docked until final ESS attitude correction, just prior to deorbit of the ESS.

No orbiter hardware impact has been identified thus far which can be attributed to the ESS engine or avionics recovery operation.

3.7 ESS DEORBIT

Following ESS subsystem module recovery by the orbiter, the two vehicles will remain docked and undergo stationkeeping by the orbiter for the desired deorbit phasing interval. Prior to the intended deorbit burn initiation location, the orbiter will turn around the docked unit and orient into the ESS retrograde attitude. Orbiter undocking will be conducted subsequent to activation of those ESS subsystems needed for deorbit. The ESS-to-orbiter docking adapter will be stored in the orbiter bay after separation.

The actual retro-maneuver includes the initial ESS hold attitude for the OMS engine retro-burn, and subsequent ocean impact. The ESS retro-burn will be initiated approximately 135 angular degrees ahead of the impact area. The vehicle retrograde attitude will be maintained until engine cutoff.

3.8 ESS EARTH IMPACT

Consideration of ESS deorbit fragmentary effects upon populated ocean areas has shown that usually two opportunities exist during each orbit for selection of a safe impact zone. Examining the orbit (270 nautical miles, 55 degrees inclination) indicates there exists the capability to schedule ESS deorbit maneuvers within any orbit in a 24-hour lifetime, assuming that any unpopulated ocean area is acceptable, although some ocean regions are distant from ground tracking and support forces.

The definition of unpopulated ocean areas has been formulated from A Study of Maritime Mobile Satellite Service Requirements, Frequency Planning, Modulation, and Interference Analysis. Volume I of that study, Contract DOT-GG-00505A, "National and International Merchant Vessel Population and Distribution: Present and Forecast," included the data presented in Figure 1-17. Shaded zones represent ship densities of 8 or less forecast for 1980. Using the predicted ship density and an estimated

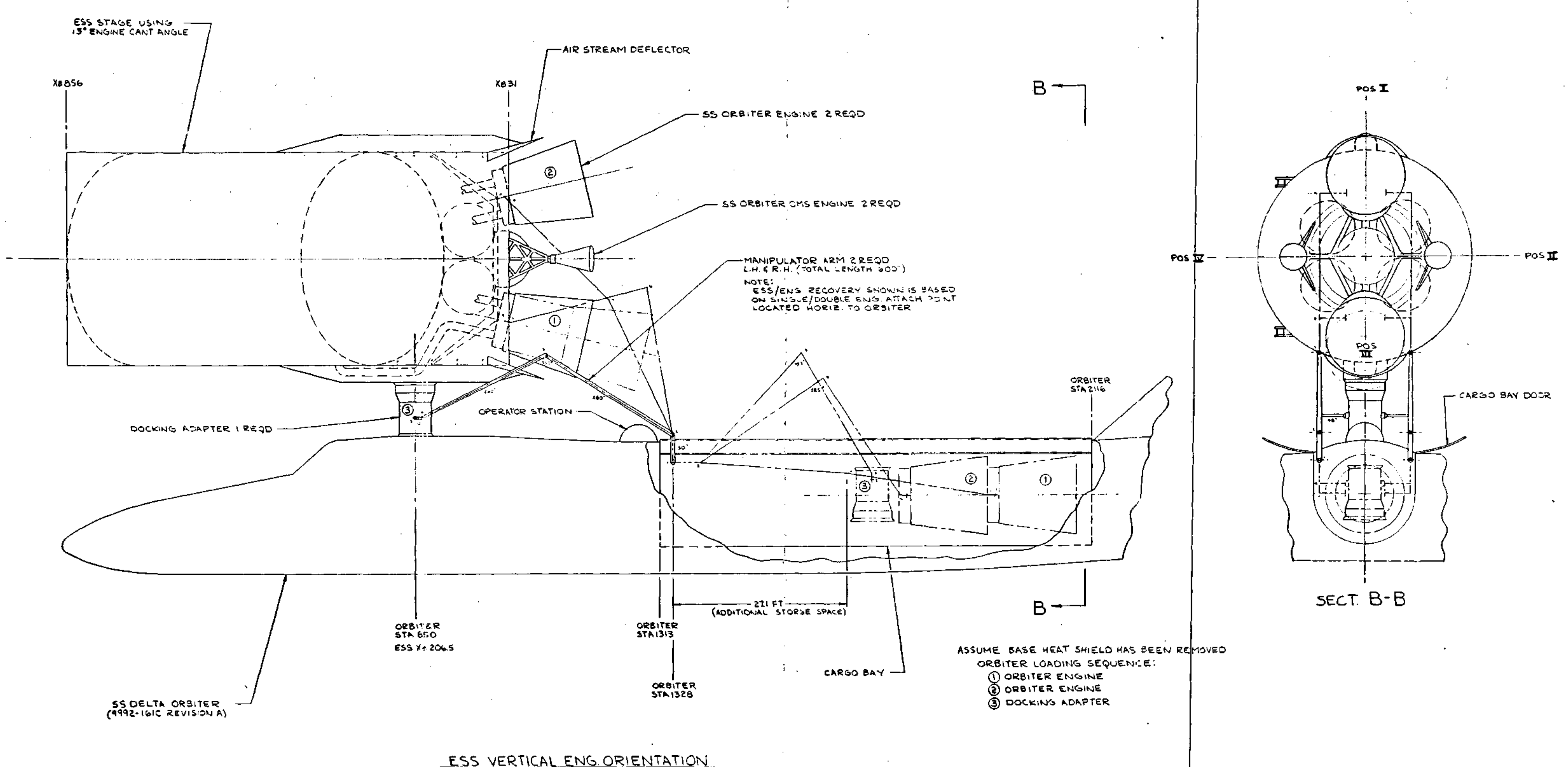
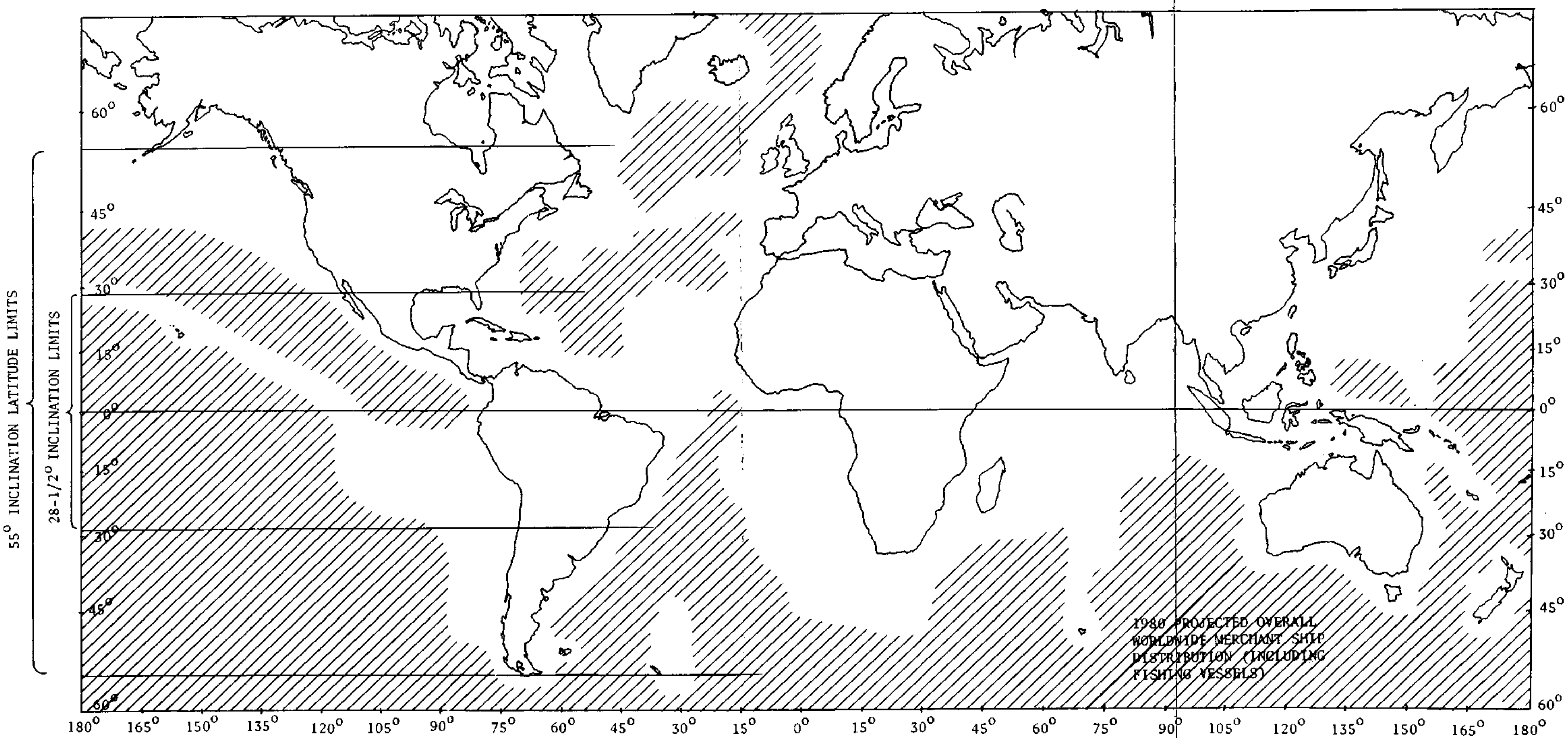


Figure 1-16. Recovery Operations

I-39

FOLDOUT FRAME 1



I - 41

Figure 1-17. Ship Distribution

FOLDOUT FRAME 1

FOLDOUT FRAME 2

ESS fragment quantity, the hit probability can be projected. This probability was based on an assumed ship size of 360 by 80 feet and an average earth ocean area of 75,000 square miles for each ship density value. As an example, in Figure 1-18, a vehicle breakup upon reentry into 25 pieces would result in a ship impact probability of 10 per one million (10^{-5}) in any world zone where the ship density was 8. This probability is comparable to the present commercial airline accident rate, which represents a realistic value. Based on a ship density of 8 yielding the 10^{-5} impact probability, a definition of unpopulated ocean areas is those regions of 8 or less projected ships.

A landing footprint of 1500 by 60 nautical miles will fit in most open ocean areas having ship densities of 8 or less. Figure 1-19 presents the expected range variation or resulting footprint size due to variable parameters of deorbit impact. Either northeasterly or southeasterly launch azimuth into a 270 nautical mile by 55 degree circular orbit would allow at least one opportunity each orbit for ESS deorbit, considering the acceptable impact areas of Figure 1-19 within 55 degrees north and south latitudes.

For missions with orbit inclinations of less than 55 degrees, reduced orbit tracing of acceptable ocean impact zones occurs. The opportunities for deorbit will be more restricted than would be possible for the 55-degree mission.

3.9 MISSION ABORT OPERATIONS

The primary abort situations are assumed to be (1) critical (fire and/ or explosion) and (2) noncritical (partial loss of thrust or TVC system failures). The failure criteria of fail operational/fail safe for mechanical, electrical, and electronic subsystems will result in an abort action at the fail-safe level for these subsystems. Catastrophic system failures that may occur in the lifetime of the vehicle system are minimized through emphasis on design. Assessment of abort conditions depends upon mission rules and is continuous throughout prelaunch, boost, and mission operation phases.

The decision to abort can result from critical or noncritical failures. A critical failure is defined as any failure which can result in loss of life or loss of the vehicle. Noncritical failures are defined as (1) any failure which can cause an immediate (safe) mission flight termination; (2) inability to achieve primary or secondary mission objectives; or (3) launch scrub or delay.

3.9.1 Booster/ESS Pad Abort

The pad abort (prelaunch) mode begins with crew loading and terminates at vehicle liftoff. Pad abort operations are similar for shuttle and ESS. A

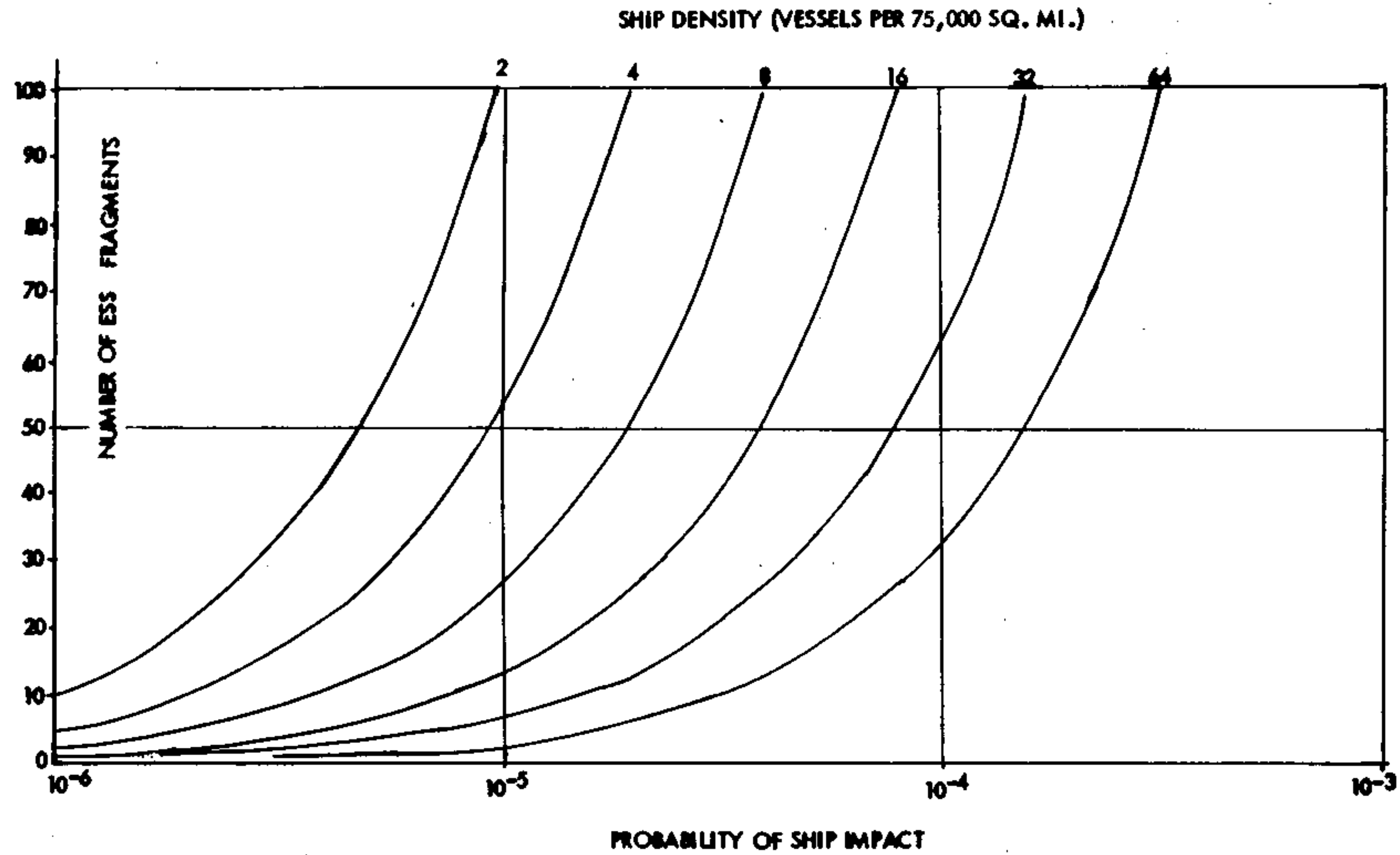
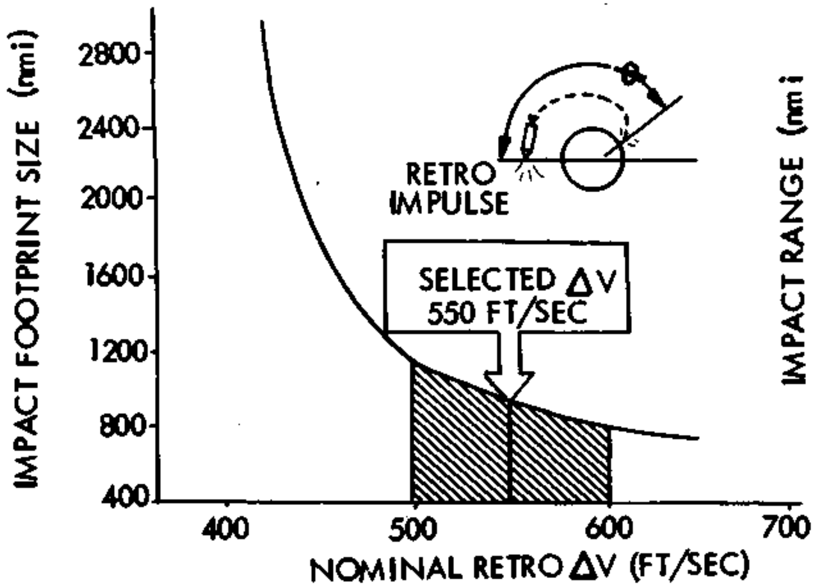
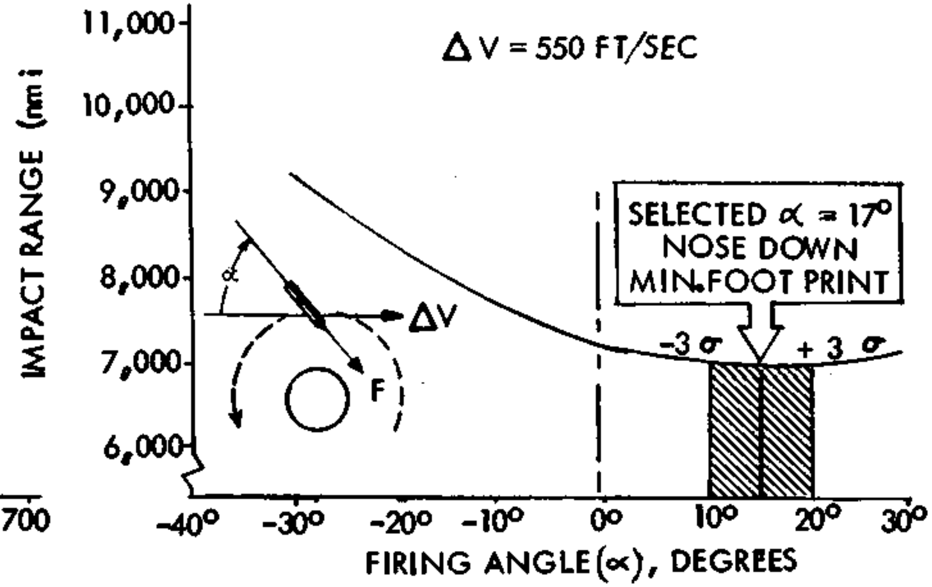


Figure 1-18. ESS Debris Probability of Ship Impact





VARIABLE	NOMINAL VALUE	BEST CONDITIONS PERTURBATION	BEST CONDITIONS TOTAL RANGE VARIATION (nmi)	WORST CONDITIONS PERTURBATION	WORST CONDITIONS TOTAL RANGE VARIATION (nmi)
VEHICLE BREAKUP	BREAKUP AT 300,000 FT ASSUMED	W/C_DA VARIES FROM 10 TO 1000 LB/FT^2	400	W/C_DA VARIES FROM 10 TO 1000 LB/FT^2	400
RETRO ΔV	550 FT/SEC	±1%	130	±4%	510
FIRING ANGLE	17°	±5°	100	±20°	450
ALTITUDE	270 nmi	±1 nmi	60	±1 nmi	60
OTHER VARIATIONS (WINDS IGNITION TIME ERROR, γ ERROR, ATMOSPHERIC DENSITY)	-	-	100	-	100
TOTAL FOOTPRINT (ALGEBRAIC SUM)	-	-	$390 + \overbrace{400}^{\text{BREAKUP}} =$ 790 nmi	-	$1120 + \overbrace{400}^{\text{BREAKUP}} =$ 1520 nmi
TOTAL FOOTPRINT (ROOT SUM SQUARE)	-	-	$201 + \overbrace{400}^{\text{BREAKUP}} =$ 601 nmi		$690 + \overbrace{400}^{\text{BREAKUP}} =$ 1090 nmi

Figure 1-19. ESS Deorbit Impact Footprint

decision to abort, attributable to either the booster or the ESS, would include immediate shutdown of booster engines and crew egress. The booster crew egresses rapidly, when crew safety is jeopardized, while subsystems are being deactivated. Critical systems are safed and propellants are detanked, if necessary. These are all remote operations. An inspection is then performed, along with any necessary maintenance and repairs. Correction of the abort condition is followed by a return to launch countdown or standby status.

3.9.2 Flight Abort

Conditions that might result in abort during the mated ascent phase of the mission are monitored continuously by the shuttle booster subsystem and crew. During initial program flights, the ground station will supplement the integrated vehicle system by coordinating operations for implementation of contingency actions.

Mated Ascent Booster Abort

From liftoff until normal mission staging, this operational capability will exist. Any booster critical failures will require early ESS separation prior to booster propellant depletion. After early staging, the booster performs an ascent to propellant depletion and then cruise maneuvers to permit recovery at the launch site.

For non-critical failures causing a premature flight termination, the mated vehicle is flown to booster propellant depletion and to near-normal staging separation.

Mated Ascent ESS Abort

The decision to perform a mated ascent ESS abort is based on critical failures, as for the booster. A critical failure is defined as any failure which can jeopardize the booster crew and/or result in loss of the vehicle. Within the ESS structural and control design capability, early staging with resulting operable propulsion requires flight to a downrange disposal site. Alternate contingency planning would permit the ESS to seek an alternate low parking orbit.

4.0 OPERATIONS SUPPORT

Operations support encompasses the equipment and services necessary to support space shuttle vehicles for scheduled launches, and associated mission support equipment and services are prepared to assist in successful mission completion. The primary tasks of operations support are to provide operations management, ground operations support, and flight operations support. Operations support requirements for the ESS are basically satisfied by the support required by the space shuttle, and do not add any major new requirements. The elements discussed in the paragraphs which follow are defined as essential to space shuttle/ESS program objectives and mission operations support.

4.1 FLIGHT OPERATIONS SUPPORT

Flight operations support includes the functions, equipment, and services required for the flight.

Mission flight support requires the following capabilities:

A. Capability to coordinate all ground flight support activities and facilities

B. Data analysis capability

C. Air and ground voice communications capability

D. Contingency support capability

E. Telemetry

F. Capability to maintain flight status information

4.1.1 Meteorological Support

The meteorological support function provides the interface among all shuttle/ESS operations and the standard available meteorological services such as forecasting space weather conditions. All meteorological activites operating together will provide meteorological support to the program.

4.1.2 Voice Communications

Voice communications to the booster and interfacing elements of the shuttle program such as space stations will be controlled to provide a single ground interface during mission operations. Voice transmission from the booster will be monitored to obtain status information and coordinate ground and onboard activities.

4.1.3 Data Communications

Data communications provide the appropriate means for uplink and downlink data transmission to and from the ESS and booster as required. Navigation aids for orbital and aeronautical operations will be provided as required. Similarly, critical crew commands will be supplied as an element of flight support.

To assure adequate communications with the ESS/booster/orbiter, a geosynchronous tracking and data relay satellite system will be used in conjunction with some of the MSFN stations to provide continuous communications path during all mission operations phases. This method maximizes the ground station operations requirements and reduces the onboard computer memory, computer programs, and storage requirements. Using this method, system condition, ESS position, error correction, etc., will be accomplished by the ground station computers and operations on a real-time basis.

4.1.4 Coordination of Flight Support Elements

This coordination involves the establishment of reporting and communication interfaces. Mission status will be supplied to all appropriate management or cognizant agencies. Voice links will be maintained between the launch facility before and during boost phases and other significant activities, as appropriate. Flight schedules will be coordinated with other space programs to minimize interference between shuttle launches and other space programs. Space station and other space program activities will be coordinated with space shuttle operations. During preoperational missions, tracking sites will be supplied with ephemeris and schedule information should tracking be required.

4.1.5 Boost Monitoring

Boost monitoring will provide the responsible ground and support elements with appropriate systems status data, range safety data, and data to support launch operations. This function also will monitor the ascent of the booster and ESS when mated to support the preparation of appropriate ground systems. Voice communications with the booster crews will be maintained. Telemetry data received from onboard systems will be recorded and the launch trajectory monitored. Vehicle separation will be monitored to verify system performance.

4.1.6 Mission Support

The mission-support function will provide ground support for the missions. Navigation aids will be supplied, as appropriate, to the operations of each mission; navigation updates, particularly of orbital position, ephemeris of other vehicles, etc., will be provided. These aids may be especially important in the rendezvcus with other vehicles. All activities in this function will be oriented toward the systematic collection of data and the implementation of alternative plans so that contingencies can be supported from the ground.

During missions, the ground will provide mission support similar to Apollo and Skylab ground support. Telemetry and tracking data will be received, processed, and evaluated in real time. Trajectory evaluation and maneuver planning will be performed on the ground to verify onboard computations.

4.2 OPERATIONS MANAGEMENT SUPPORT

Shuttle system support during operational phases include the operational tasks of maintaining a management information system, providing crew training and software preparation for each mission, and providing a scheduling capability for all system elements. Additional operations support effort is covered in the Logistics and Maintenance Plan (Section 5 of this volume).

4.2.1 Fleet Management and Planning Support

The fleet management and planning (FMP) system will be capable of overall planning and scheduling of shuttle activites including ground support operations and individual mission sequences. In addition, the FMP system will prepare and verify vehicle onboard software systems for each flight.

Both long- and short-range mission profiles will be generated. Inputs from NASA management will be required six months to two years prior to a mission with descriptions of major mission objectives and constraints. Preliminary mission profiles will indicate mission feasibility and contain preliminary mission data that can be used for mission planning. As the mission approaches, refinements and alterations will be made to the mission description in response to feedback from the preliminary mission description. These refinements will include more precise mission descriptions, including both detailed trajectory and crew timelines.

The fleet management and planning function will provide long- and short-range schedules for both planning and implementing. Selected levels of detail will be provided for the turnaround center, simulation for training, network facilities, mission profiles and operations, crews, inventory consumables, resources, ground and flight operations, boosters, orbiters, and ESS.

4.2.2 Training and Development Support

Simulation systems will be used to provide training and development support. The primary purposes will be to train shuttle crews, support training of ground flight support personnel, and validate the booster/ESS onboard software.

Periodic training will be provided on a continuing basis for flight crews for specific mission training. The training system will allow crews to exercise their skills and practice flight procedures and operation of manipulator arms. All phases of shuttle operational activities will be covered including nominal and alternate missions. Training will include the effects of various payloads.

Contingency and abnormal condition training will be provided, including malfunctions, sensor errors, communications problems, and multipoint failures.

Simulation will support other specified ground support equipment facilities as a producer of simulated data. These data will be supplied as a tape formatted for use directly by the facility or as "live" data through data links between the facility and simulation. When data are transmitted via data link, they will include changes reflecting responses to data sent to simulation via the return data line by the facility. Support will be given to launch support, contingency control, and turnaround operations.

New or changed flight software will be tested and verified prior to use onboard by either the ESS or booster.

Specific mission training will be provided to the crews. The booster crews, their backup crews, payload personnel (when applicable), and contingency-control personnel will participate in the training sessions. The training will cover those portions of the mission that are unique or require special crew efforts. Specific mission training will vary with the missions from briefing sessions to comprehensive format-training sessions.

4.2.3 Mission Information Support

Management information upon which the operations management, scheduling, and mission preparation are based will be provided. Systematic collection of data is fundamental to the other management functions.

The fleet management and planning functions will be directly supported. The roles of fleet management, planning, and scheduling of the fleet missions and ground support, and development of flight software will be most active in the operational phase, but will commence during the development and testing phases to reach the required operational capability. The fleet management and planning system will require this function to receive, store, process, and distribute planning and scheduling information flowing among the fleet management and planning function and all ground and flight support elements of the space shuttle program. A subfunction that will provide a library repository of flight software is also included.

The need exists among all space shuttle elements to have rapid access to accurate information regarding their own and other elements. This information management capability of the mission information system (MIS) will be tailored to support individual program element requirements and will include provisions that permit any element to acquire information generated by other elements. Information may reside in MIS files or in individually maintained files at other facilities. Significant MIS subfunctions include responding to inquiries from other space programs regarding shuttle schedules and support requirements and providing administrative and utility services in the areas of system design aids, computer-assisted instructions, statistical analysis, modeling, and mathematical computations.

Operational configuration and interface information will be maintained to provide the means through which the configuration and interfaces of the total space shuttle program and all of its elements and systems can be currently statused.

4.2.4 Launch Support System

The launch support system will support launch-readiness testing and fueling, pad support, range safety, launch abort, and pad cleanup functions necessary to fulfill the launch schedule projected for the shuttle program.

Preceding page blank

5.0 SAFETY CRITERIA

The safety criteria delineated in the following paragraphs establish the preliminary safety baseline constraints and requirements required for manufacturing operations, test, checkout, prelaunch, launch, mission operations, and deorbit of the ESS.

5.1 SAFETY CRITICAL OPERATIONS

This section identifies operations involving hardware products and associated software which are considered hazardous. Included are operations identified as having a hazard potential to hardware products, associated equipment, facilities, or operating personnel during manufacture, test, checkout, static firing, launch, flight, deorbit, transport, handling, packaging, and customer use. Training for work in hazardous areas is also included.

5.1.1 Categories

The following operations have a high hazard potential to hardware product systems and are identified as hazardous:

A. Ordnance Systems - Any operation involving the handling, transporting, installing, maintenance, testing, and checkout of live ordnance devices; any operation, deactivation, or checkout of a system after live ordnance items have been installed.

B. High-Energy Pressure Systems - Any operation involving systems which use pressures in excess of 150 psi; any operation of gaseous systems having pressure vessels in which the contained energy exceeds the equivalent of 0.01 pound of TNT.

C. Cryogenic Propellant Systems - Any operation involving loading, off-loading, or system activation with cryogenics.

D. Electrical/Electronic Systems - Any operation involving the initial power-up or power-down of electrical/electronic systems of a test facility, ground support equipment, or end-item vehicle following initial installation, modification, or system repair; any power-up or power-down during initial checkout of integrated systems; any operation of a battery-powered electrical system of 28 volts or higher which does not have current-limiting devices.

PRECEDING PAGE BLANK NOT FILMED

E. Handling Operations - Any operation involving the lifting, loading, packaging, or transporting of deliverable end items, subassemblies, major assemblies, delicate components, support equipment, or dangerous materials or fluids where there is risk of damage to deliverable products or injury to operating personnel.

F. Material and Equipment Operations - Any operation involving the use of toxic, explosive, flammable, or corrosive materials or radiation devices which present a high hazard potential to products or personnel.

G. Launch and Static Firing Operations - Any operation conducted during prelaunch preparations and countdown for any launch or static firing.

H. Other Operations - Any operation classified as hazardous as a result of a hazard analysis which could damage the hardware product or injure personnel and which is not a candidate for classification as safety-critical under one of the above definitions.

5.1.2 General Criteria

The ESS and GSE designs will incorporate safety features and characteristics which permit maximum personnel and equipment safety during all phases of the ESS program ground and flight operations. Safety criteria contained herein will include, but are not limited to, the following:

A. ESS Vehicle

Units will be so located and mounted that access to them can be achieved without danger to personnel from electrical charge, heat, moving parts, chemical contamination, pyrotechnic devices, and other harmful sources.

Individual grounds will be provided for all electrical equipment.

Electrical equipment will be explosive-proof.

Sharp edges and protrusions will be avoided.

Any plumbing and tubing for liquid, gas, and steam will be clearly marked as to the contents, pressure, temperature of contents, flow direction, and any specific hazard properties.

Colors for identification of equipment and conditions will be used to guard against inadvertent operation of or accidental contact with equipment which may result in injury or damage.

B. Ground Support Equipment

GSE will be designed so that potential hazardous or dangerous areas—electrical, mechanical, or fluid—will not be a safety constraint when the GSE is being maintained, repaired, installed, and calibrated.

Propellant tanks, feedlines, engines, and liquid hydrogen ground supply systems will be attached to the site grounding grid.

Precautions will be taken to prevent formation of dangerous mixtures of hydrogen and oxygen or air. Hydrogen detection systems will be utilized to detect buildup of hydrogen concentrations, thus warning of leaks. Hydrogen equipment and piping will be purged to an acceptable chemical content with a compatible inert gas prior to introduction of hydrogen.

Sources of ignition will be removed. High operating temperature equipment or hot exhaust gases will not be permitted in the immediate area, and electrical components will be hermetically sealed and no arcing will be permitted.

Provisions will be made to prevent air ingestion in the propellant systems.

Provision will be made to safely dispose of surplus liquid hydrogen.

Ground support equipment fuel and oxidizer lines for vehicle tanking and detanking will be separated. During cryogenic tanking operations, the ullage pressure will be continuously monitored. The support equipment will be capable of unloading and safing the vehicle under any credible accident or vehicle failure.

The ground support equipment will provide a rapid means for shutoff and isolation of fuel from ignition sources. Provisions will be made to stop flow of propellants in case of line rupture.

The launch pad service tower design must incorporate emergency egress capability for personnel during launch operations.

5.1.3 Procedures for all Hazardous Operations

Each operations document will be reviewed by Engineering and Test Operations and those considered safety-critical will be so designated to assure special consideration by all responsible functions.

Once an operation is determined to be safety-critical, the following actions are required to alert personnel, to minimize potential hazards, and to establish controls and emergency procedures:

A. The cover sheets of the operations procedures and other control documents will be labeled to warn personnel that safety-critical operations are involved. (Examples: "This Procedure Includes Safety-Critical Operations," or "Safety Critical".)

B. A numbered section devoted to safety requirements will be included in the operations procedures. This section will describe the safety responsibilities, equipment, controls, procedures, and restrictions, and will identify simultaneous operations that are incompatible and are to be avoided.

C. Immediately preceding safety-critical steps throughout the text of procedures and control documents will be pertinent safety notes and warnings which define the hazards and limitations and prescribe controls.

5.1.4 Range Safety

Range safety operations are to include clearance of downrange areas, safety monitoring of pad operations, and the other traditional roles of range safety as called out by the Range Safety Manual, AFETRM 127-1.

5.2 PERSONNEL QUALIFICATION AND CERTIFICATION FOR HAZARDOUS OPERATIONS

5.2.1 Personnel Qualification and Certification Definition

The following definitions apply to personnel qualification and certification:

A. Certification - The act of attesting, by an objective witness, that a qualified person can proficiently apply his ability, training, and experience within acceptable levels necessary to accomplish a specified task.

B. Qualification - The act of assessing personnel ability, training, experience, and individual identification to a minimum set of requirements required to perform a specified task.

5.2.2 Requirements

The following requirements must be fulfilled:

A. Hazardous Operations - To assure product integrity through all phases of product testing, it is mandatory that all activities which contain hazardous operations are performed by qualified/certified personnel.

B. Records - Complete, accurate, permanent records of the qualification/certification program will be maintained and audited to ensure that every possible training factor which could contribute to delayed schedules or adverse program conditions is eliminated.

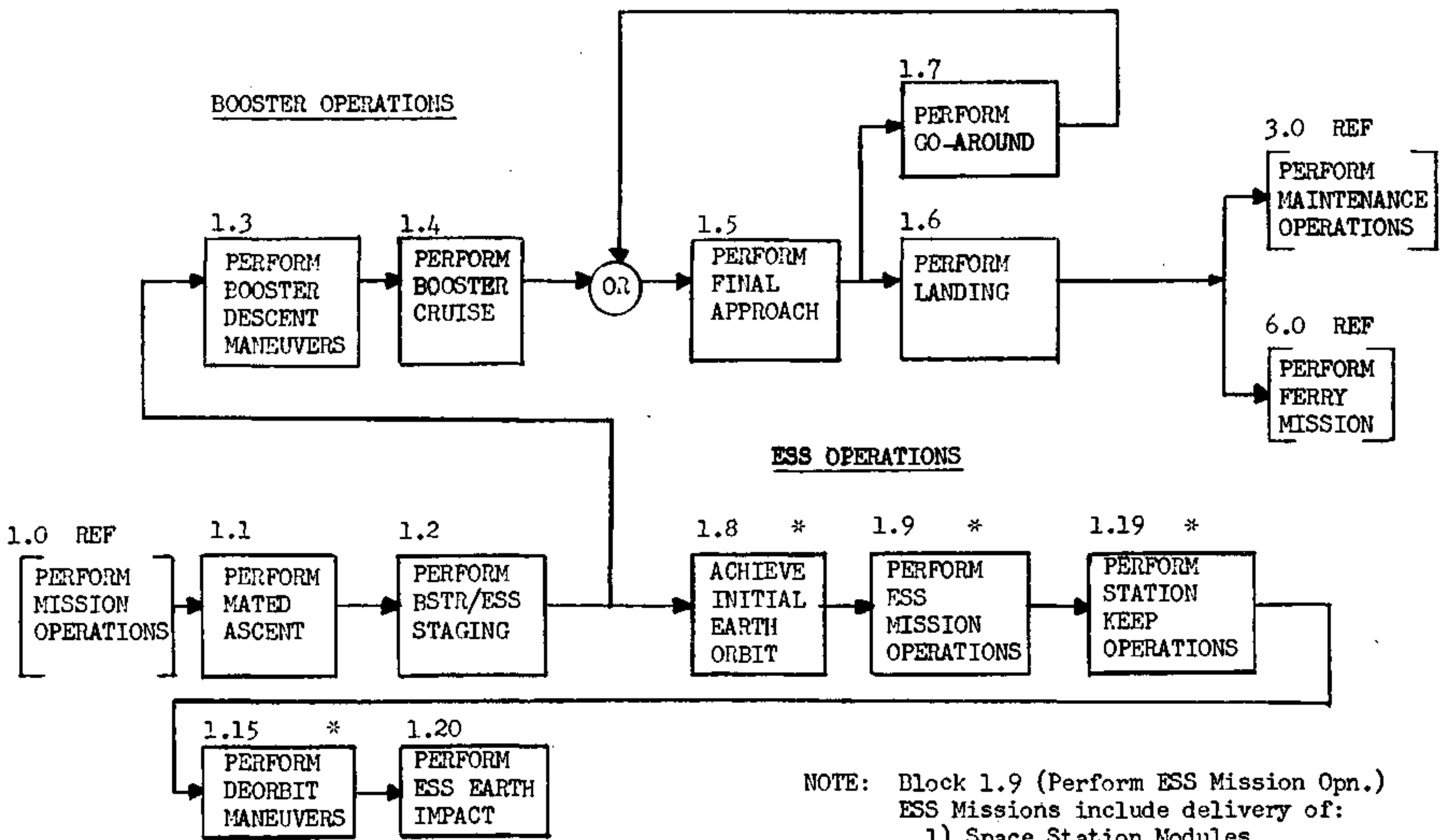
C. Implementation - A personnel/qualification/certification plan will be prepared which establishes minimum requirements for individual and test crew/team certification.

Preceding page blank

APPENDIX A.

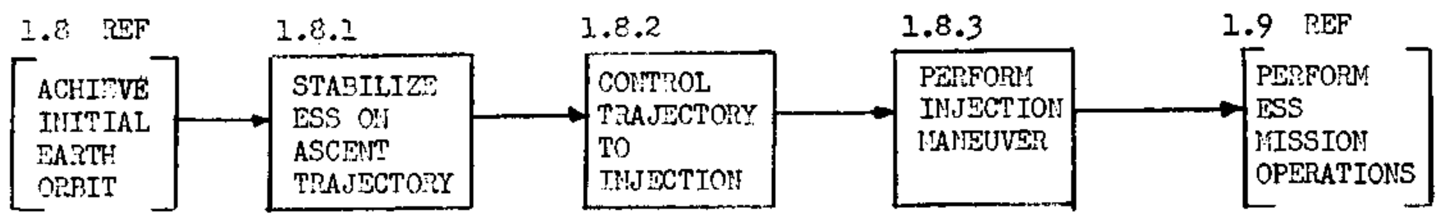
FUNCTIONAL FLOW DIAGRAMS

PRECEDING PAGE BLANK NOT FILMED

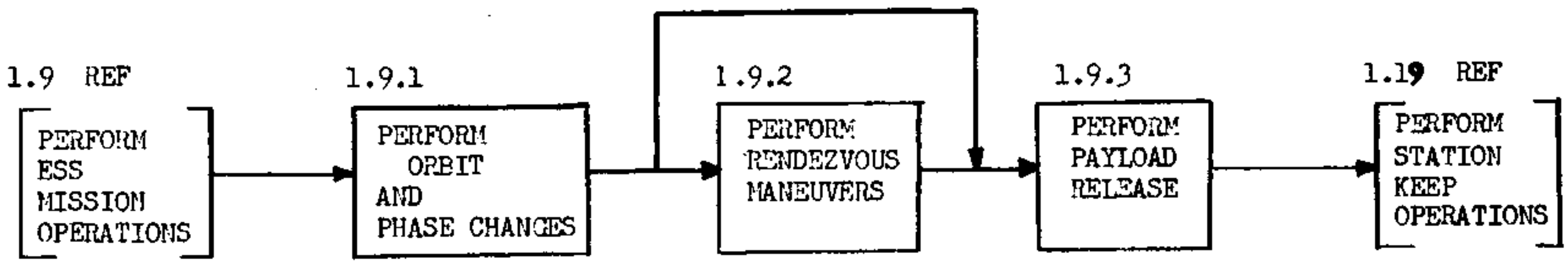


NOTE: Block 1.9 (Perform ESS Mission Opn.)
ESS Missions include delivery of:
1) Space Station Modules
2) Nuclear Shuttle Modules
3) Space Tug Modules
4) Other Payloads Listed in SOW

1.0 Perform Mission Operations (ESS)

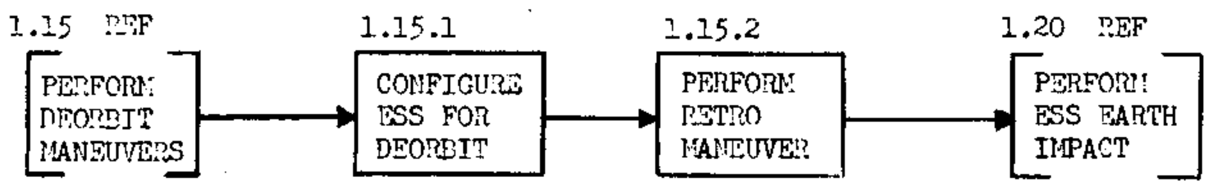


1.8 Achieve Initial Earth Orbit

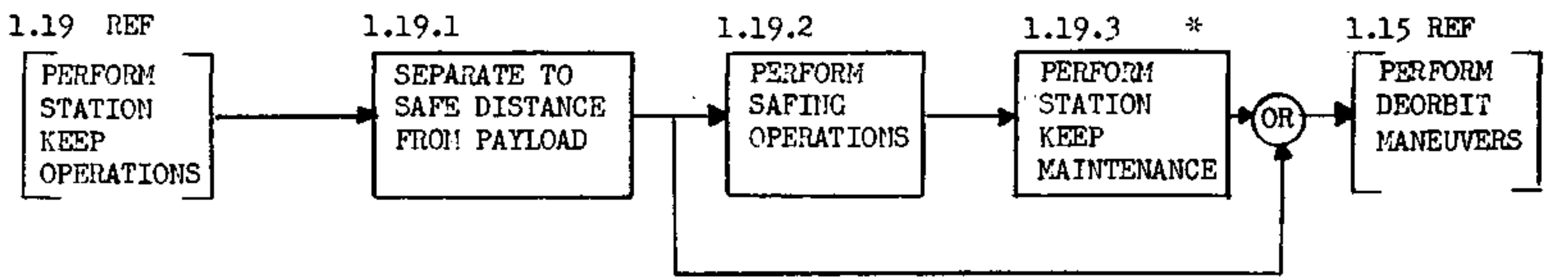


NOTE: ESS Missions include delivery of:
1) Space Station Modules
2) Nuclear Shuttle Modules
3) Space Tug Modules
4) Other Payloads Listed in SOW

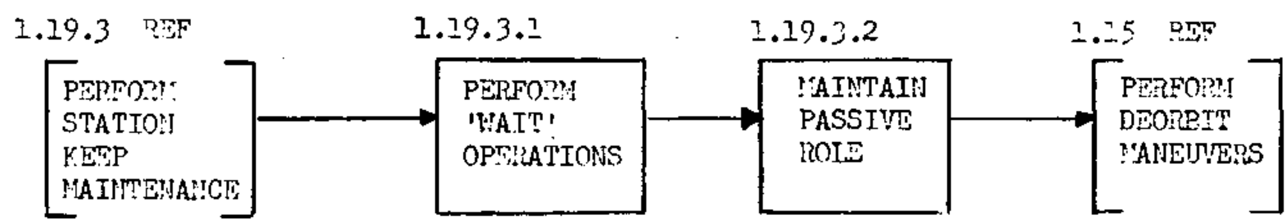
1.9 Perform ESS Mission Operations



1.15 Perform Deorbit Maneuvers

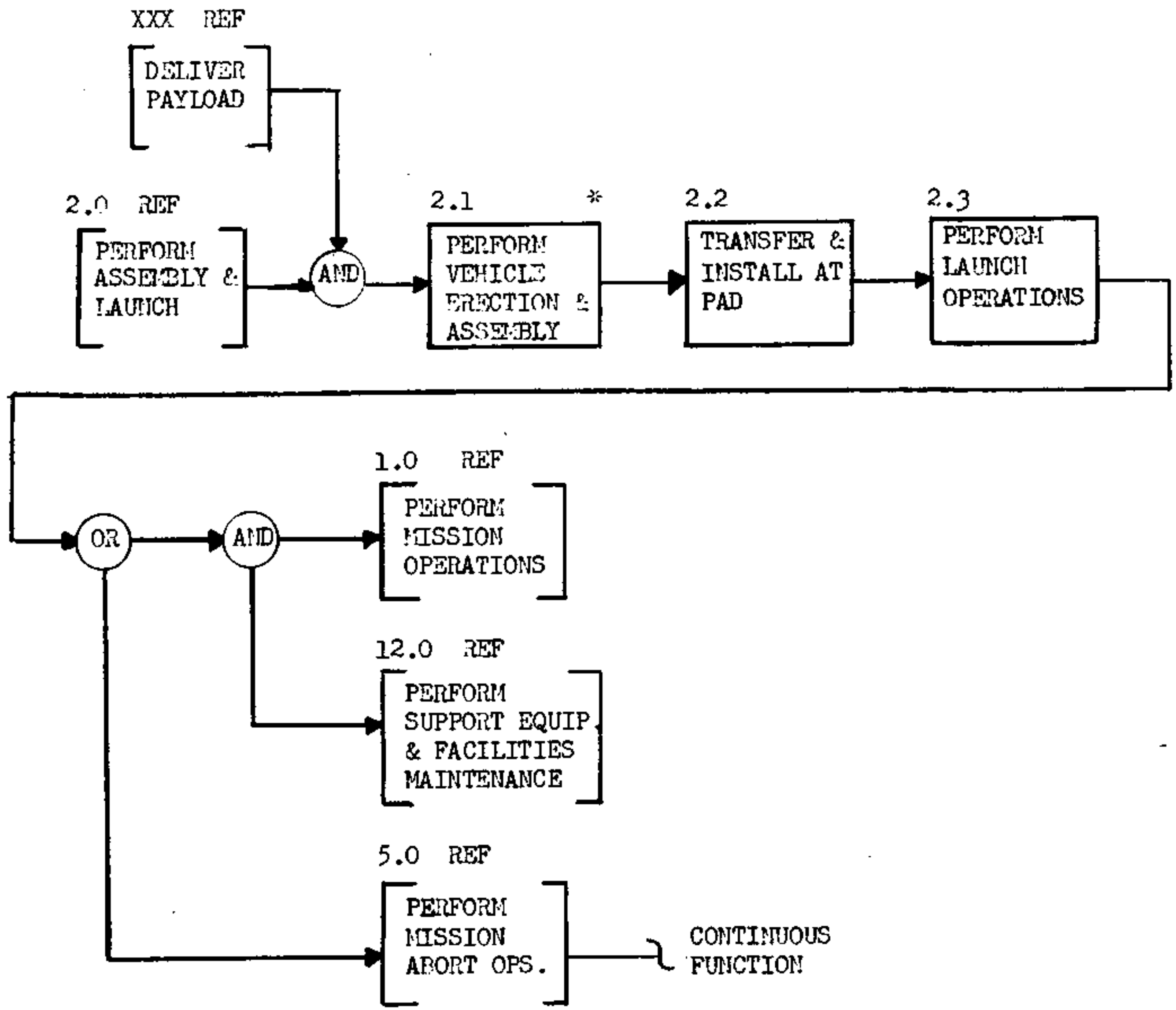


1.19 Perform Station Keep Operations

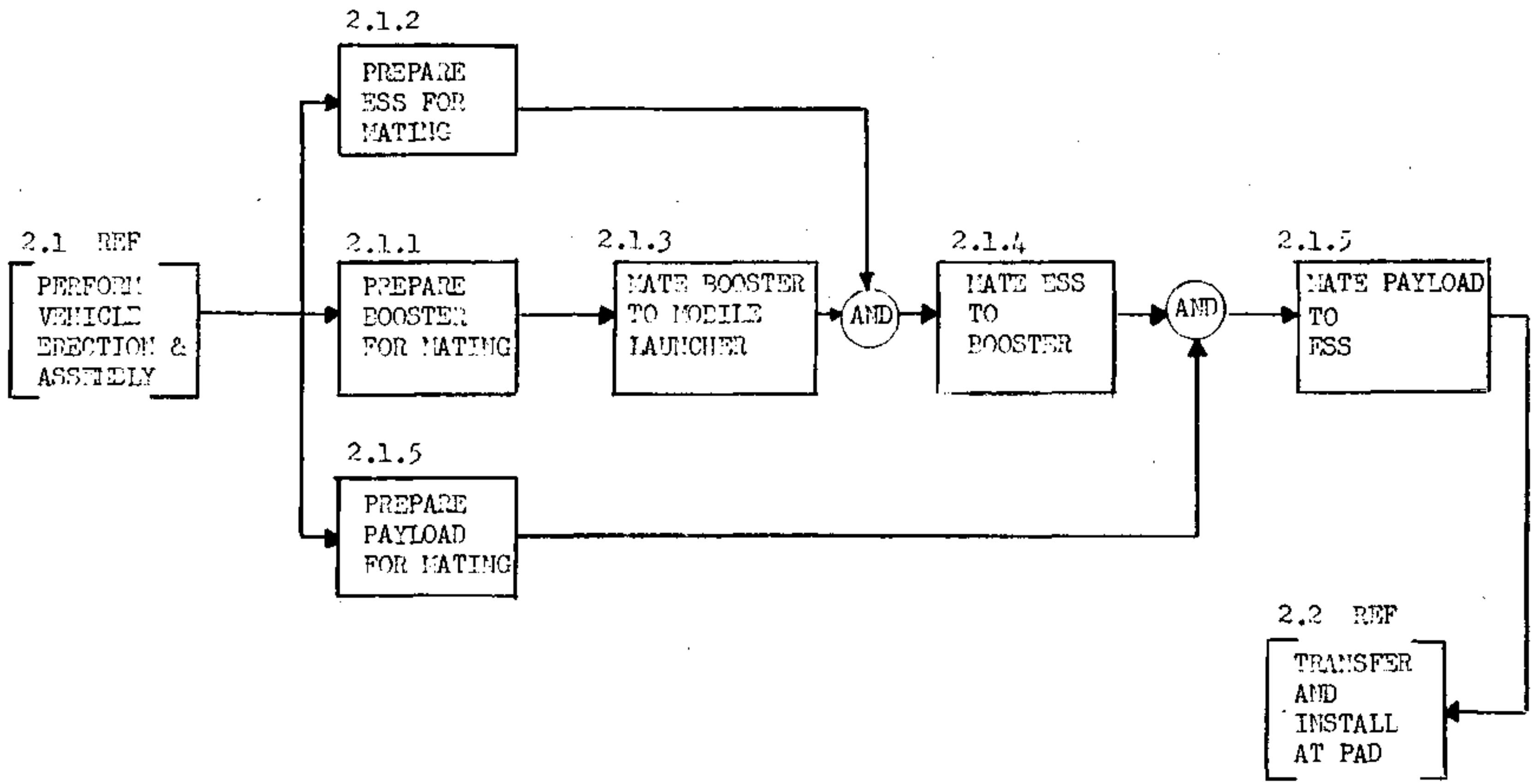


NOTE: Block 1.19.3.2 (Maintain Passive Role) involves S.S. Orbiter removal of ESS elements.

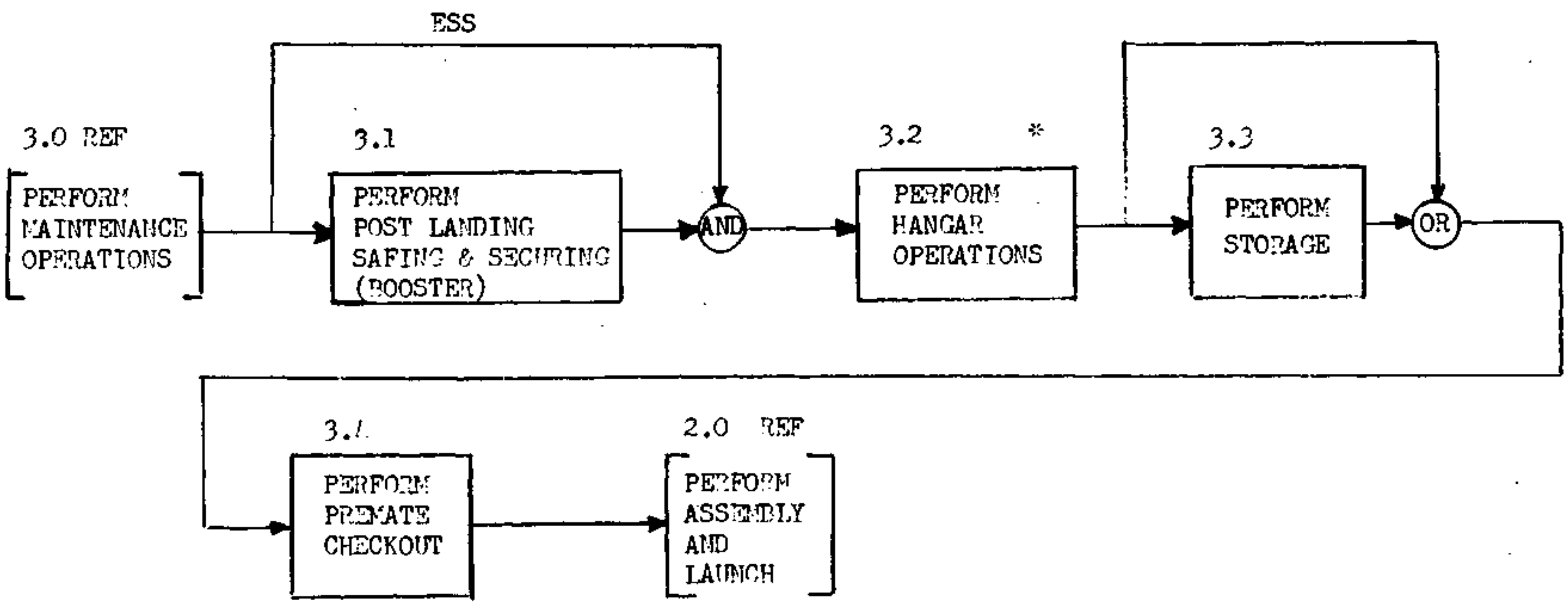
1.19.3 Perform Station Keep Maintenance



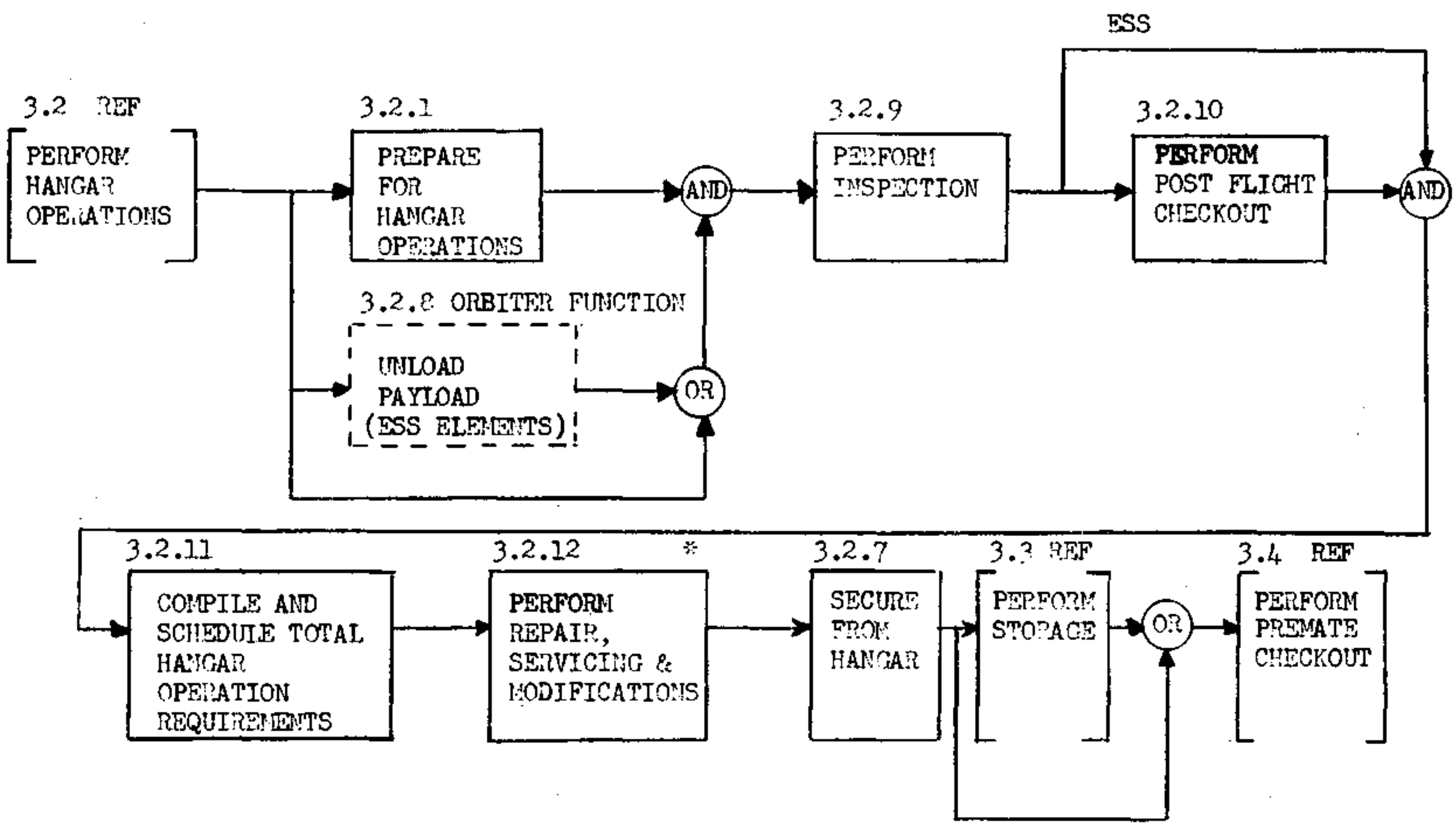
2.0 Perform Assembly and Launch



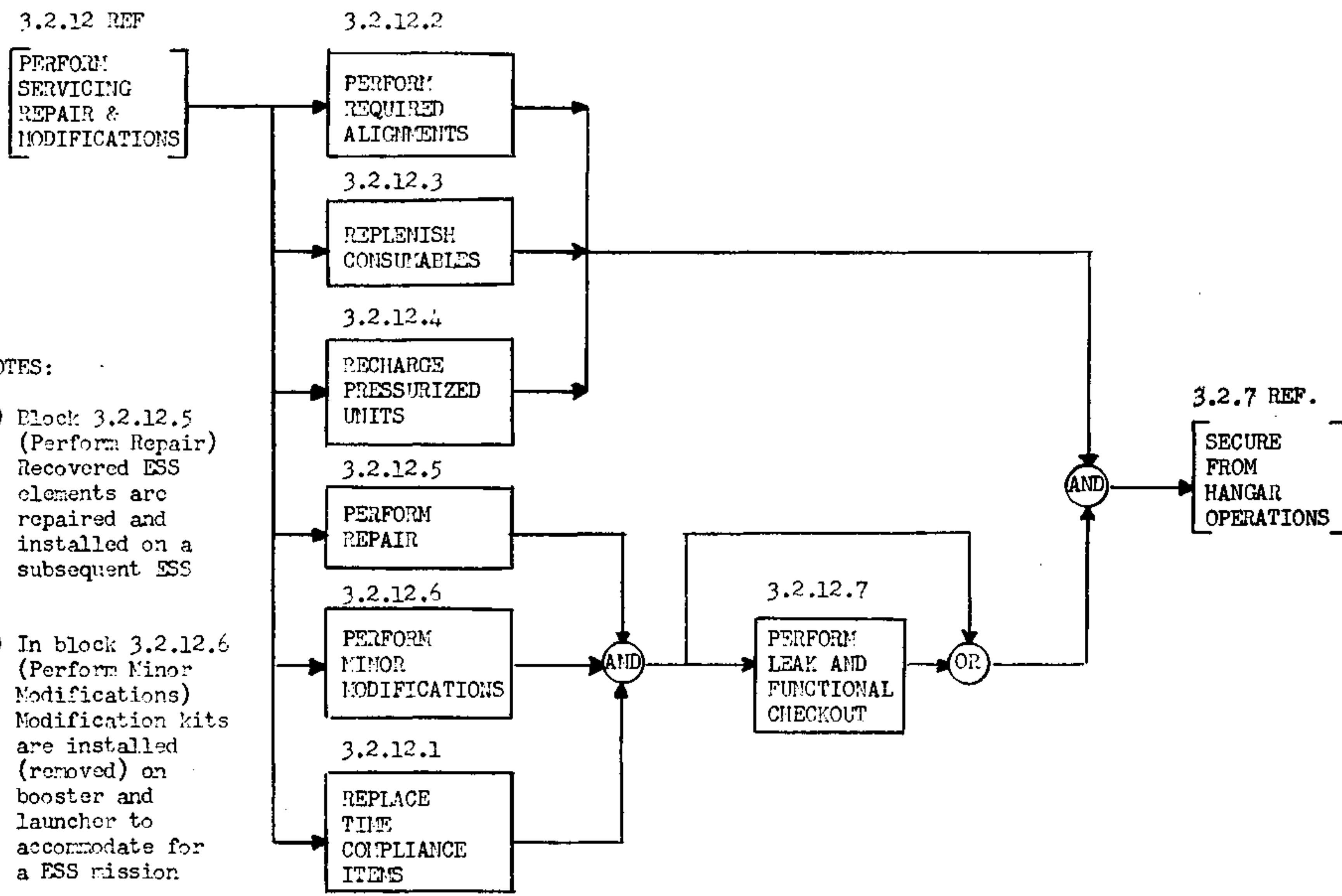
2.1 Perform Vehicle Erection and Assembly



3.0 Perform Maintenance Operations



3.2 Perform Hangar Operations

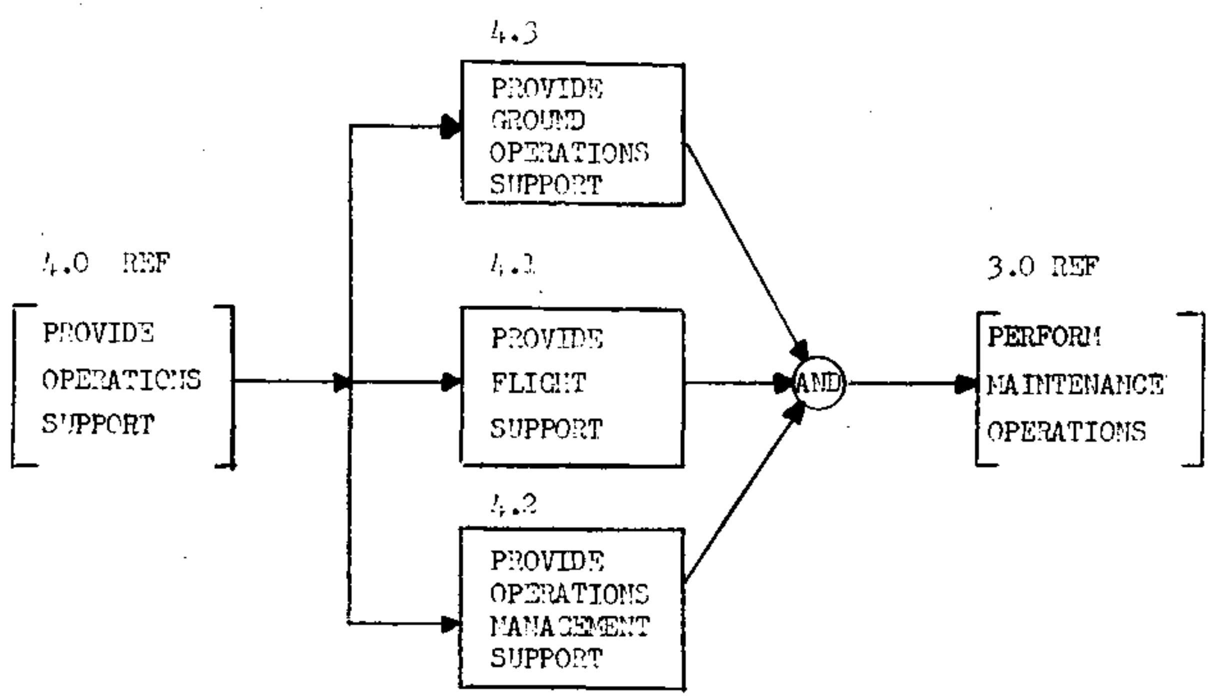


NOTES:

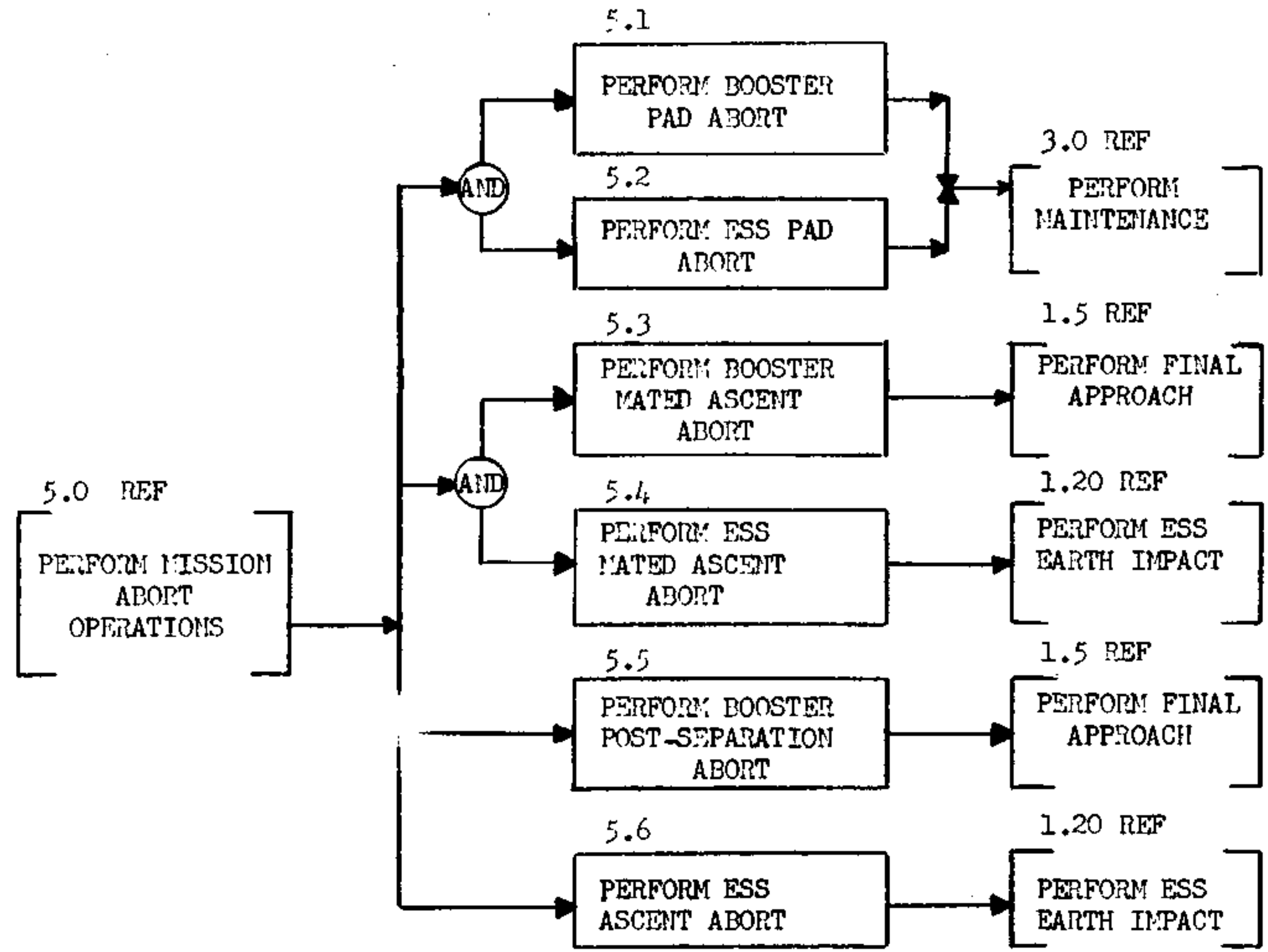
1) Block 3.2.12.5 (Perform Repair) Recovered ESS elements are repaired and installed on a subsequent ESS

2) In block 3.2.12.6 (Perform Minor Modifications) Modification kits are installed (removed) on booster and launcher to accommodate for a ESS mission

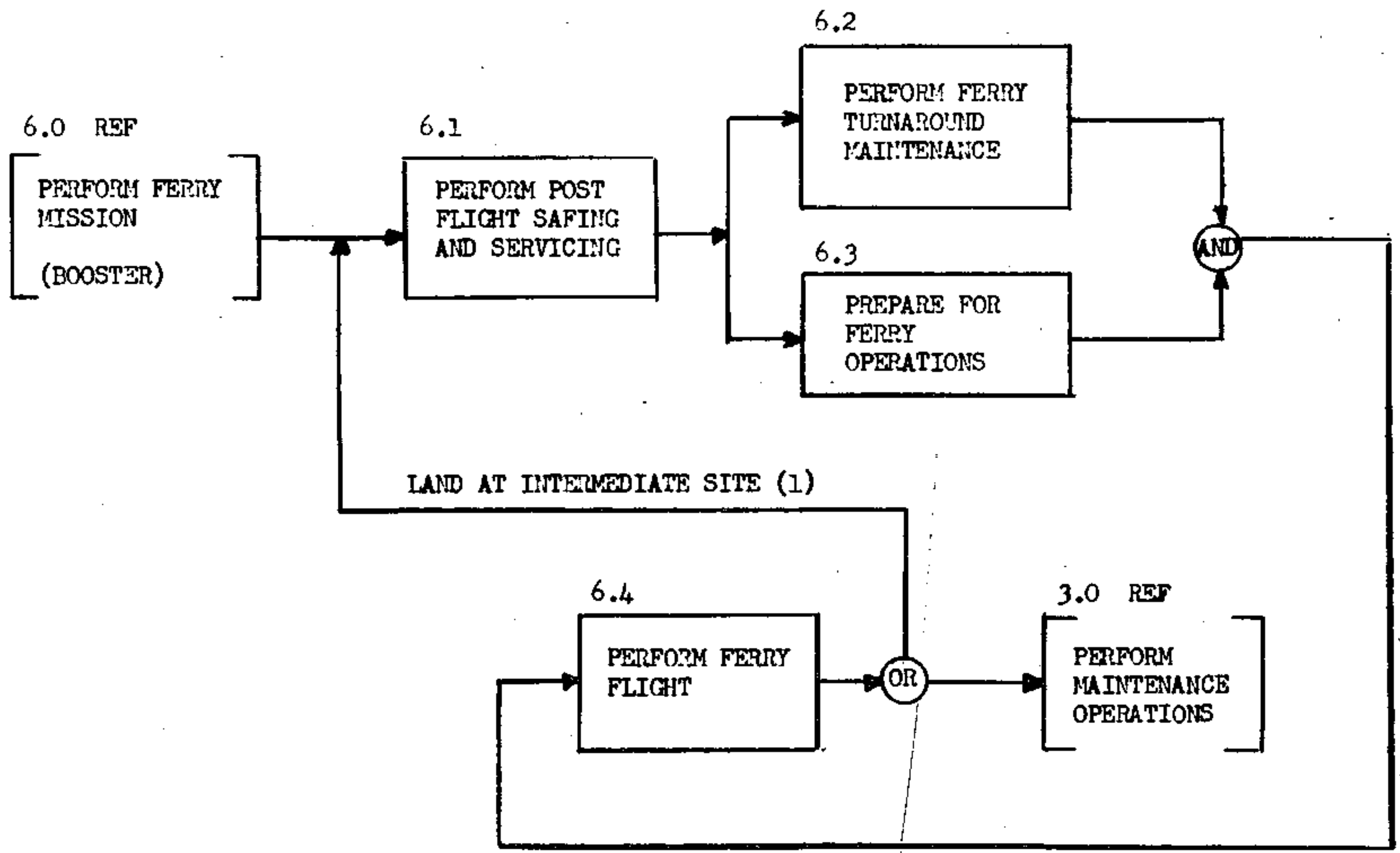
3.2.12 Perform Servicing, Repair, and Modifications



4.0 Provide Operations Support



5.0 Perform Mission Abort Operations



6.0 Perform Ferry Mission (Booster)

Preceding page blank

APPENDIX B. ESS/REUSABLE SHUTTLE BOOSTER OPERATIONS

Operations personnel must be paid on an annual basis, not per operation; therefore, to be cost-effective, either the launch rate of ESS must be sufficiently high to warrant a dedicated operations crew or the ESS and space shuttle should have adequate commonality of subsystems so as to share operations personnel.

Assume:

t_e = working days required per ESS operation = 36

y_e = number men required per ESS operation = 40

R_E = ESS flights per year

$36\ R_E$ = working days required per year of ESS operations

$1440\ R_E$ = working man-days required per year of ESS operations

Assume 260 working days per year

$$Y_E = \frac{1440\ R_E}{260} = 5.54\ R_E$$

$$Y_E \geq y_e = 40 \qquad 40 \leq 5.54\ R_E \qquad R_E \geq 7.23$$

This reveals that 40 men are required per ESS operation, and if this program (ESS) is exclusive, then 40 men are required on an annual basis for any launch rate less than 7.23 per year. However, this ESS operation should not be exclusive and should be able to share personnel from the space shuttle because of the proposed commonality in subsystems. Since the ESS operation is additive, more personnel are required for the space shuttle to compensate for manpower losses during ESS operations through the following:

X_s = number of personnel required (annually) for space shuttle

$260\ X_s$ = man-days required (annually) by space shuttle

PRECEDING PAGE BLANK NOT FILMED

then

$$(X_s + \Delta_p)\ (260 - 36\ R_E) + (X_s + \Delta_p - 40)\ (36\ R_E) = 260\ X_s$$

$$260\ X_s - 36\ R_E X_s + 260\ \Delta_p - 36\ R_E\ \Delta_p + 36\ R_E X_s + 36\ R_E\ \Delta_p$$

$$260\ \Delta_p - 1440\ R_E = 260\ X_s - 260\ X_s = 0$$

$$260\ \Delta_p = 1440\ R_E$$

$$\Delta_p = \frac{1440\ R_E}{260} = 5.54\ R_E$$

where R_E = two flights per year

$$p = 11.08 \approx 12$$

(p must be rounded up to the nearest whole number, since partial personnel cannot be maintained)

where $R_E = 4$

$$\Delta p = 22.2 \approx 23$$

where $R_E = 6$

$$\Delta p = 33.2 \approx 34$$

where $R_E = 10$

$$\Delta p = 55.4 \approx 56$$

This information can be plotted in several ways (see Figure B-1).

1. If the number of launches per year must be a whole number, then the number of personnel can be found (minimum point) on the stairstep when sharing (with space shuttle) is assumed.

2. If sharing (with space shuttle) is not possible, then 40 dedicated personnel are required from 1 to 7.23 launches per year.

3. Since it is necessary to provide personnel in whole numbers, the number of launches per year can be a mixed number; thus, the number of launches per year can be found by entering with the quantity of shared personnel, and using the straight line, e.g., 20 personnel are required for three launches per year, but they are capable of 3.6 launches per year.

$$- 1440\ R_E = 260\ X_s$$

4. The quantity of personnel required per ESS operation was estimated as 40, which should be capable of up to 7.23 launches per year; therefore, 40 persons are required if no sharing is possible.

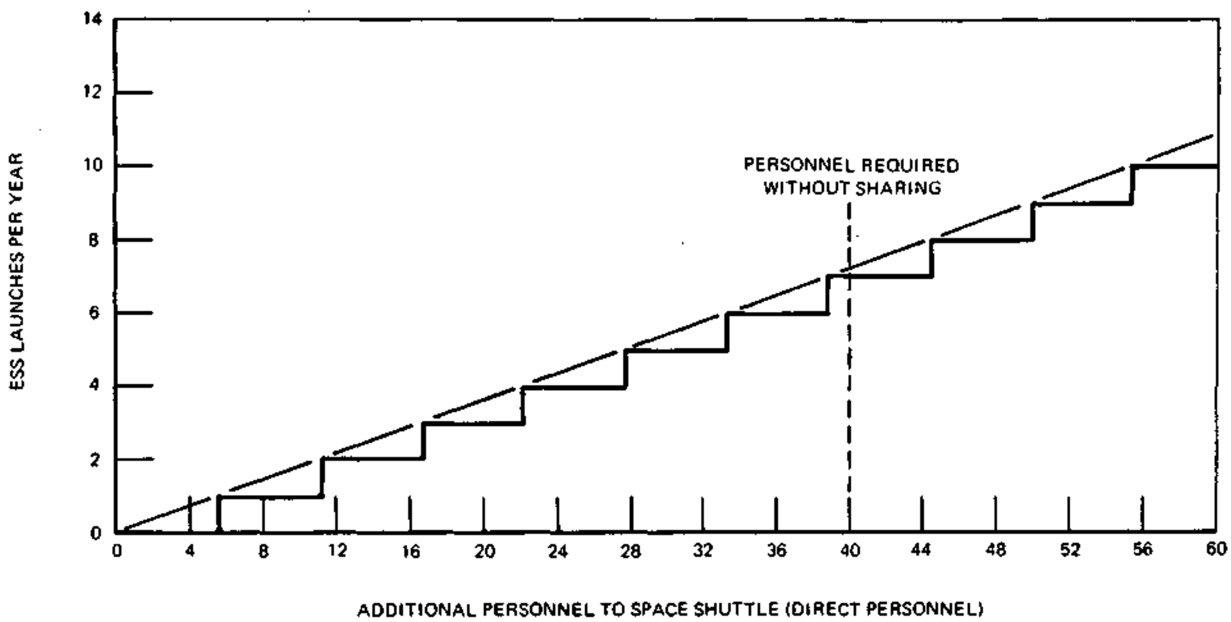


Figure B-1. ESS Operations Personnel Requirements

SECTION II

FACILITIES UTILIZATION AND MANUFACTURING PLAN

Preceding page blank

CONTENTS

Section		Page
1.0	INTRODUCTION	2-1
	1.1 PURPOSE	2-1
	1.2 SCOPE	2-1
	1.3 SCHEDULE	2-1
2.0	FACILITIES	2-3
	2.1 SUMMARY	2-3
	2.2 DEVELOPMENT/QUALIFICATION TEST FACILITIES	2-3
	2.2.1 Structural/Dynamic Testing	2-5
	2.2.2 Wind Tunnel Test	2-5
	2.2.3 Orbit Maneuvering and Auxiliary Propulsion Subsystem	2-6
	2.2.4 Integrated Avionics Subsystem Tests	2-6
	2.2.5 Static Firing Tests	2-6
	2.3 PROPELLANT TANK FABRICATION AND SUBASSEMBLY FACILITIES	2-6
	2.3.1 Fuel and Oxidizer Bulkheads	2-6
	2.3.2 Fuel Tank Cylinders	2-10
	2.4 STRUCTURAL FABRICATION AND SUBASSEMBLY FACILITIES	2-13
	2.4.1 Bolting Ring	2-13
	2.4.2 Aft Skirt	2-13
	2.4.3 Forward Skirt	2-16
	2.5 ASSEMBLY FACILITY	2-16
	2.5.1 Stage Final Assembly	2-16
	2.5.2 Forward Skirt and Aft Skirt Installation	2-19
	2.5.3 Pneumostatic Test	2-22
	2.5.4 Tank Cleaning and Drying	2-22
	2.5.5 Insulation Closeout Application	2-22
	2.5.6 Engine, Systems Installation, and Erosion Barrier	2-22
	2.6 SYSTEM AND ACCEPTANCE TEST	2-23
	2.6.1 Acceptance Level Tests	2-23
	2.6.2 Buildings and Structures	2-23

Preceding page blank

ILLUSTRATIONS

Figure		Page
2-1	ESS Production Operations Schedule	2-2
2-2	Seal Beach Facility	2-4
2-3	Propellant Tank Fabrication and Test Facility	2-7
2-4	Tank Bulkhead Assembly	2-8
2-5	Forward LH_2 Bulkhead Spray Foam Application	2-9
2-6	LH_2 Tank Cylinders	2-11
2-7	S-II Stage Spray-Foam and Finish-Trim Concepts	2-12
2-8	Subassembly Facility	2-14
2-9	Aft Skirt Structure Assembly	2-15
2-10	Forward Skirt and Cylinder 5 Mating	2-17
2-11	ESS Manufacturing Flow Plan	2-18
2-12	Vehicle Rotation and Foam Application, Station V	2-20
2-13	Stage Final Assembly Building	2-21
2-14	Insulation Erosion Barrier	2-24
2-15	System and Acceptance Test	2-25
2-16	Paint and Packaging Building	2-27
2-17	ESS/Booster at Launch Pad	2-29

TABLES

Table		Page
2-1	Commonality Analysis	2-32
2-2	Manufacturing Task Analysis	2-36
2-3	Manufacturing Material/Personnel Handling Equipment Requirements	2-41
2-4	Manufacturing Checkout Requirements at the System Level	2-42

Section Page

2.7 PREPARE AND SHIP STAGE 2-23
2.8 VEHICLE STATIC FIRING 2-26
2.9 PRELAUNCH PREPARATION 2-26
2.9.1 Buildings and Structures 2-28
2.10 LAUNCH PREPARATION 2-28

3.0 MANUFACTURING TECHNOLOGY 2-31
3.1 MANUFACTURING METHODS 2-31
3.1.1 Forming and Maching 2-31
3.1.2 Welding Machines/Tooling 2-34
3.1.3 Cryogenic Insulation 2-34
3.1.4 Erosion Barrier 2-34
3.1.5 Tank and Component Handling 2-34
3.2 MANUFACTURING CONCERNS 2-35
3.2.1 ESS/SS Booster Linkage-Attach Fitting . . 2-35

4.0 GOVERNMENT-FURNISHED EQUIPMENT AND MACHINE TOOLS 2-37

5.0 MAJOR TEST EQUIPMENT AND GSE 2-39

6.0 BOOSTER MODIFICATIONS AND SEPARATION STRUCTURE . . 2-45
6.1 FACILITIES 2-45

SECTION II. FACILITIES UTILIZATION AND MANUFACTURING PLAN

1.0 INTRODUCTION

1.1 PURPOSE

The Facilities Utilization and Manufacturing Plan (FUMP) has been prepared to describe the major facility requirements for the Expendable Second Stage (ESS) (WBS item 1.0), Booster Modifications (WBS 3.0), and Separation Structure (WBS 7.0). The plan also describes the Manufacturing technology requirements and presents the areas of concern for the production of the ESS. Paragraphs 2.0 through 5.0 are specifically oriented towards the ESS. Paragraph 6.0 describes the FUMP for the booster modifications and the separation structure.

1.2 SCOPE

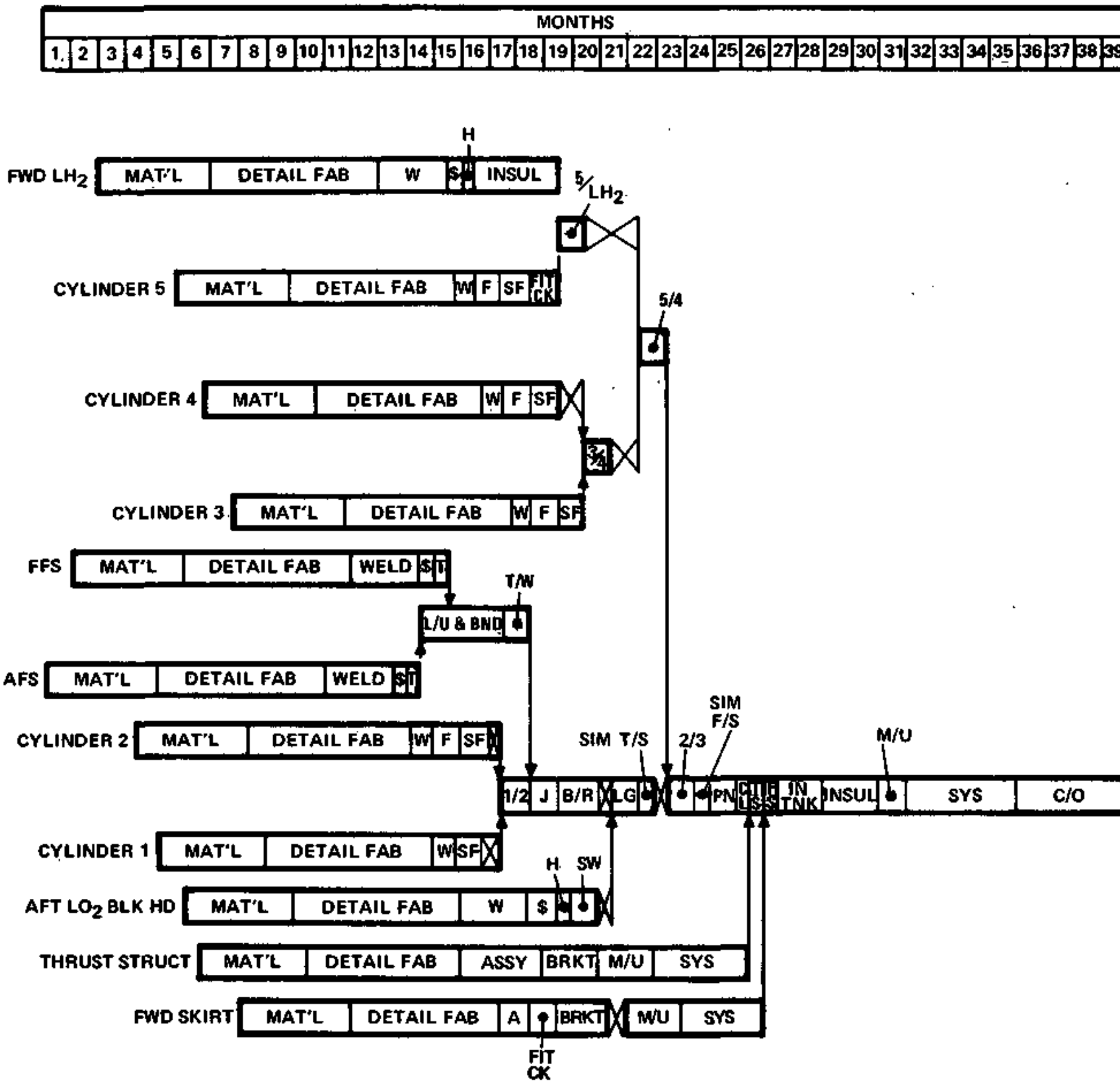
The facilities part of this section is organized by the major divisions of effort. The facilities requirements for testing, fabrication, assembly, and operations are described in this section. The NR, NASA, and major subcontractor facilities required are identified.

The Manufacturing Technology section of the plan describes the various technologies required to produce the ESS. This section includes a task analysis, an S-II/ESS commonality study, and describes the major manufacturing areas of concern.

The plan indicates the use of government furnished equipment and machine tools, major test equipment, and GSE.

1.3 SCHEDULE

The production operations schedule for an Expendable Second Stage is shown in Figure 2-1.



LEGEND

B/R = BOLTING RING
CL = CLEAN
C/O = CHECKOUT
F = FRAMING
FS = FORWARD SKIRT
H = HYDROSTATIC TEST
J = J WELD
LG = LO_2 GIRTH WELD
M/U = MOCKUP
PN = PNEUMOSTATIC TEST
SW = STUD WELD
T = TRACE CONTOUR
TS = THRUST STRUCTURE
T/W = TRIM AND WELD
W = WELD

Figure 2-1. ESS Production Operations Schedule

2.0 FACILITIES

2.1 SUMMARY

Selection of facilities to support the ESS program was based upon consideration of several sites for development, qualification and acceptance testing, and the fabrication of stage detail parts. The subassembly and assembly operations are ground ruled to the NASA Seal Beach assembly facility. Launch operation facilities are discussed only briefly in this plan since they were discussed in some detail in the Operations Plan, Section I of this volume. The approach will be to utilize existing government-owned facilities, contractor-owned facilities, and facilities available through other government contractors for detail and component fabrication.

The ESS production program will use the NASA Seal Beach assembly facility in total. The facility does not have the capability however to handle two major programs concurrently.

The recommended facility utilization is that: development, qualification and acceptance testing will be conducted at the NR Downey facility, NR Seal Beach facility, NASA Seal Beach facility, MSFC, KSC, Wyle Laboratories (Huntsville), and either Langley Research Center, Ames Research Center, or AEDC Von Karman Gas Dynamics Facility; detail fabrication will be conducted at NR's Downey facility, NR's Los Angeles facility, and selected subcontractors; subassembly and assembly will be conducted at NASA Seal Beach's assembly facility. This facility contains adequate floor space to accommodate the ESS production operations and provides sufficient bridge crane capacity to handle the movement and transfer of subassemblies and assemblies.

The NR Seal Beach facility contains sufficient office area to accommodate the required ESS engineering staff in either Building 80 (8 floors) or Building 81 (3 floors), see Figure 2-2.

2.2 DEVELOPMENT/QUALIFICATION TEST FACILITIES

This section lists specific functional test operations and describes, where applicable, the sites and facilities required. The utilization of existing sites, facility equipment and special test equipment is used as a base in determining and recommending the facilities for the support of these major tests.

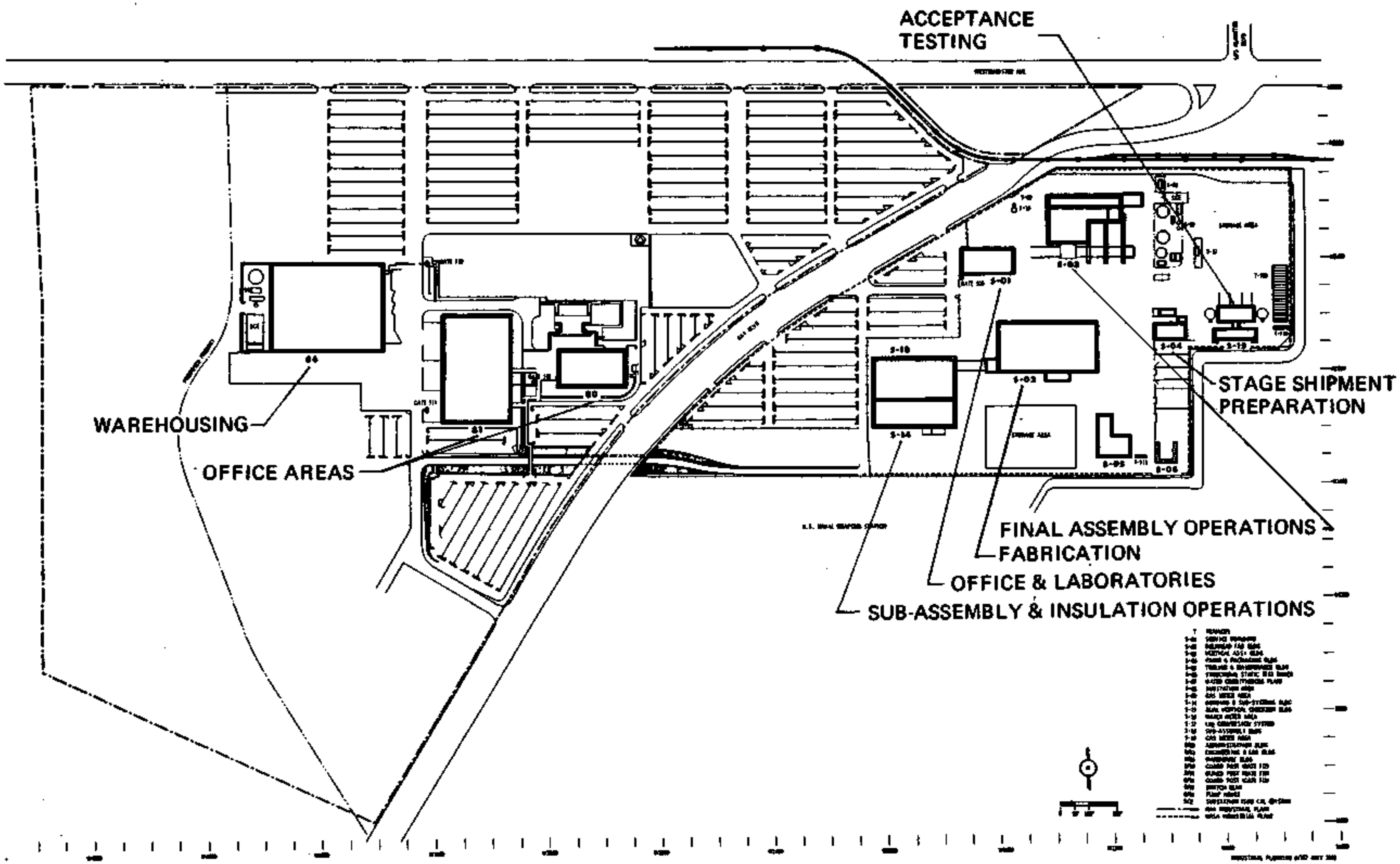


Figure 2-2. Seal Beach Facility

2.2.1 Structural/Dynamic Testing

The contractor's engineering development laboratories will perform testing of structural components during the design phase and throughout the development period. These tests will be accomplished to evaluate fabrication methods, materials, and processing, and to verify design concepts. During this phase of development, close association of design and tests will be required at the prime contractor's central base. The testing of subassemblies and assemblies will require the use of specialized facilities, with extensive capabilities, within the government or industrial base.

Structural Tests

Structural tests will be conducted on a dedicated full-scale test vehicle and on major subassemblies. The tests require miscellaneous load application devices for various tensions, torsions, and compressions. Load and strain measuring and recording systems will also be required to support these tests on the forward skirt, LH_2 tank, aft skirt, booster attachment fittings and other vehicle components. The tests to be performed on the full scale vehicle in a vertical position will require a large test structure capable of supporting the loaded vehicle. These tests will be accomplished at NASA furnished facilities.

Dynamic Tests

Horizontal dynamic tests will be performed on the first mated Space Shuttle Booster and Expendable Second Stage. This will consist primarily of a ground vibration test. The vehicles will be supported on a low-frequency suspension system with multiple shakers attached to the vehicle. Data acquisition and control equipment will be portable. This test will be conducted at the launch site using available buildings and equipment.

2.2.2 Wind Tunnel Test

Wind tunnel testing will be conducted on models to provide the aerodynamic and dynamic data needed to support final design decisions, criteria and configuration. This test operation will be performed at several wind tunnel facilities: Langley Research Center, Ames Research Center, AEDC Von Karman Gas Dynamics Facility, or NR Los Angeles Division. These facilities have the capability for hypersonic, transonic, supersonic, and subsonic test. The actual facilities to be used will be determined following definition of a final ESS development schedule to be developed during Phase C.

2.2.3 Orbit Maneuvering and Auxiliary Propulsion Subsystem

Development of the orbit maneuvering and attitude control engines will be accomplished at the respective manufacturer's facilities. Integration testing of these subsystems will be performed at the projected space shuttle facility at White Sands.

2.2.4 Integrated Avionics Subsystem Tests

Development of each avionics subsystem will be accomplished using breadboards and/or flight hardware and integration testing of each subsystem at the contractor's engineering laboratories. Integration of avionics subsystems will be accomplished in the Avionics Subsystems Integration Laboratory (ASIL) established for the Space Shuttle Program.

2.2.5 Static Firing Tests

The first two production ESS vehicles will be subjected to static firing at KSC. Without the Space Shuttle Program, this static firing would have been planned for MTF; however, the Space Shuttle Orbiter is to be static fired at KSC, supported from the normal separation fittings. The ESS separation fittings will also fit that support. The support will simulate the booster in size, so the orbiter and ESS will be properly positioned to receive the operational swing arms and services. Use of this support for static firing at KSC eliminates the need for modification of MTF to provide for the ESS.

2.3 PROPELLANT TANK FABRICATION AND SUBASSEMBLY FACILITIES

This section describes the fabrication of the propellant tank details, the subassembly and the verification tests required during the normal product flow. The facilities described are existing buildings and equipment utilized during the fabrication of the Saturn S-II booster and are located at Seal Beach unless noted otherwise (Figure 2-3).

2.3.1 Fuel and Oxidizer Bulkheads

The bulkheads which will form the upper portion of the LH_2 fuel tank, the aft section of the LO_2 tanks, and the common bulkhead separating the LH_2 and LO_2 tanks, are welded assemblies composed of 12 gore sections and a dollar, or polar cap. The gore panels for the bulkheads will be either stretch or high-energy formed, chem-milled, and then square-butt fusion welded to form a dome. Each bulkhead will then have a dollar section fusion welded to the apex of the gore sections to complete the assembly (Figure 2-4).

NASA SEAL BEACH	BUILDING S-02
NET AREA	63,870 SQ FT
ATSU	12,165 SQ FT
GROSS AREA	76,035 SQ FT
HC CAPACITY	235

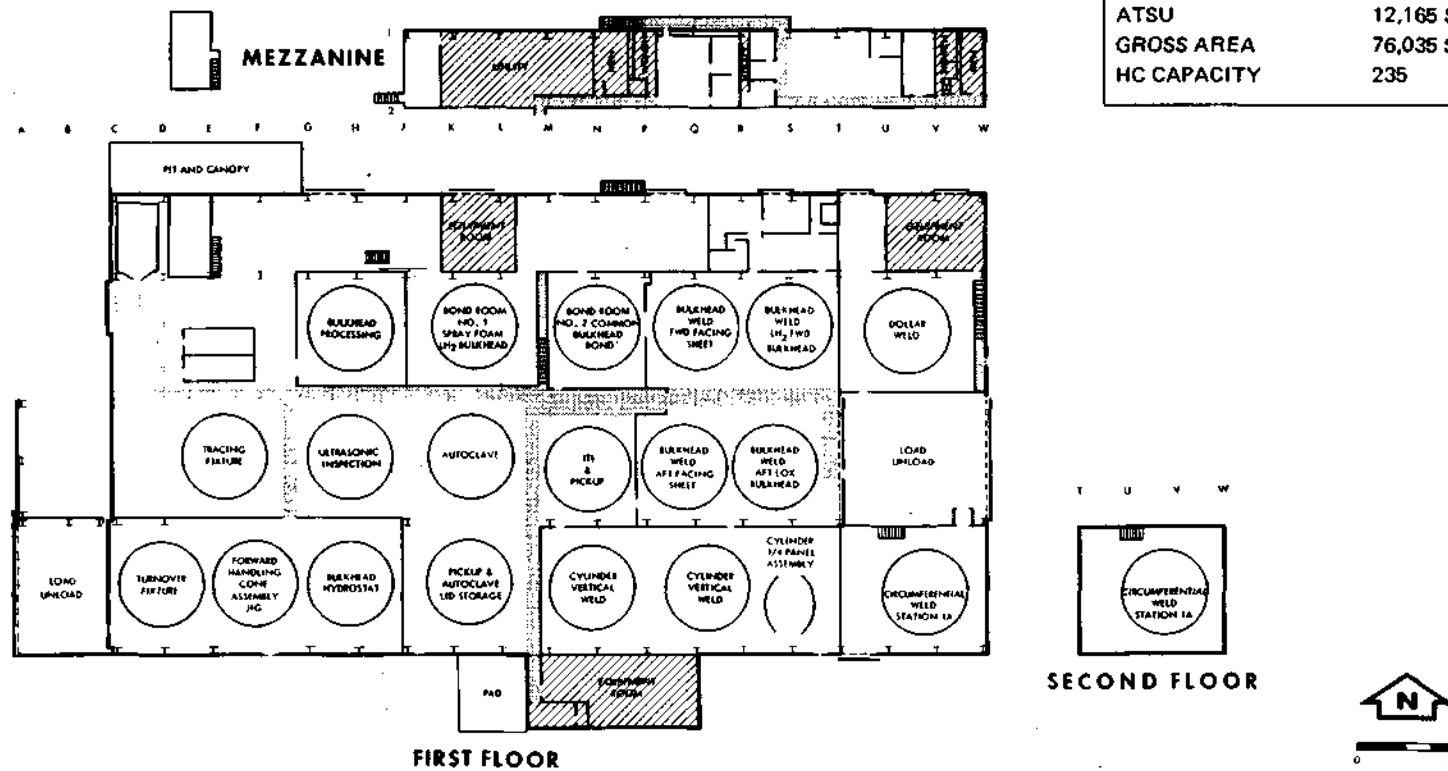


Figure 2-3. Propellant Tank Fabrication and Test Facility

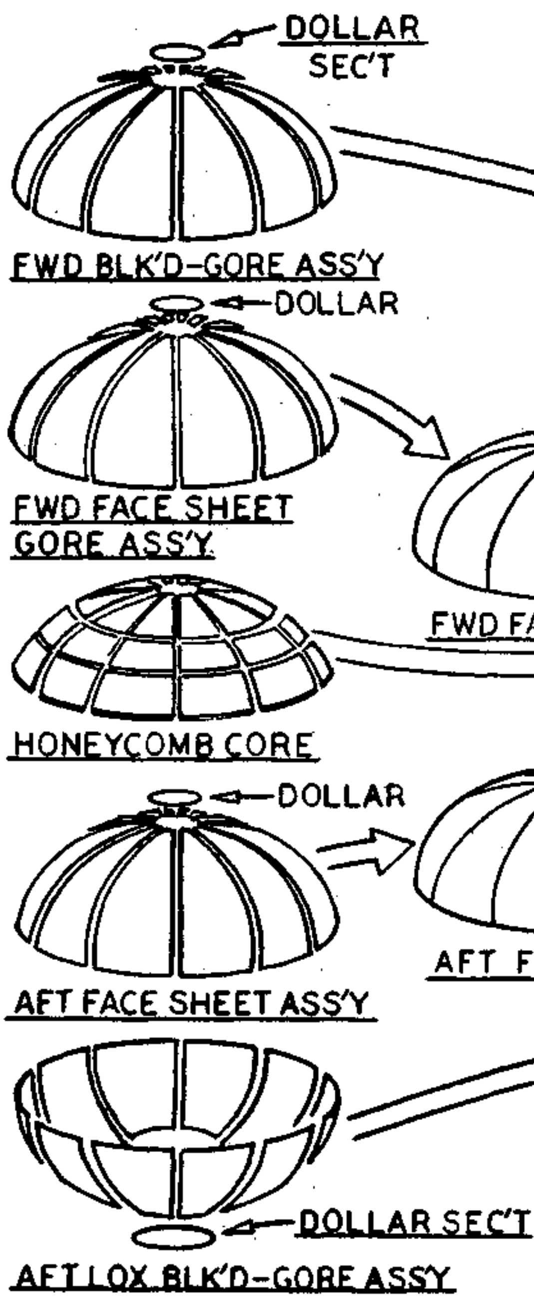


Figure 2-4. Tank Bulkhead Assembly

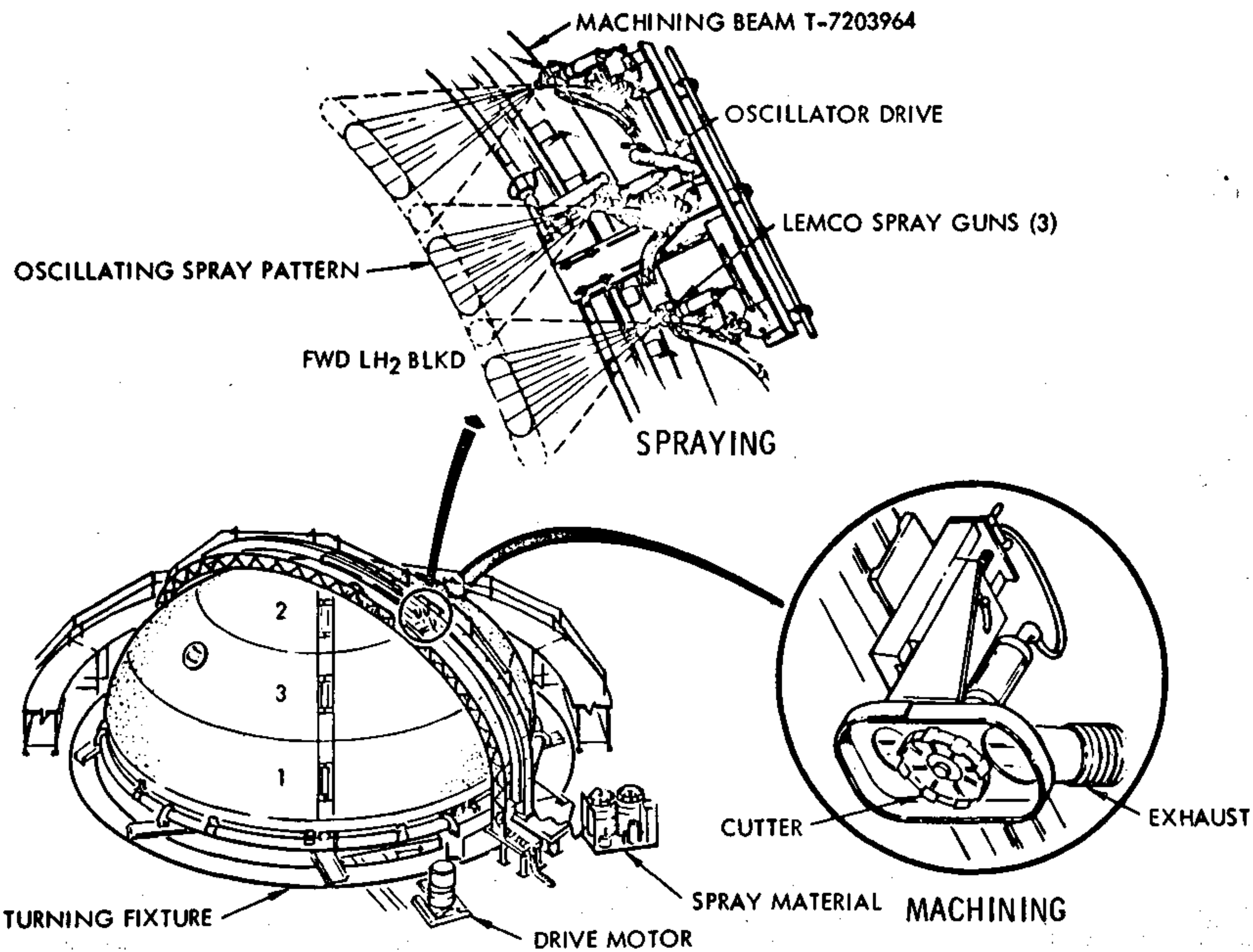


Figure 2-5. Forward LH_2 Bulkhead Spray Foam Application

The LH_2 forward bulkhead, the common bulkhead aft facing sheet, and the LO_2 aft bulkhead will be hydrostatically tested after completion of the dollar weld. After the completion of hydrostatic testing, spray foam insulation will be applied to the LH_2 bulkhead. The common-bulkhead forward-facing sheet will be helium leak tested (Figure 2-5).

The common bulkhead is a complex structure unique to the S-II and its derivatives, consisting of the two, welded, aluminum bulkheads with a honey-comb core bonded between them.

Buildings and Structures

The fabrication of the bulkhead gore sections can be accomplished at the contractors facilities utilizing existing equipment and tooling. The high-energy forming and the chem-mill operation will be subcontracted to vendors presently facilitized to handle these processes. The subassemblies operations include: welding gore sections together; testing the completed bulkheads, and applying the spray foam insulation. These operations will be accomplished at the existing NASA Seal Beach assembly facility in the bulkhead fabrication building which includes the required environmentally controlled area.

2.3.2 Fuel Tank Cylinders

Each LH_2 tank cylinder assembly will be composed of four, machined, brake-formed panels fusion-welded together. Five cylinder assemblies will comprise the tank, with four of them having internal frames mechanically attached to integrally machined ribs on the skin panels. The No. 2 cylinder for the ESS will differ from the equivalent S-II cylinder in that it will have two fuel outlet openings instead of the five required on the S-II. The tank cylinder assemblies will be fabricated and assembled utilizing the tooling and welding processes developed for production of the S-II (Figure 2-6).

After completion of the welding and framing operations, spray foam insulation will be applied to the cylinders (Figure 2-7). The welded areas will be left open to permit quality control operations after the completion of stage pneumostatic testing.

Buildings and Structures

Facilities are available at the contractor's sites to perform the detail fabrication of the cylinder quarter panels and framing. The subassembly operation will consist of vertically welding, in a controlled environment, the four LH_2 panels together to form a cylinder. The completed cylinders

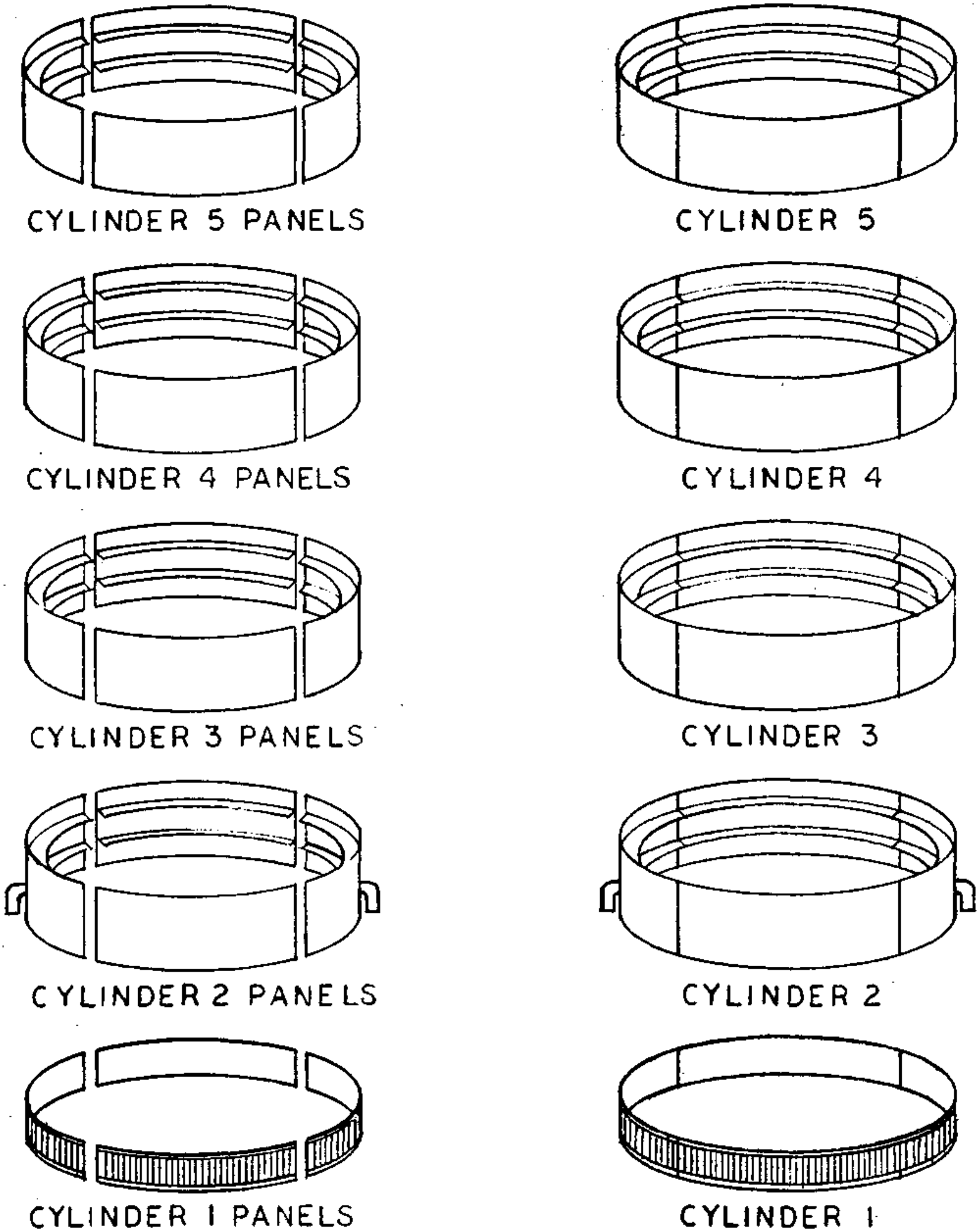


Figure 2-6. LH_2 Tank Cylinders

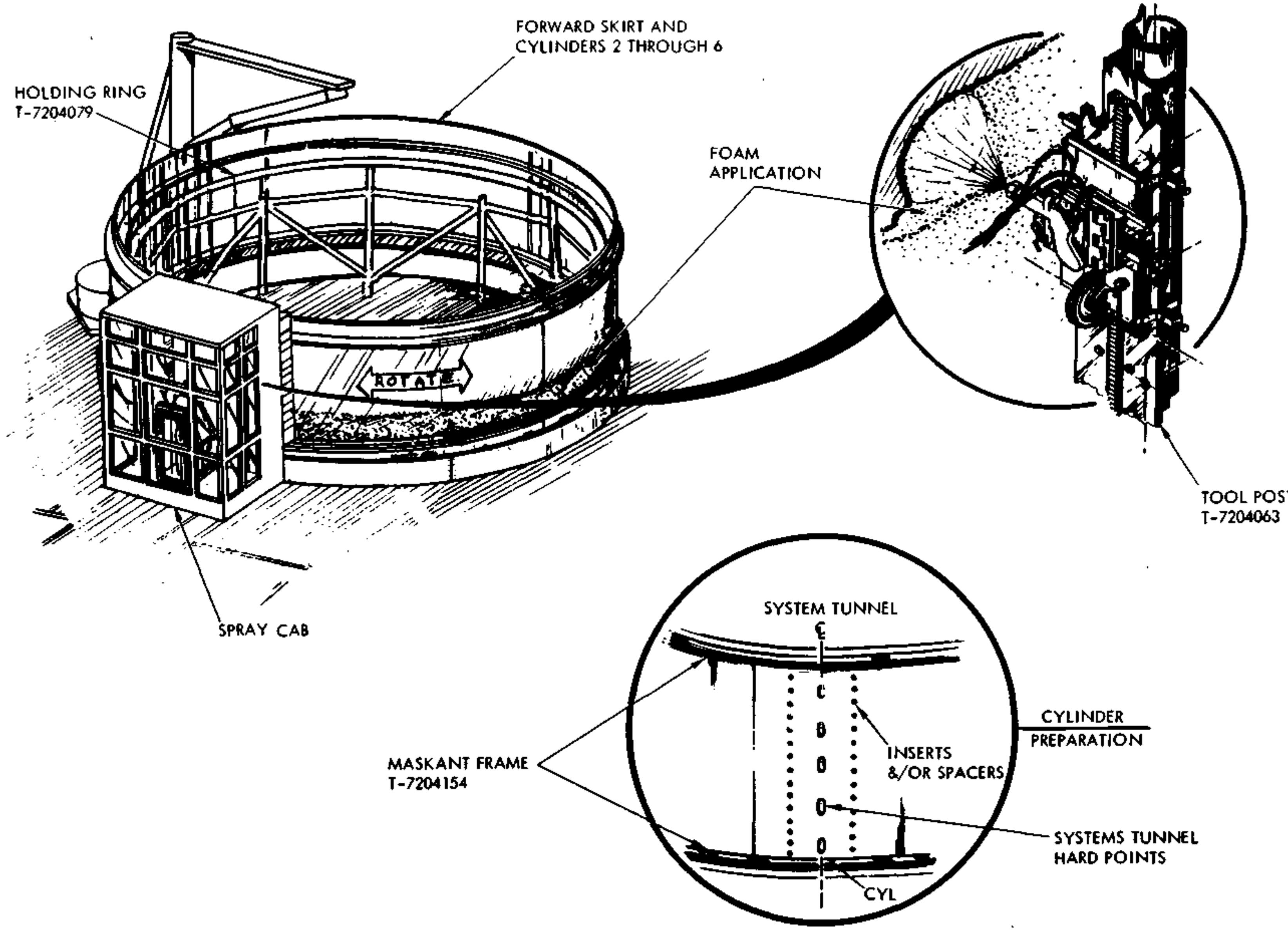


Figure 2-7. S-II Stage Spray-Foam and Finish-Trim Concepts

will then be spray foamed with the polyurethane insulation in an environmentally controlled area after installation of the erosion-barrier spacer blocks. The welding and the spray foam application will be accomplished with existing facilities at the NASA Seal Beach assembly facility in the bulkhead fabrication building.

2.4 STRUCTURAL FABRICATION AND SUBASSEMBLY FACILITIES

The fabrication of structural details and subassembly operations for the bolting ring, thrust cone, aft skirt, and the forward skirt will be in facilities existing in the contractor's industrial base, NASA assembly facilities, and from available subcontractors (Figure 2-8).

2.4.1 Bolting Ring

The bolting ring will be an external structural ring used to join the previously welded LH_2-tank lower cylinder and LH_2/LO_2-tank common bulkhead assembly, to the LO_2-tank aft bulkhead and the thrust structure. The ring will consist of 12 segments approximately 16-inches high and will be pocket-milled with integral flanges and stiffeners on the outside surface.

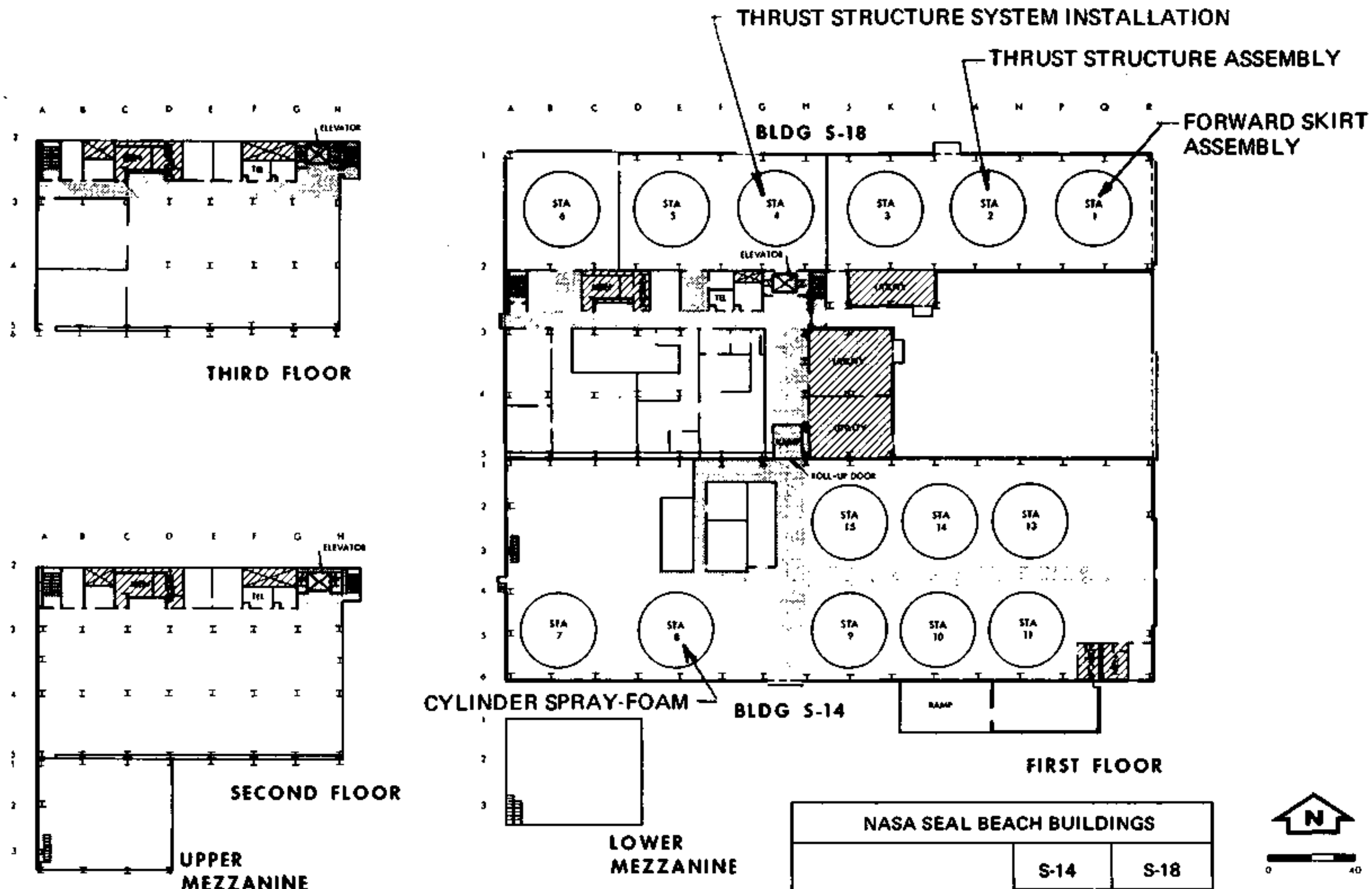
Buildings and Structures

The detail fabrication of the bolting ring will be accomplished within the contractor's existing industrial base, with installation taking place during final assembly at the NASA Seal Beach assembly facility.

2.4.2 Aft Skirt

The ESS aft skirt assembly (Figure 2-9) will consist of two major subassemblies; the aft skirt and the thrust cone. The aft skirt will be of semimonocoque construction with hat-shaped external stringers mechanically attached to skin panels and internal frame assemblies. Two large separation attach fittings for attachment to the booster separation platform will be mechanically attached to the skin panel and internal frame assemblies. The thrust cone and engine beam will be assembled and joined to the aft skirt which will also contain the fuel and oxidizer tanks for the auxiliary propulsion system engines. The aft-skirt bolting-ring engine attach and launch attach fittings will be master jig located during assembly.

After joining of the two subassemblies, the OMS tanks and fuel and oxidizer feed lines will be installed and proof-tested, after which the avionics and other system components will be installed for final assembly mating.



NASA SEAL BEACH BUILDINGS		
	S-14	S-18
NET AREA (SQ FT)	32,365	51,990
ATSU (SQ FT)	4,725	14,755
GROSS AREA (SQ FT)	37,090	66,745
HC CAPACITY	200	150

Figure 2-8. Subassembly Facility

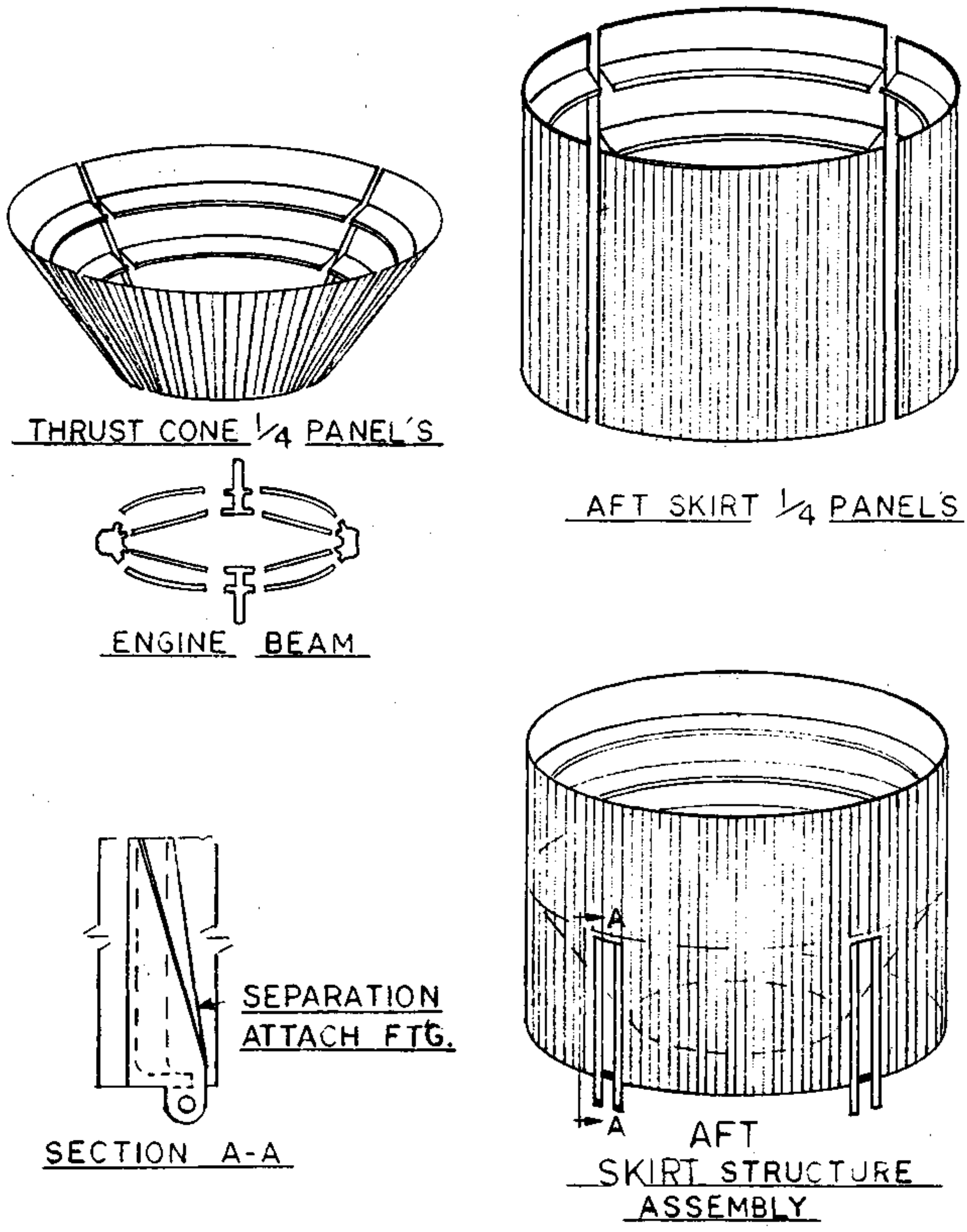


Figure 2-9. Aft Skirt Structure Assembly

Buildings and Structures

The aft skirt, thrust cone, and engine beam details will be fabricated at the contractor's industrial base. The individual parts will be shipped, after prefit, to the NASA assembly facility at Seal Beach and assembled to form the aft skirt in the existing subassembly facility (SAF). The installation of systems will be accomplished in an environmentally controlled area.

2.4.3 Forward Skirt

The ESS forward skirt will be of mechanical semimonocoque construction with hat-shaped external vertical stringers riveted to skin panels and internal frame assemblies. This structure will have access doors, umbilical connectors for both ESE and booster interfaces, instrument attachments, and the fittings for attachment to the shuttle booster attach and separation platform. The skirt will be assembled in an inverted position to control the interface-mating planes for attachment to the payload. After assembly, the skirt will be mated to cylinder No. 5 and the attaching bolt-hole pattern drilled. The No. 5 cylinder will then be removed and delivered to the weld station for joining to the balance of the tank section (Figure 2-10).

After structural completion, the forward skirt will be moved to an installations area and the payload-separation provisions installed prior to final assembly mating.

Buildings and Structures

Detail fabrication and the prefitting of subassemblies will be performed within the contractor's industrial base. Assembly will be performed at the NASA Seal Beach subassembly facility.

2.5 ASSEMBLY FACILITY

Specific assembly and final assembly activities utilizing compatible S-II tooling, buildings, and facility equipment will occur in the existing NASA Seal Beach assembly facility, in conjunction with the total program plan of using available national resources. This site contains the necessary facilities required to perform the described operations.

2.5.1 Stage Final Assembly

The manufacturing breakdown (in Figure 2-11) illustrates the flow of the major subassemblies into a completed stage. The commonality of the ESS to the S-II vehicle permits utilization of existing tooling and equipment as

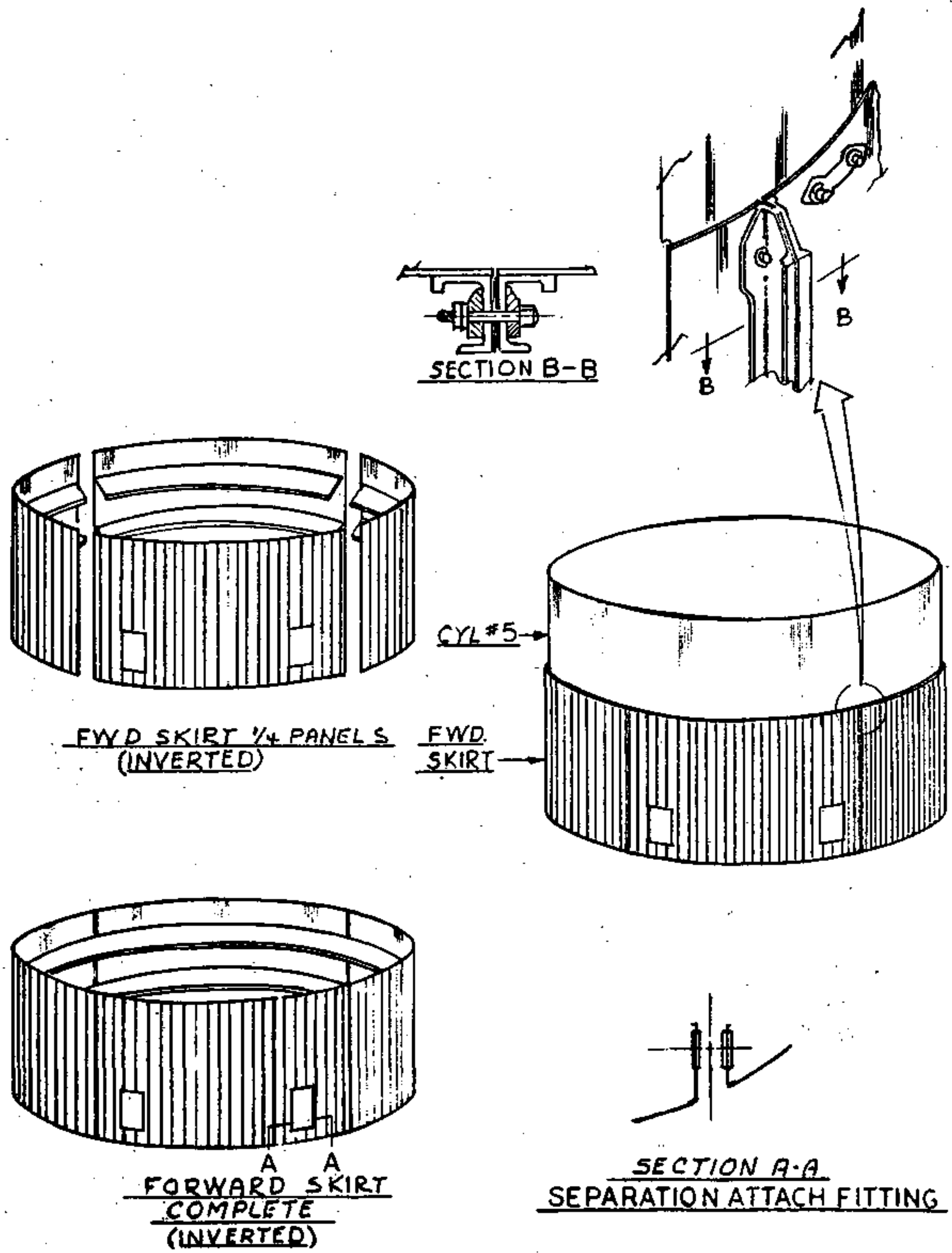


Figure 2-10. Forward Skirt and Cylinder 5 Mating

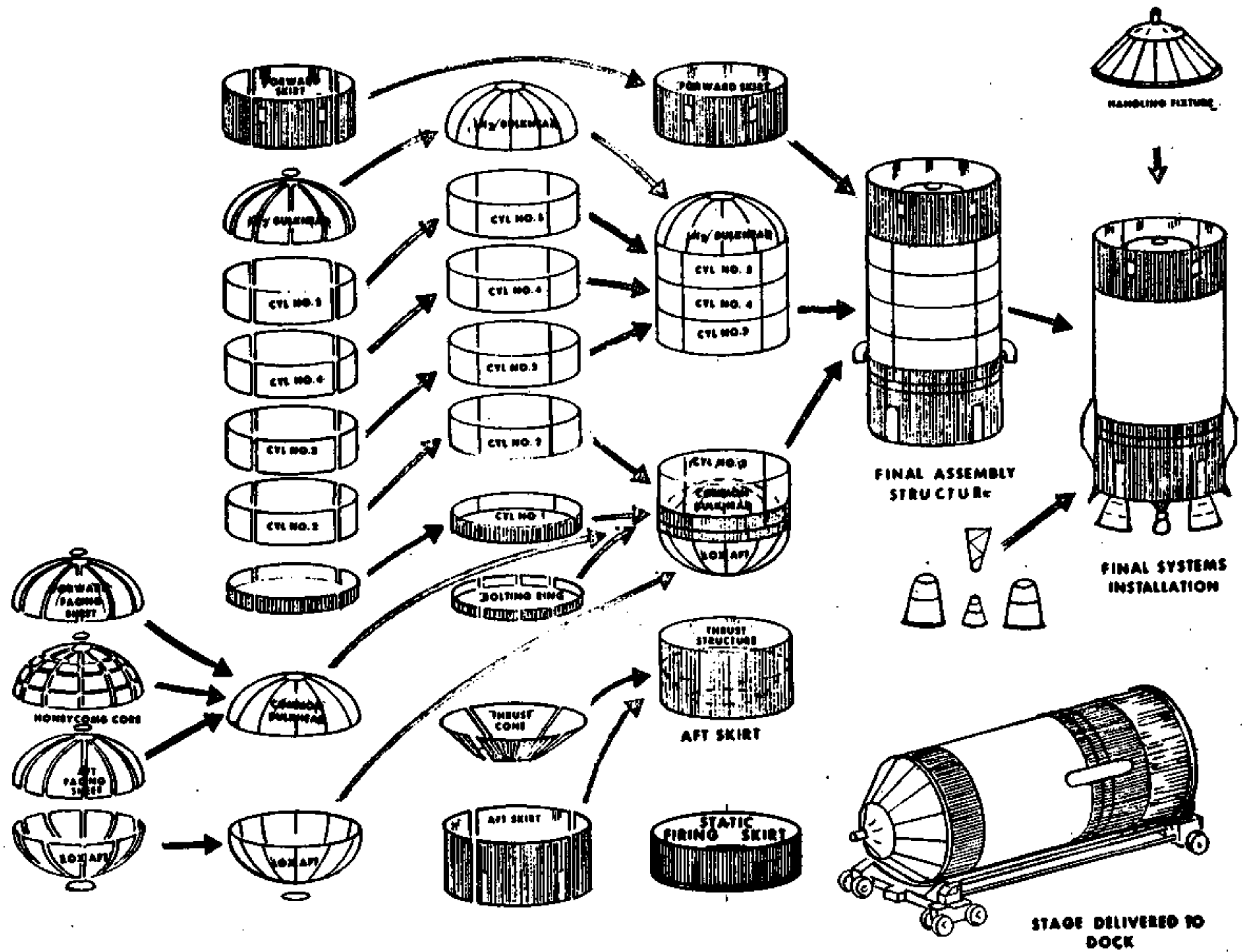


Figure 2-11. ESS Manufacturing Flow Plan

well as proven processes and techniques. The structurally completed LO_2 and LH_2 tanks will be subjected to a pneumostatic test. Subsequent to the pneumostatic test, the remaining erosion barrier spacer blocks will be attached and the stage will undergo tank cleaning operations, spray-foam insulation will be applied to the lower forward skirt area, cylinder No. 1, the bolting ring, and the LH_2 tank weld areas, (Figure 2-12) and final installations will be accomplished, including the erosion barrier panels and ablative coatings. A static firing skirt will be installed on the aft structure surface to facilitate handling and transportation of the stage.

Buildings and Structures

The vertical assembly weld stations situated in the vertical assembly building (Figure 2-13) and the bulkhead fabrication building (Figure 2-3) at the NASA Seal Beach site are air-conditioned and environmentally controlled, providing proper accommodations for the assembly of the propellant tanks.

In order to make the most effective use of existing facilities, it is proposed to produce the ESS at the least cost rate, three vehicles per year. This rate oversupports the projected launch rate of two flights per year, and will require storage of the stages at KSC. As a further means of being cost effective, the operations plan requires the recycling of high value ESS components. The main propulsion engines, engine actuators, the data control management (DCM), and guidance, navigation, and control (GN&C) packages will be recovered from the ESS by the Space Shuttle Orbiter after payload delivery and prior to deorbiting of the stage. The recovery will be accomplished as the secondary mission of a normal space shuttle logistics flight. The recovered items will be refurbished as required before installation into another vehicle.

The first three vehicles will be completely assembled and will undergo integrated checkout run, at the Seal Beach facility. Use of recycled engines and actuators will begin with the fourth vehicle, requiring the use of an engine system simulator during the Seal Beach integrated checkout. The refurbished engines and actuators will be installed in the low bay area at KSC. Recycling of the avionics packages will begin with the sixth vehicle, following the above process of using simulators at the manufacturing site. These recycled items will be included in the normal prelaunch operations and combined systems test, thereby verifying their flight worthiness.

2.5.2 Forward Skirt and Aft Skirt Installation

The completed forward skirt and aft skirt will be mated to the LH_2/LO_2 tank assembly in the final assembly sequence. This operation will be accomplished in the vertical assembly building utilizing the existing facilities.

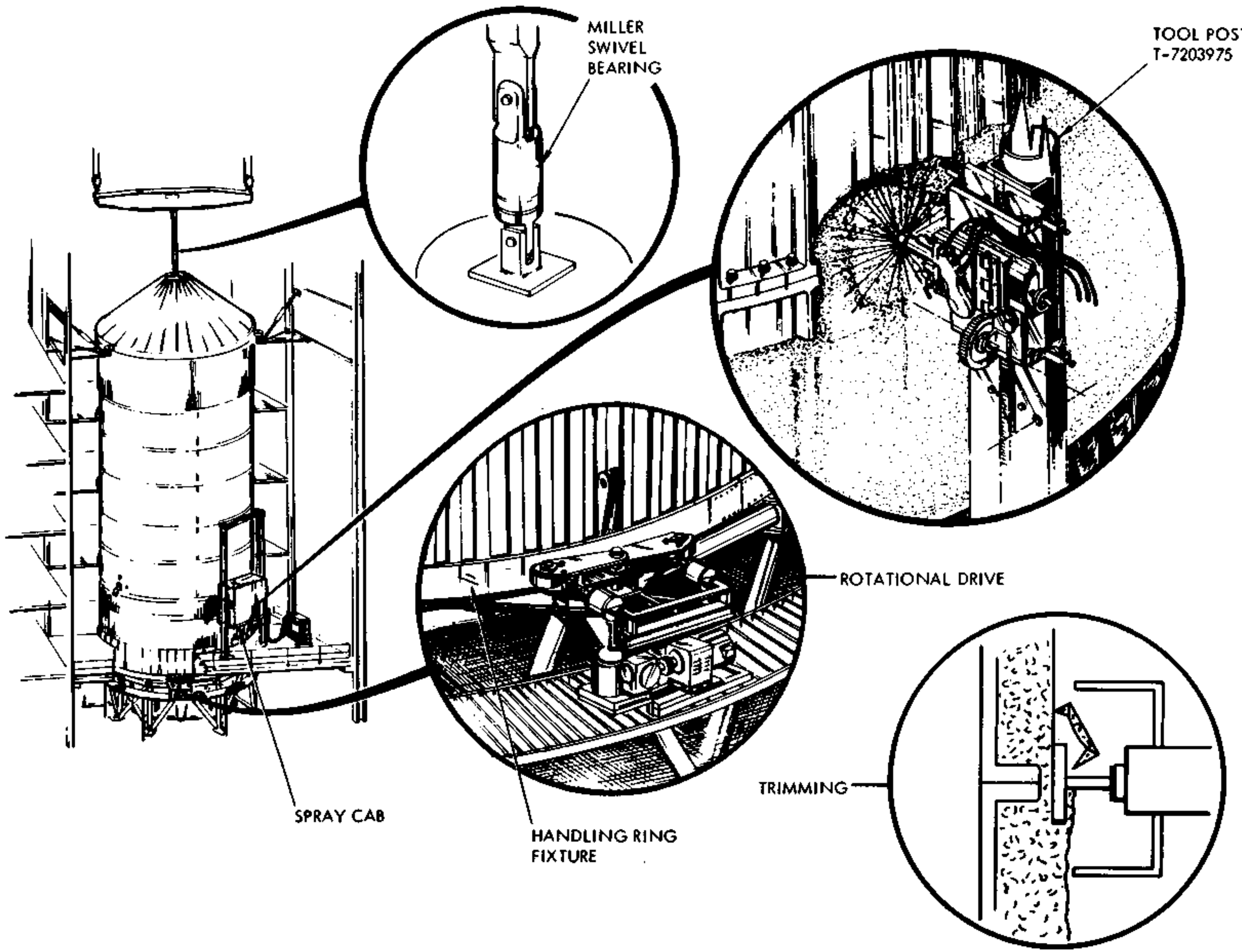
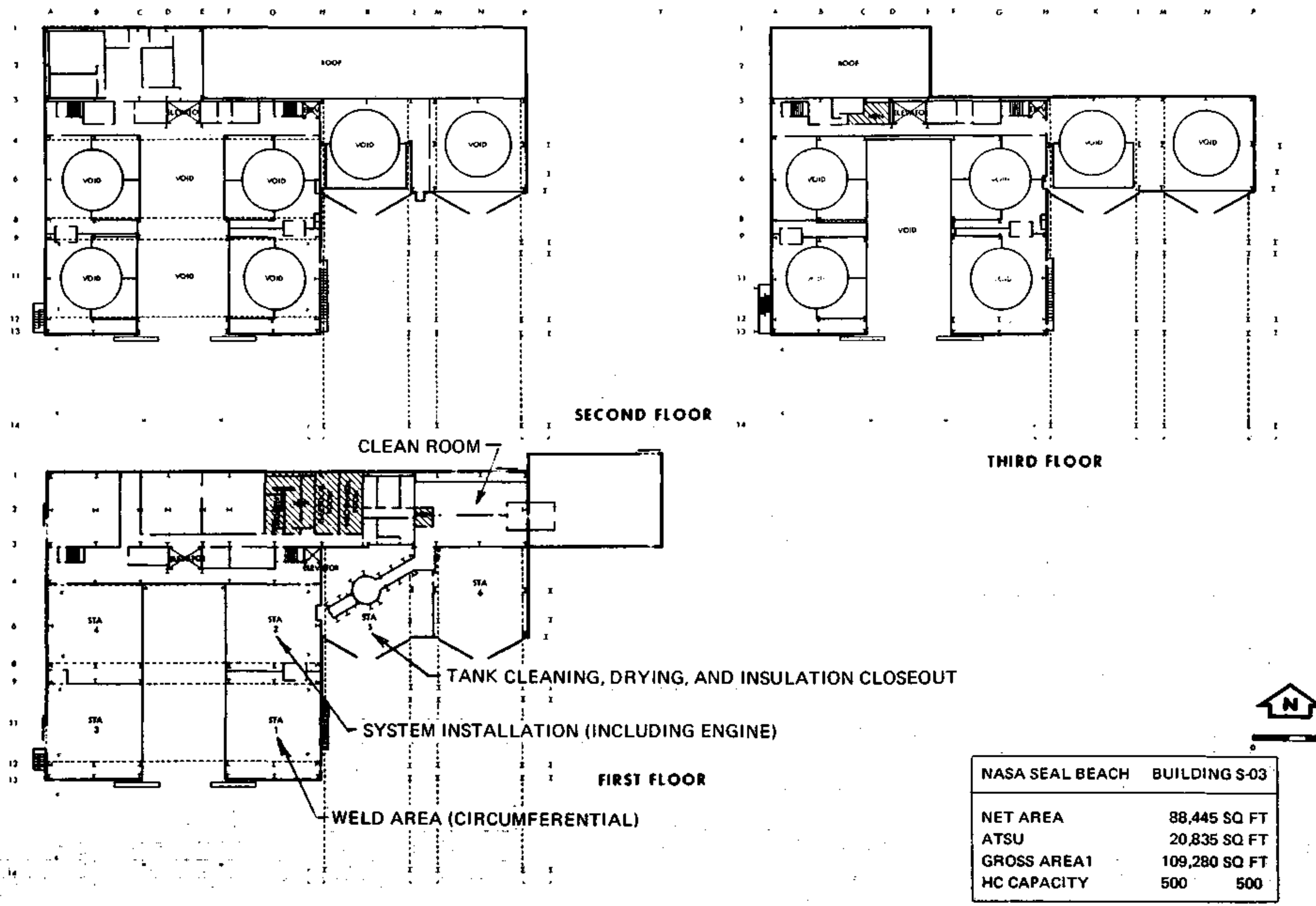


Figure 2-12. Vehicle Rotation and Foam Application, Station V



NASA SEAL BEACH	BUILDING S-03	
NET AREA		88,445 SQ FT
ATSU		20,835 SQ FT
GROSS AREA1		109,280 SQ FT
HC CAPACITY	500	500

Figure 2-13. Stage Final Assembly Building

2.5.3 Pneumostatic Test

The completed propellant tank assemblies will be transferred on an existing S-II stage transporter to the U. S. Naval Weapons Station, Seal Beach, California (adjacent to the NASA Seal Beach site) where the ESS tanks will be pneumostatically tested to prescribed engineering specifications. It is assumed that continuing use of this facility will be permitted.

2.5.4 Tank Cleaning and Drying

The ESS will be placed in the vertical assembly building's cleaning and drying station and both the LH_2 tank and LO_2 tank will be cleaned, rinsed, and dried according to engineering specifications. This process will be accomplished with the stage in a vertical position, with the stage turned end for end for access into both tanks through the LH_2 tank access door and the LO_2 tank sump.

2.5.5 Insulation Closeout Application

The assembled ESS (excluding engines) will be placed in the vertical spray foam station (Figure 2-12) situated in the vertical assembly building. This station provides the environmentally controlled conditions necessary to apply the spray foam. The station contains a device which rotates the stage and allows the spray foaming and machining equipment to be fixed on a platform which can be positioned at the various closeout levels.

2.5.6 Engine, Systems Installation, and Erosion Barrier

The stage will be positioned in the existing systems installation station in the vertical assembly building at the Seal Beach manufacturing site, and the engines, actuators, and remaining systems installed using existing or modified equipment. As noted under Paragraph 2.5.1, engine and engine actuator installation will be deferred from the fourth vehicle onward to allow the use of recycled items, with the DCM and G&C avionics package installation being deferred from the sixth unit onward. Installation for the affected items at Seal Beach will be limited to simulator packages to allow an integrated checkout to be performed.

A GSE static firing skirt will be mechanically attached to the aft skirt and will remain joined during stage final assembly, checkout, transportation, and static firing. This static firing skirt will permit the ESS to use S-II transportation equipment.

The insulation erosion-barrier panels, fabricated from polyimide skins bonded to high-temperature honeycomb core, will be assembled and their installation bolt-hole patterns will be drilled prior to the start of installation on the ESS (Figure 2-14). The polyimide laminate spacers, installed prior to the spray foam operation, will be drilled and tapped to receive the erosion barrier fasteners. Coordinated tooling will be used to assure proper fastener location. The installation of the erosion barrier panels and the high temperature ablative materials will be accomplished after the spray foam insulation closeout operations and while the stage is in the vertical position in the systems installations station. This station is air-conditioned and contains the required environmental control facilities.

2.6 SYSTEM AND ACCEPTANCE TEST

The systems and acceptance testing and checkout will be performed at the assembly site. The facilities supporting these test operations are existing at the NASA Seal Beach assembly facility and will be used with moderate modifications to accommodate the difference in engine and stage height.

2.6.1 Acceptance Level Tests

The system acceptance-test operation will consist of telemetry and RF systems checkout, electrical power systems checkout, mechanical system leak and functional checkout, instrumentation systems checkout, verification of electromagnetic compatibility, propulsion and pressurization systems checkout, and simulated flight of integrated systems checkout. Engine alignment verification, stage weight, and center of gravity determination will also be accomplished.

2.6.2 Buildings and Structures

The checkout operations will be accomplished in the vertical checkout building (Figure 2-15) and will utilize the air-transportable Universal Test Console (UTC) developed for the space shuttle program. This building has the equipment for checkout of the indicated stage systems, and the control room and computer complex situated in the building are environmentally controlled. The engine alignment, weighing, and center-of-gravity determination will be performed in the horizontal paint and package station used for final inspection, painting, and packaging of the stage.

2.7 PREPARE AND SHIP STAGE

The process for preparing the stage for shipment will consist of (1) installing sensing elements for intransit instrumentation; (2) covering all

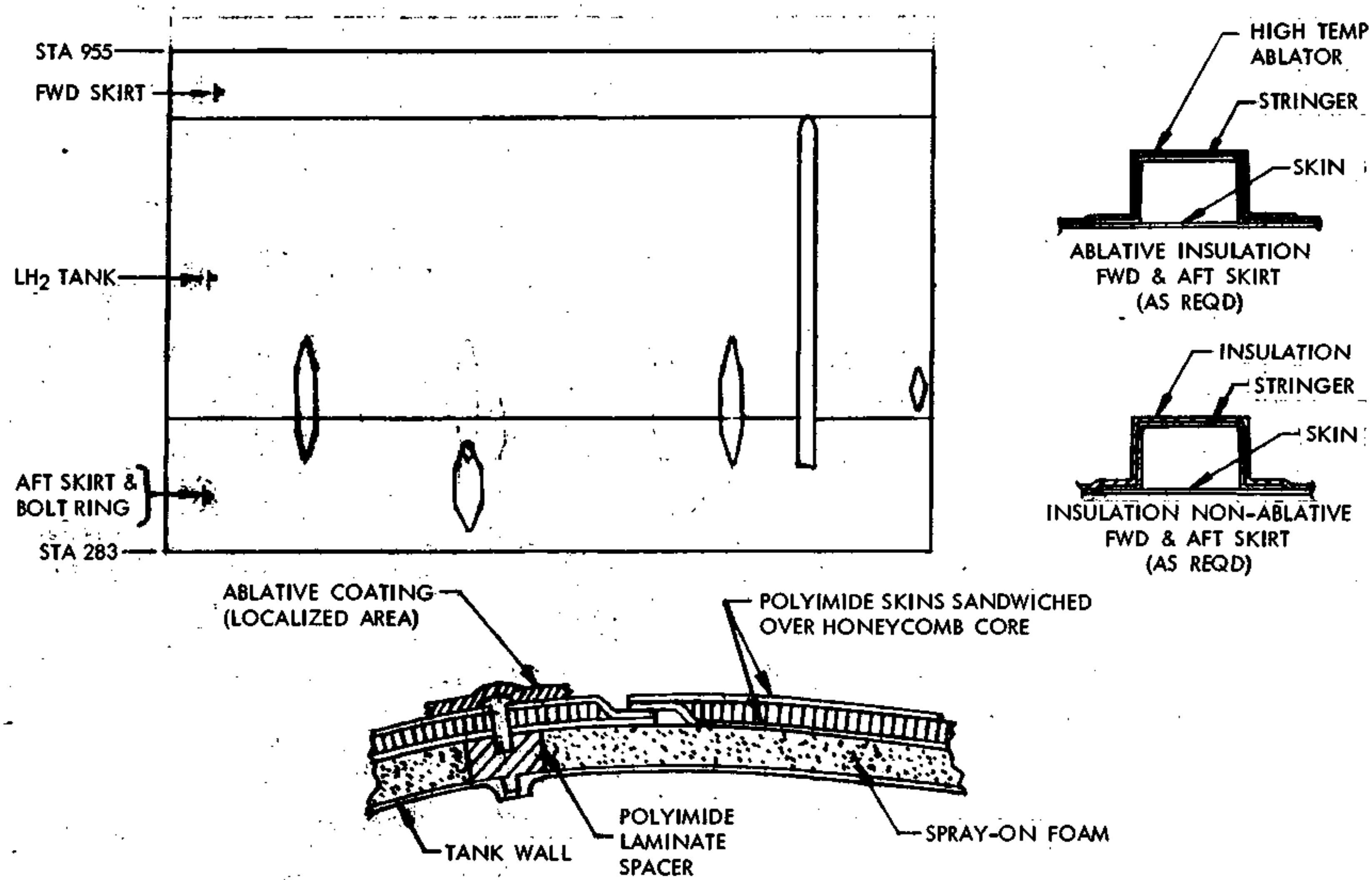
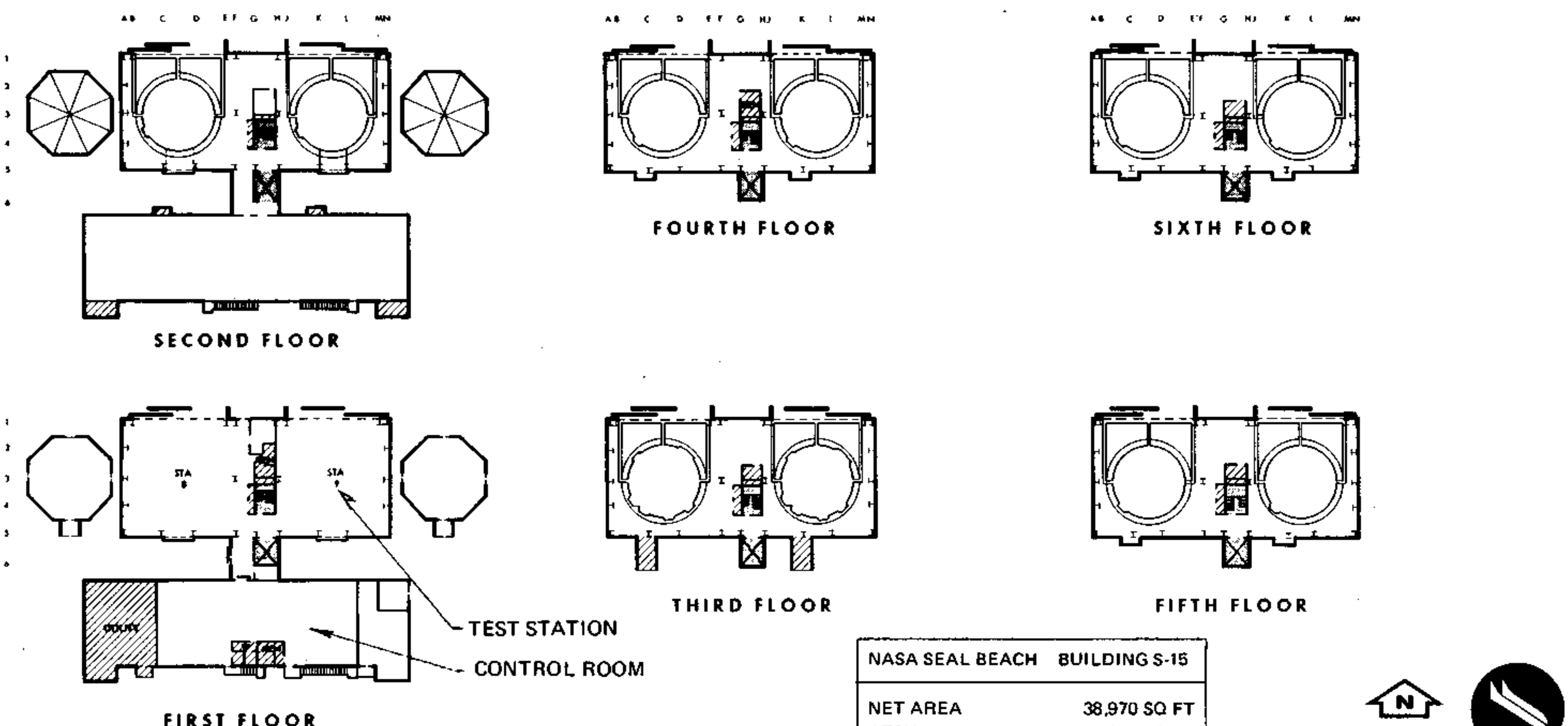


Figure 2-14. Insulation Erosion Barrier



NASA SEAL BEACH	BUILDING S-15
NET AREA	38,970 SQ FT
ATSU	12,970 SQ FT
GROSS AREA	51,940 SQ FT

Figure 2-15. System and Acceptance Test

access doors and ports; (3) covering the instrumentation, separation, and control system components; (4) securing engines in position; (5) purging the propulsion system; (6) placing desiccant charges; (7) installing the GSE static firing skirt; and (8) installing protective covers on the stage.

The facilities required for this operation are available within the existing paint and packaging building on the NASA Seal Beach site (Figure 2-16).

After all preparations have been completed, the stage will be placed on one of the two existing S-II transporters and towed by a prime mover to the U.S. Naval Weapons Station loading dock at Seal Beach. The stage and transporter, together with the required ground support equipment, will be loaded aboard the AKD Point Barrow (presently decommissioned) for shipment. The first two units delivered to the Kennedy Space Center (KSC) will be subjected to static firing tests.

2.8 VEHICLE STATIC FIRING

The Main Propulsion Subsystem (MPS) will be tested during the integrated vehicle static firing tests. The integration testing will require a test site equipped with propellants, pressurants, test stand, control center, fluid distribution system, instrumentation, and operational items necessary to support cluster engine firings. NASA facilities being provided for the space shuttle orbiter would be available to support the static firing operation. The avionics systems will utilize the shuttle GSE during KSC operations. Engine component development and qualification testing will be conducted at the engine contractor's facilities.

2.9 PRELAUNCH PREPARATION

The first three vehicles to be completed will be received at the launch complex ready for inspection, preparation, and checkout. The first two of these vehicles will be prepared for static firing and then static fired. The prelaunch activities will consist of the preparation of the stage for flight readiness, checkout of systems, validation of the connections, and performance of combined system test verifications. Upon completion of the prelaunch operations, the stage will be delivered to the launch operation contractor for stacking/mating with the booster and payload.

Beginning with the fourth production vehicle, the installation of the recovered and refurbished ESS engines and engine actuators will be performed in the low bay area of the KSC VAB. The recovered and

NASA SEAL BEACH BUILDINGS	S-04	S-05
NET AREA (SQ FT)	9,560	15,655
ATSU (SQ FT)	855	1,885
GROSS AREA (SQ FT)	10,415	17,540

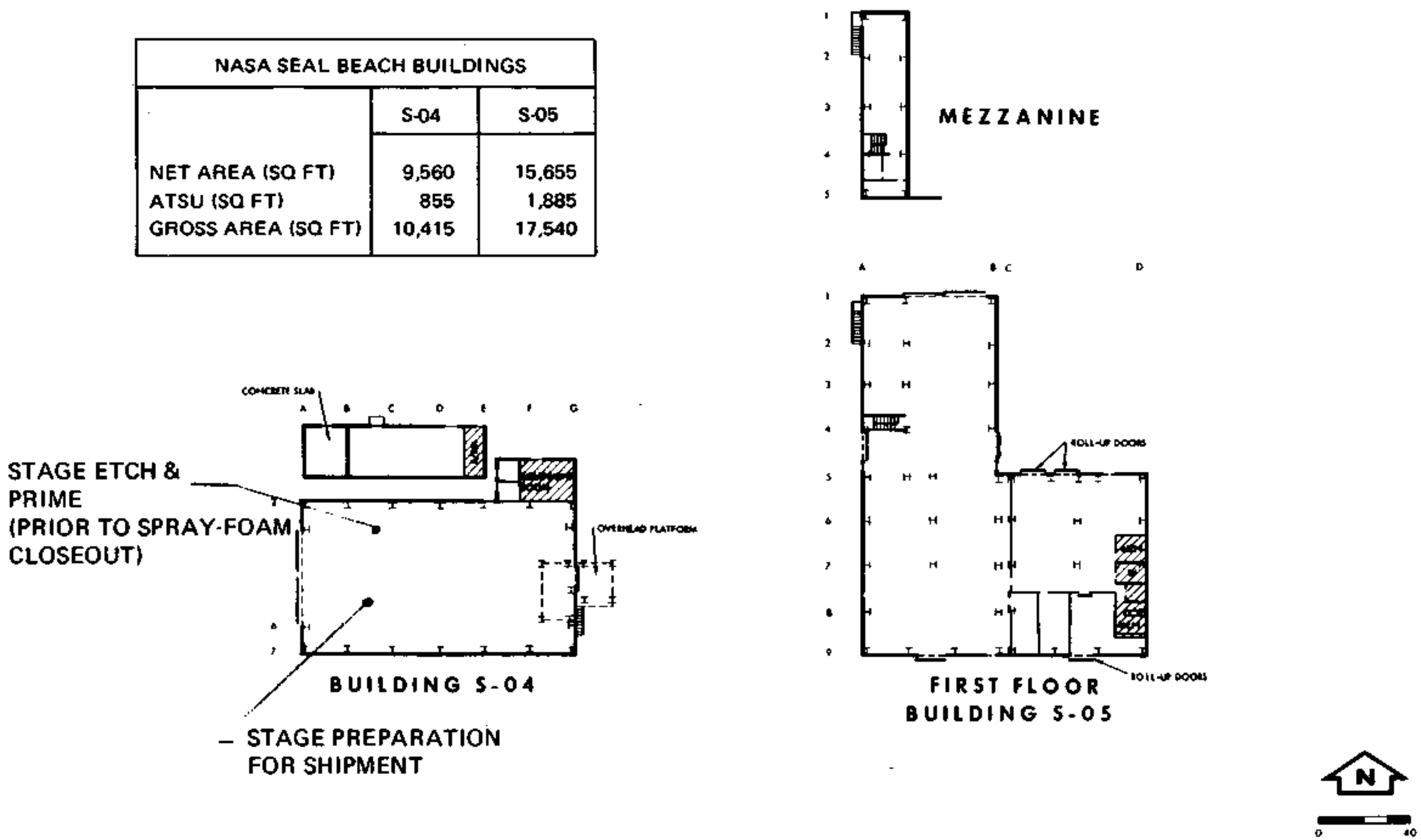


Figure 2-16. Paint and Packaging Building

refurbished ESS avionics packages to be installed in the boattail region will begin with the sixth vehicle. Since the items to be recovered and refurbished are basically space shuttle components, the space shuttle GSE can be used for the refurbishment, handling, installation, and checkout.

2.9.1 Buildings and Structures

Existing KSC facilities will be utilized for the prelaunch operations. The low bay area of the vertical assembly building (VAB) will be utilized for receiving, inspection, and pre-mate operations on the ESS. The booster will use facilities defined in the space shuttle program. The high bay of the VAB, situated at Launch Complex 39, will be utilized for the erecting, mating, and checkout operations for the ESS, booster, and payload. Refer to SD 71-104-2, "Facility Utilization and Manufacturing Plans For Phase C/D" (MSC-03311), for descriptions of the facilities required by the booster for its maintenance, erecting, mating, transport to the launch pad, launch, and recovery. The space shuttle plan is to erect and mate the vehicles onto the launcher umbilical tower (LUT), sometimes referred to as the mobile launcher, in a high bay of the VAB, then to transport them to the launch pads by use of the crawler on the existing crawlerways. The expendable second stage on a reusable shuttle booster adapts the operational philosophy and facilities to the greatest extent possible.

2.10 LAUNCH PREPARATION

The use of the ESS does not require any change to the LUT, but does require that an additional tower be installed (or mobile) on one of the two launch pads, with appropriate services (LH_2, LO_2, etc.) plumbed in. Only one launch pad is required due to the low flight rate of two per year. The tower can be located on the pad so as not to interfere with normal space shuttle operations. This tower would provide swing-away access arms for the required services (with pull-away disconnects, based on first motion) to the ESS. While access to, and services for, payloads of the ESS is beyond the scope of this study, this tower could also provide those. This tower is shown in Figure 2-17, with more details in Volume 7, Preliminary Design Drawings, of this report. Disconnects for the propellants are the same as presently used on the S-II.

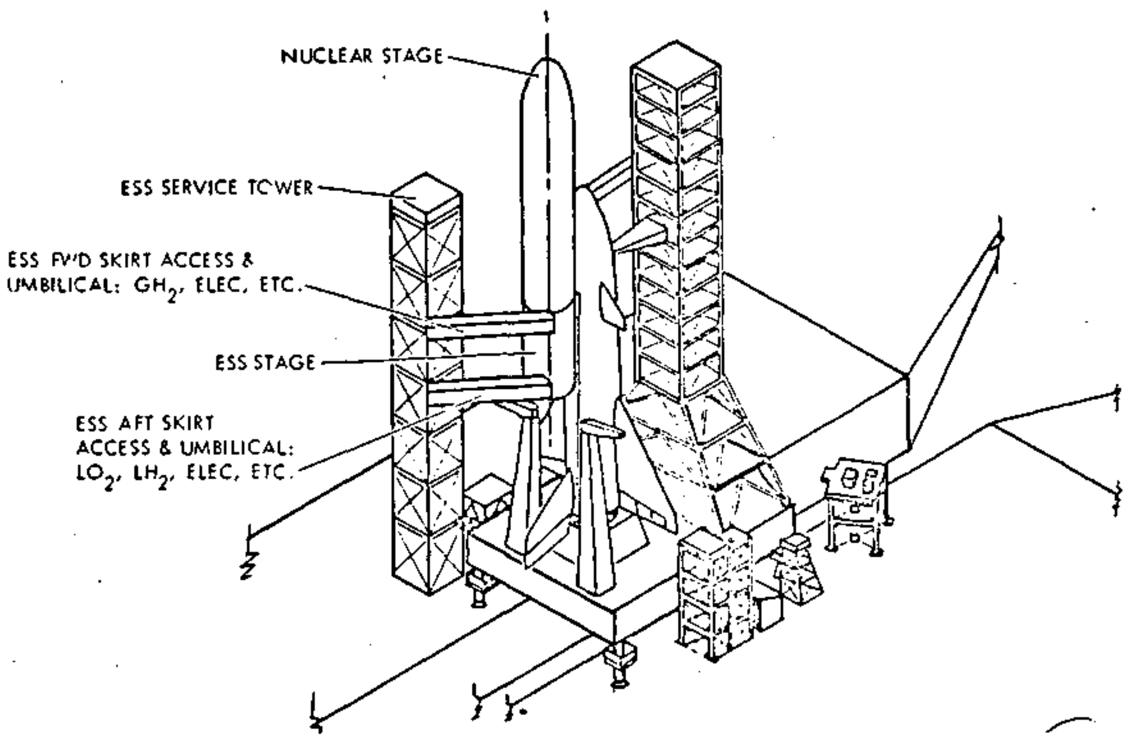


Figure 2-17. ESS/Booster at Launch Pad

Preceding page blank

3.0 MANUFACTURING TECHNOLOGY

The Expendable Second Stage (ESS) is a derivative of the expendable Saturn second stage (S-II), using different engines and carrying an advanced avionics system capable of unmanned rendezvous. Thirty-three feet in diameter, the ESS will consist of a forward skirt which will interface with the payload, an LH_2 tank and a LO_2 tank with a common bulkhead, and an aft skirt carrying the main and auxiliary engines. The forward and aft structures will be of conventional, mechanically fastened construction, with some of the avionics subsystem packages mounted around the interior of the forward skirt and some on the aft thrust structure to achieve the best thermal environment during orbital operations. The LH_2 tank section will be made up of machined panels welded to form a cylinder, using a hemispherical forward bulkhead of machined and formed gores welded together. The common bulkhead is of sandwich construction, with the forward face sheet acting as the aft bulkhead of the LH_2 tank, and the aft face sheet serving as the forward bulkhead of the LO_2 tank. These face sheets, as well as the aft LO_2 bulkhead, are welded assemblies made from machined and formed gores similar to the LH_2 forward bulkhead.

The technology required in the fabrication of the assembly and checkout of the S-II and the ESS is compared in Table 2-1. The materials used in the tank walls and bulkheads will be similar to the S-II, and will be welded using existing, proven processes and tooling. The forward skirt, and aft skirt structure requires no new concepts, and will be manufactured where applicable with the existing S-II tooling. Commonality between the two vehicles extends to the use of the same handling devices and transportation equipment.

Subsystems installation and checkout are anticipated to be similar to proven S-II practices. The avionics subsystems, while more complex than those required for the S-II mission, will be developments of space shuttle and should present no problems in installation or checkout.

3.1 MANUFACTURING METHODS

3.1.1 Forming and Machining

Fabrication of the bulkheads and skin panels will be accomplished with the existing techniques that are already proven on the S-II vehicle. The machining of the large cylinder panels and gore panels will be

PRECEDING PAGE BLANK NOT FILMED

Table 2-1. Commonality Analysis

Item	S-II-15	ESS
Bulkheads	Forward LH_2 bulkhead Common bulkhead Aft LO_2 bulkhead	Same as S-II-15 Same as S-II-15 New sump
LH_2 Cylinders	No. 6 cylinder No. 5 cylinder No. 4 cylinder No. 3 cylinder No. 2 cylinder No. 1 cylinder	Same as S-II-15 Deleted Same as S-II-15 Same as S-II-15 New (2 fuel elbows) Same as S-II-15)
Bolt ring	12 Segment, mechanically joined to LO_2 tank, No. 1 cylinder, and aft skirt	Same as S-II-15
Forward skirt	Skin panels Frames/caps Stringers Fittings N/A	New requirements New requirements New requirements New requirements Special booster link attachment
Thrust structure	Aft skirt Thrust cone Engine beam N/A	New requirements New requirements New requirements OMS Engine mount
Interstage	Skin panels Frames/caps Stringers	N/A N/A N/A
Fairings	5 Feedlines 1 LO_2 vent 1 Fill and drain	2 Feedlines (new 13-in. diameter) Same requirements Same requirements 1 Deflector - SSEO Engines
Systems tunnel	1 External phenolic tunnel	Same requirements

Table 2-1. Commonality Analysis (Cont)

Item	S-II-15	ESS
External insulation	Spray foam LH_2 bulkhead, LH_2 cylinder, forward skirt - partial, bolt ring and aft skirt	Spray foam on tank area, with honeycomb panel erosion barrier and localized hot-spot added ablative coating. Ablative coatings on forward skirt and thrust structure in areas subject to interference heating.
Stage systems	The S-II vehicle has basically independent systems. They are: 1. Electrical power and control separation 2. Ordnance system 3. Propellant system 4. Propellant management measurements 5. Instrumentation 6. Telemetering 7. Thermal control 8. Flight control 9. Pressurization 10. Engine actuation system 11. Safing system 12. Engine servicing The stage electrical hardware consists mainly of relay modules and discrete component designs.	The ESS has an integrated avionics system in which the various stage systems are controlled and monitored from a central computer through a data bus and standard digital interface units. The main ESS systems are: 1. Data and control management 2. Guidance, navigation and flight control 3. Electrical power 4. Electrical control 5. Communications 6. Instrumentation 7. Environmental control 8. Deorbit subsystem
Engines	Five J-2	Two SSEO engines
Auxiliary propulsion	N/A	Two shuttle OMS engines Fourteen attitude control Propulsion system thrusters Cryo tankage

accomplished on the large skin mills at the NR Los Angeles Division. High energy forming and stretch forming will both be used on the bulkhead gore panels with the tank skin panels being brake-formed after machining.

3.1.2 Welding Machines/Tooling

Automatic (gas tungsten arc) DC/SP-GTA welding machines will be used to fabricate the ESS fuel tank assemblies. All machines are constant current with automatic voltage control. ESS weld joints, the same configuration as the S-II, will involve significant tapered thicknesses, welded from one side by linear taper-adaptive control integrated into the equipment programmer to provide precise weld-bead geometry control. The exception to this is the LO_2 dollar weld which, due to thickness, will be welded by the opposed nugget technique. The skate-weld tooling and the rotating turntable developed and proven on the S-II program will be used for the ESS weld joining, employing both the controlled nugget and free-fall weld techniques.

3.1.3 Cryogenic Insulation

The ployurethane foam insulation will be applied by spray guns to the LH_2 forward bulkhead, the lower portion of the forward skirt, the LH_2 tank cylinders, and the bolt ring. Processes and equipment used on the S-II are available and will be used on the ESS in view of the similar requirements.

3.1.4 Erosion Barrier

The erosion-barrier honeycomb panels will be prefit and bonded on multiple use bonding fixtures at the Downey facility. Coordinated master tooling will be developed to allow drilling of the attachment holes prior to fitting to the ESS.

Processes and equipment used in making the fairings and system tunnel for the S-II will be readily adaptable for use on the ESS.

3.1.5 Tank and Component Handling

Handling systems as well as equipment requirements were developed and proven on the S-II Program. Extensive use of Vacu-Lifts, padded contour boards mounted on pallet bases, and handling fixtures adapted to transporting, lifting, and positioning will be used for flat or contoured skin panels and bulkheads.

3.2 MANUFACTURING CONCERNS

The manufacturing techniques for the fabrication, assembly, and installations of the ESS are within present technology and it is not anticipated that NR will encounter any significant technical problems. However, there is an area of concern due to the interface requirements for attachment to the shuttle booster as shown in Table 2-2.

3.2.1 ESS/SS Booster Linkage-Attach Fitting

Because of the close tolerance necessary in the alignment of the ESS to the shuttle booster, the ESS/booster linkage-attach fitting installation and checkout is an area of manufacturing concern.

To ensure the interface of the ESS to the shuttle booster, an in-depth study of the linkage-attach system will be made. Close coordination will be maintained between the shuttle booster contractor and the ESS by an assigned manufacturing engineer. Where required, master tooling will be utilized to ensure the close tolerances required in the alignment of the ESS separation linkage-attach fittings.

Table 2-2. Manufacturing Task Analysis

Task	Assembly																	
	Forward Skirt	Fwd Attach Fittings	LH_2 Bulkhead	LH_2 Cylinders	Common Bulkhead	Bolt Ring	LO_2 Bulkhead	LO_2 Sump	Aft Skirt	Thrust Cone	MPS Engine Beam	OMS Engine Beam	Tank Insulation	MPS Engines	OMS Engines	Static Firing Skirt	Attach Structure Ftg	Fairings
Fabrication	S	S	S	S	S	S	S	S	S	S	S	S	N/A	N/A	N/A	S	S	S
Processing	S	N/A	S	S	S	S	S	S	S	S	S	S	S	N/A	N/A	S	S	S
Assembly	S	N/A	S	S	S	S	S	S	S	S	S	S	S	N/A	N/A	S	C	S
Installations	S	N/A	N/A	N/A	N/A	N/A	N/A	N/A	S	S	N/A	N/A	N/A	S	S	N/A	N/A	N/A
Checkout	S	N/A	N/A	N/A	N/A	N/A	N/A	N/A	S	S	N/A	N/A	N/A	S	S	N/A	N/A	N/A
Handling	S	N/A	S	S	S	S	S	S	S	S	S	S	N/A	S	S	S	N/A	S
Transportation	S	N/A	N/A	N/A	N/A	S	N/A	N/A	S	S	S	S	N/A	S	S	S	N/A	S
Inspection	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

Key: S = State of Art; C = Concern; NA = Not Applicable

4.0 GOVERNMENT-FURNISHED EQUIPMENT AND MACHINE TOOLS

The government-owned equipment and machine tools used for the fabrication and assembly of the Saturn S-II will be available at the various sites within the contractor's industrial base to support the requirements of the ESS program. In addition to the government-owned equipment, a substantial amount of NR-owned equipment and machine tools used on the S-II and other major programs will be available at these same sites.

The development and qualification laboratories utilized to provide test capabilities in support of the S-II program will be available for similar tests on the ESS. This equipment can be used singly or in combination with other specialized facilities scheduled for development in support of the space shuttle program.

Preceding page blank

5.0 MAJOR TEST EQUIPMENT AND GSE

Major test equipment and ground support equipment (GSE) are government-furnished equipments required for the handling of assemblies during fabrication, assembly, final assembly, and checkout. A listing of the operations site GSE requirements follow.

Launch Hardware

1. Umbilical carrier plate assembly, aft
2. Umbilical carrier plate assembly, forward
3. LH_2 fill and drain disconnect assembly
4. LO_2 fill and drain disconnect assembly

Checkout and Servicing Equipment

1. Pneumatic servicing unit
2. Purge and leak detection console set
3. LH_2 heat exchanger
4. Blanking plate set
5. Flow monitoring unit
6. Pump-shaft seal leakage indicator
7. Portable leak detector set
8. Thermal conditioning and purge console
9. Pneumatic console test set
10. Portable vacuum and purge unit
11. Stationary vacuum pump unit
12. Propellant tank pressurization unit
13. LH_2- and LO_2-vent valve checkout system
14. Universal test console

Handling and Auxiliary Equipment

1. Maintenance walkway, forward skirt
2. Clean-room LH_2 tank
3. Adapter set - air-conditioning tank servicing
4. Access platform, forward stage
5. Indicator - No. 2 piston position
6. LH_2 tank cover, servicing mechanism
7. Tool set-engine actuator pin
8. Platform set, engine compartment
9. Ladder, thrust cone access

10. Protective ring, LO_2 tank access
11. Protective ring, LH_2 tank access
12. Protective set, forward bulkhead
13. Access platform, forward bulkhead extendable
14. Center platform, engine compartment
15. Ring, forward, stage support
16. Ring, aft, stage support
17. Dolly, static firing skirt
18. Cover, static firing skirt
19. Cover, aft thrust structure
20. Simulator, actuator
21. Sling, stage erecting
22. Frame, hoisting, forward
23. Frame, hoisting, aft
24. Sling, static-firing skirt segment
25. Sling, ring segment, support
26. Static firing skirt (for shipment)
27. Adapter set, tag lines
28. Sling, static firing skirt
29. Lock, engine actuator
30. Adapter, vertical installation, main engine
31. Adapter, vertical installation, orbital maneuvering-system engine
32. Installer, separation linear-shaped charge
33. Handle, access cover, LH_2 tank
34. Illumination set, transporter
35. Platform, LO_2 tank access
36. Access kit - LO_2 tank internal
37. Cover, LO_2 tank internal protection
38. Bench measurement tool - servo actuator
39. Fixture - servo actuator, torque rod, and J-nut
40. Support tool, servo actuator
41. Adapter set - ESS component handling
42. Entry kit, LH_2 tank
43. Internal access kit, LH_2 tank
44. LH_2-tank entry adapter
45. Decoder plug-removal tool
46. Battery handling equipment

A listing of the manufacturing site handling equipment requirements is given in Table 2-3. Equipment required for checkout at the system level and integrated checkout in the final assembly station is listed in Table 2-4.

Table 2-3. Manufacturing Material/Personnel Handling Equipment Requirements

Assemblies	Dollies and Trailers	Platforms	Ladders	Slings	Adapters	Spreader Bars	Manipulators	Positioners	Racks	Protective Devices	Vacuum Lifts	Bridge Crane Hoist	Shackles	Yard Tractor	Stiffening Angle	Tag Lines	Fork Lift	Mobile "Stick" Cranes	Turnover Fixture	Mobile Gantry Crane	Jacks	Pneumagrip
Gore sections	X			X							X	X		X	X	X	X					
Bulkheads	X					X					X	X	X	X	X				X		X	
Dollar insert				X								X										
Quarter panels	X	X		X	X	X			X			X	X			X						
Cylinders	X	X	X	X	X	X				X		X	X	X		X		X	X	X	X	X
Stacking	X	X	X	X	X	X				X		X	X	X		X					X	X
Skirts, forward and aft	X	X	X	X	X	X						X	X	X		X		X			X	
Thrust structure	X	X	X	X		X						X	X	X							X	
Interstage	X	X	X	X	X	X			X			X	X	X		X					X	
Stage	X	X	X	X	X	X				X		X	X			X						
Fuel lines		X		X			X	X		X		X	X			X	X	X				
Miscellaneous hardware	X			X					X					X			X					

Table 2-4. Manufacturing Checkout Requirements at the System Level

Manufacturing Service/Test Requirement	Hydrostatic Test System	Pneumostatic Test System	Purge Control Console	Hydraulic Service Consoles	Functional Test Systems	Proof and Leak Test Consoles	Blanking Plate Set	Pressure and Monitor Console	Mass Spectrometer	Functional Test Consoles	Circuit Analyzer	IMU Test Console	Computer and Memory Test Console	Universal Test Console	RF Equipment Test Console	Transducer Test Console	Radar Test Console
Mechanical																	
Propellant tank structure		X					X	X									
Common bulkhead assembly			X				X										
Propellant tank bulkheads	X						X		X								
Engine actuation systems				X													
Mechanical components					X		X			X							
Line assemblies	X	X					X										
Fluid systems						X	X	X	X								
Insulation			X			X											
Integrated Astrionics System																	
Data and control management											X		X	X			
Guidance, navigation and flight control											X		X	X	X		X
Electrical power											X			X			
Electrical control											X			X			
Communications											X			X	X		X
Instrumentation											X			X		X	

Development testing requires specialized equipment for use in the various development and qualification laboratories. The following is a preliminary listing of required development equipment, grouped by systems.

Data and Control Management

1. Portable universal test console (UTC)
2. Simulation language (Simulation Laboratory)
3. Control and data acquisition computer
4. Checkout software
5. Utility software (ASIL)
6. Flight software
7. Cooling system
8. Electrical power

Electrical Power Distribution and Control

1. Control and data acquisition console (integration with both avionic and nonavionic loads)
2. Power sources (avionics integration)
3. Cooling (avionics integration)
4. Actual or simulated nonavionic loads (example: hydraulic power, starters)

Hydraulic Power

1. Programmable loads for actuators (Hydraulic Controls Laboratory)
2. Control and data acquisition console (Hydraulic Controls Laboratory and Avionics-Hydraulics Integration Laboratory)
3. Electric motor drives for hydraulic pumps (Hydraulic Controls Laboratory)
4. Structure for support of hydraulic system (Hydraulic Controls Laboratory)
5. Equipment for interface of Avionics Integration Laboratory with Hydraulic Controls Laboratory

Guidance, Navigation and Control

1. Power source
2. Simulators (servo drivers)
3. Computer and software
4. Cooling system
5. Data acquisition system

Communications

1. Power (ASIL)

Auxiliary Propulsion System

1. Data acquisition system (ground test vehicle, GTV)
2. Control computer (GTV)

GSE Listing for Final Assembly and Integrated Checkout

1. Miscellaneous access-work stands, etc., fixtures, tools, tooling, cables, hoses, connectors, etc.
2. Hydraulic ground power
3. Pneumatic control console
4. GH_e service units
5. Electric power
6. Universal test console (portable)
7. Moisture monitor
8. Mass spectrometer
9. Digital volt-ohmeter and other miscellaneous instruments
10. Antenna checkout group
11. RF system checkout unit
12. Modulation checkout unit
13. S-Band checkout unit
14. Rocket engine alignment set
15. Electrical/avionics container cooling system unit

6.0 BOOSTER MODIFICATIONS AND SEPARATION STRUCTURE

6.1 FACILITIES

The ESS program will have no significant impact on facility requirements to develop and manufacture ESS capability into the Phase B Baseline Space Shuttle Booster. This conclusion is predicated on the B-9U baseline configuration being designed and manufactured with both orbiter and ESS boost capability, and on no increase in total booster production rates.

Task differences with potential facility impacts are essentially limited to the manufacturing and testing of the new separation system. This system includes a structural adapter and separation mechanism. Fabrication of this hardware will not require any new facilities. Assembly will require approximately 5,000 square feet of additional factory area. Requirements for this area are:

1. 10-ton capability overhead crane with 20-foot minimum hook height
2. Standard factory utilities including 90 psi air, 115v 60 Hz and 440v 3-phase 60-Hz electrical power
3. Portable GTA welder, 400 amps
4. Floor loading capacity not to exceed 5,000 psf

Structural testing will require approximately 3,000 square feet within a structural test facility that can react loads up to 2.2-million pounds and with a minimum clear height of 35 feet. Standard support equipment and utilities normally available in structural test facilities will suffice. These tests can be scheduled for accomplishment using the same facilities as used for the baseline separation system structural tests.

Vehicle dynamic tests, as planned for the B-9U baseline booster, may be required. This test can be accomplished at KSC utilizing the same facilities.

SECTION III

ENGINEERING AND DEVELOPMENT PLAN

Preceding page blank

CONTENTS

Section		Page
1.0	INTRODUCTION	3-1
	1.1 Purpose	3-1
	1.2 Scope	3-1
2.0	EXPENDABLE SECOND STAGE SYSTEM	3-3
3.0	PERFORMANCE AND OPERATIONAL REQUIREMENTS	3-7
	3.1 Propulsion Subsystem Requirements	3-7
	3.2 Structural Subsystem Requirements	3-7
	3.3 Avionics Subsystem Requirements	3-8
	3.4 Support Equipment Requirements	3-8
4.0	ENGINEERING AND DEVELOPMENT REQUIREMENTS	3-11
	4.1 Engineering Functions	3-11
	4.2 Subsystem Design and Development	3-18
	4.3 Major Test Articles, Mockups, and Models	3-30
5.0	POTENTIAL TECHNICAL PROBLEMS	3-33
	5.1 Thermal Protection Subsystem	3-33
	5.2 Structures (Support Point Load Distribution)	3-33
	5.3 POGO Instability	3-34

PRECEDING PAGE BLANK NOT FILMED

Preceding page blank

ILLUSTRATIONS

Figure		Page
3-1	S-II-15 Vs. ESS Structural Commonality	3-4
3-2	Engineering Development Schedule	3-12
3-3	Engineering Process Logic (Prior to Preliminary Design Review)	3-13
3-4	Engineering Process Logic (After Preliminary Design Review)	3-15

TABLE

Table		Page
3-1	S-II-15 ESS Commonality Assessment Mechanical Systems	3-5

PRECEDING PAGE BLANK NOT FILMED

SECTION III. ENGINEERING AND DEVELOPMENT PLAN

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of the Engineering and Development Plan is to establish an engineering logic; define the required engineering design, development, and test functions; and establish engineering management requirements.

1.2 SCOPE

The scope of this plan is to present an overview of the approach felt most feasible to implement the plan. Only the more significant pertinent information is presented herein, and only in sufficient detail to demonstrate how the various elements fit into the overall plan. Program requirements and criteria are presented in more detail in other volumes of this report.

Preceding page blank

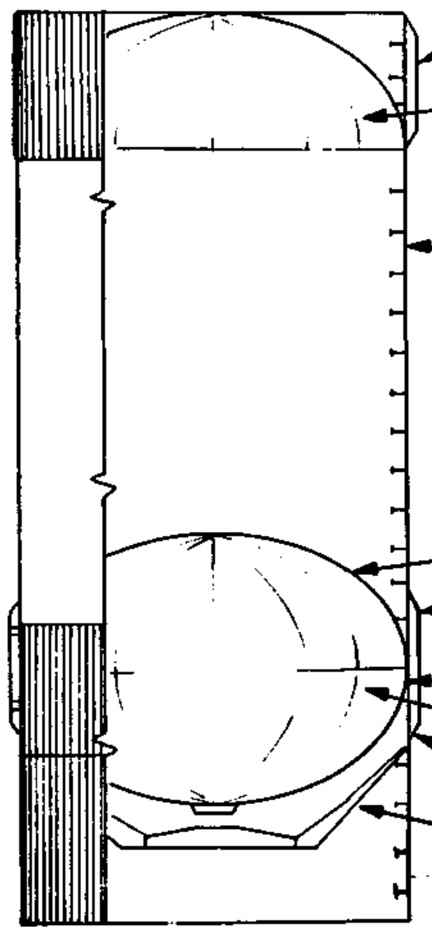
2.0 EXPENDABLE SECOND STAGE SYSTEM

The expendable second stage is designed to make maximum utilization of major Saturn S-II structural elements. The extent of the modification of S-II is shown by Figure 3-1 and Table 3-1 for structures and mechanical systems. The electrical system is essentially new and will utilize space shuttle type equipment. The ESS system will be made up of the following subsystems:

1. Structural group
   a. Body structure
   b. Thermal protection subsystem (TPS)
2. Propulsion group
   a. Main propulsion subsystem (MPS)
   b. Auxiliary propulsion subsystem (APS)
3. Avionics group
   a. Guidance, navigation and control
   b. Data and control and management
   c. Communications
   d. Electrical power, control, and distribution
   e. Vehicle software
4. Support equipment
   a. Adapted from S-II
   b. Common with shuttle
   c. Unique to ESS
5. Payload

   Payload interface provisions

PRECEDING PAGE BLANK NOT FILMED



S-II-15 STRUCTURAL COMPONENT		ESS CONFIGURATION
FORWARD SKIRT		REINFORCED STRUCTURE WITH 2 ADDITIONAL FRAMES
LH_2 BULKHEAD		USE AS IS
TANK SIDEWALL CYLINDER	6	USE AS IS
	5	DELETED
	4	USE AS IS
	3	USE AS IS
	2	NEW FEEDLINE OUTLETS
	1	USE AS IS
COMMON BULKHEAD		USE AS IS
FAIRINGS		NEW FEEDLINE FAIRING & SHORTER SYSTEMS TUNNEL
BOLTING RING		USE AS IS
LO_2 BULKHEAD		NEW LO_2 SUMP
AFT SKIRT		LONGER WITH LOCAL REINFORCEMENT
THRUST STRUCTURE		NEW STRUCTURE

Figure 3-1. S-II-15 VS ESS Structural Commonality

Table 3-1. S-II-15 ESS Commonality Assessment Mechanical Systems

S-II System	ESS Configuration
Fill and Drain	S-II system
Propellant feed	New system - 13-inch lines
Recirculation	S-II LH_2 recirculating pumps not used. Use valves, some recirculating lines and most helium injection components
Pressurization	S-II system (minor mods)
Vent	S-II system
Engine servicing	Uses some S-II components, primarily disconnects
Valve actuation	S-II system (minor mods)
Hydraulic	New system
Propellant tank safing	S-II system
Auxiliary propulsion	New system

Preceding page blank

3.0 PERFORMANCE AND OPERATIONAL REQUIREMENTS

The ESS system will be designed and developed for utilization with the space shuttle booster and will be compatible with the Space Shuttle Program requirements. Volume II of this report defines in detail the ESS requirements for attaining this compatibility, which will not be reiterated here. The more significant subsystem requirements are listed in the following paragraphs.

3.1 PROPULSION SUBSYSTEM REQUIREMENTS

1. ESS main propulsive subsystem start will occur just prior to booster main propulsion subsystem cutoff and separation and will continue following separation.

2. The propulsion subsystem will be autonomous. No propellants, power, pneumatics, or hydraulics will be drawn from the booster.

3. The ESS will be controllable with one main engine out.

4. The main propulsion subsystem will be capable of safe shutdown at any time.

5. Depletion cutoff will be provided as a backup to the normal velocity cutoff.

6. The ESS will utilize space shuttle orbiter engines in accordance with ICD 13M15000B.

3.2 STRUCTURAL SUBSYSTEM REQUIREMENTS

1. The minimum factor of safety for all vehicle structure will be 1.40.

2. Designs that compromise the booster to the extent that would preclude use with the orbiter will not be considered, and the load carrying capability of booster primary structure will not be exceeded.

3. Present S-II stage designs will be utilized where applicable and expedient.

4. Payloads used for load and performance analysis will be limited to the reusable nuclear stage, space tug, and space station (MDAC).

5. For the launch configuration, ground launch wind criteria used are those given in TMX-53872, "Terrestrial Environment (climatic) Criteria Guidelines for use in Space Vehicle Development, 1969 Revision" and TMX-53957, "Space Environmental Guidelines for use in Space Vehicle Development, 1969 Revision."

3.3 AVIONICS SUBSYSTEM REQUIREMENTS

1. Provide +28 vdc primary electrical power and distribution system and an ac power conversion system.

2. Provide redundant and separate dc power sources, ac power conversion, and distribution bus systems.

3. The electrical control system is required to interface with the data and control management (DCM) system, acquisition, control and test (ACT) units, and the end devices to be controlled or monitored.

4. Onboard computer control will be accomplished by means of a data bus system.

5. The instrumentation system must assure that accurate performance evaluation of each vehicle subsystem can be made.

6. The communications system must have the capability of transmitting and receiving all RF information necessary to accomplish the basic mission by providing telemetry data, turnaround ranging data, and receiving updata and range safety commands.

7. The guidance, navigation, and control (GN&C) subsystem is required to determine position, velocity, attitude, and attitude rate of the vehicle to compute desired changes to any or all of these vehicle states via DCM subsystem and to provide control signals to the propulsion systems.

3.4 SUPPORT EQUIPMENT REQUIREMENTS

1. The GSE must supply gases and propellants to the ESS in accordance with the GSE/ESS ICD, Document S080-1003.

2. The GSE must be capable of completely servicing the ESS within the planned space shuttle servicing time of two hours and maintaining the ESS in a launch ready condition for the four-hour duration of the launch window.

3. The GSE must provide for launch pad checkout, low bay checkout, post-manufacturing checkout and handling and access in addition to static firing and launch servicing.

4. Maximum use will be made of existing equipment for servicing and checkout of the ESS.

Preceding page blank

4.0 ENGINEERING AND DEVELOPMENT REQUIREMENTS

This section defines the engineering and development activities required to design, develop, and test the ESS. Subsection 4.1 defines the basic engineering functions required to implement the overall plan; 4.2 summarizes the basic subsystem design and development plan, and the interrelationships between the subsystems; and 4.3 describes the major test articles and their functions. The engineering development schedule is shown in Figure 3-2.

4.1 ENGINEERING FUNCTIONS

The contractor will provide engineering effort which will be based on the selective application of the system engineering process. The logic for this is shown in Figures 3-3 and 3-4. The functions that must be carried out in the design and development of the ESS system are (1) the planning, organization, implementation, and overall direction of the engineering activities; (2) the design, development, and testing of an integrated ESS; (3) the engineering effort required to design, develop, and qualify all the ESS subsystems; (4) establishment of a flight technology function; and (5) the integration of the subsystems into the ESS vehicle. These functional requirements are defined in more detail in the following subsections.

4.1.1 Engineering Management

The ESS contractor will provide the planning, organization, implementation, and direction of overall engineering activity for the ESS Program and will formulate program policies, directives, and operating procedures. This will include developing and documenting the methodology for the integration of engineering activities with other functions. The engineering activity in turn will include: preparation of master engineering program plans; subcontractor management; analysis, design, development, and testing of the ESS system; configuration control; preparation of technical documentation; technical direction of field operations.

4.1.2 Systems Analysis

The ESS contractor will conduct functional analysis of mission operations and determine detailed mission functions that must be satisfied by subsystem elements. This will include definition of the subsystem level requirements, subsystem objectives, subsystem functional performance requirements, subsystem technical characteristics, subsystem effectiveness

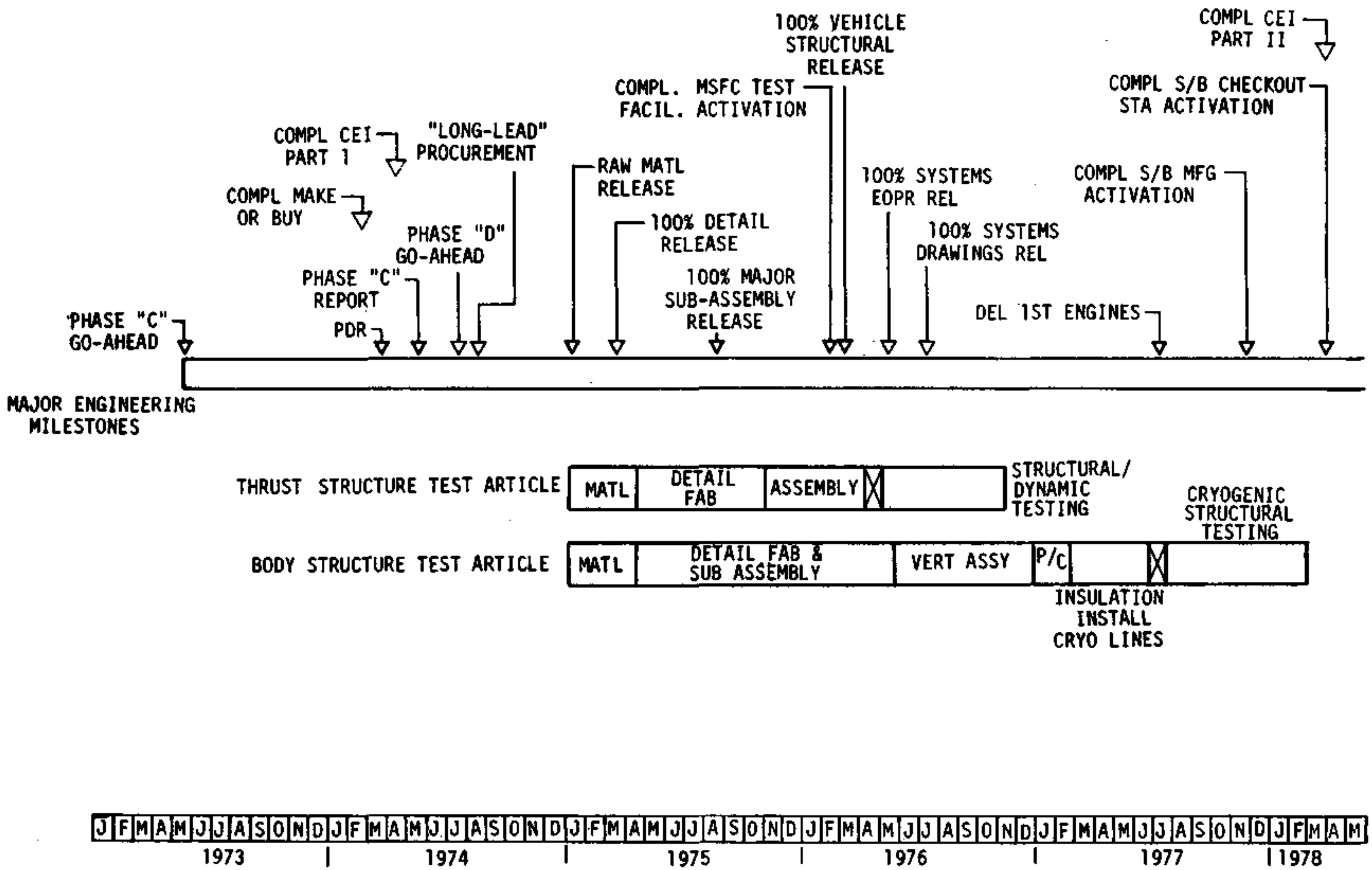


Figure 3-2. Engineering Development Schedule

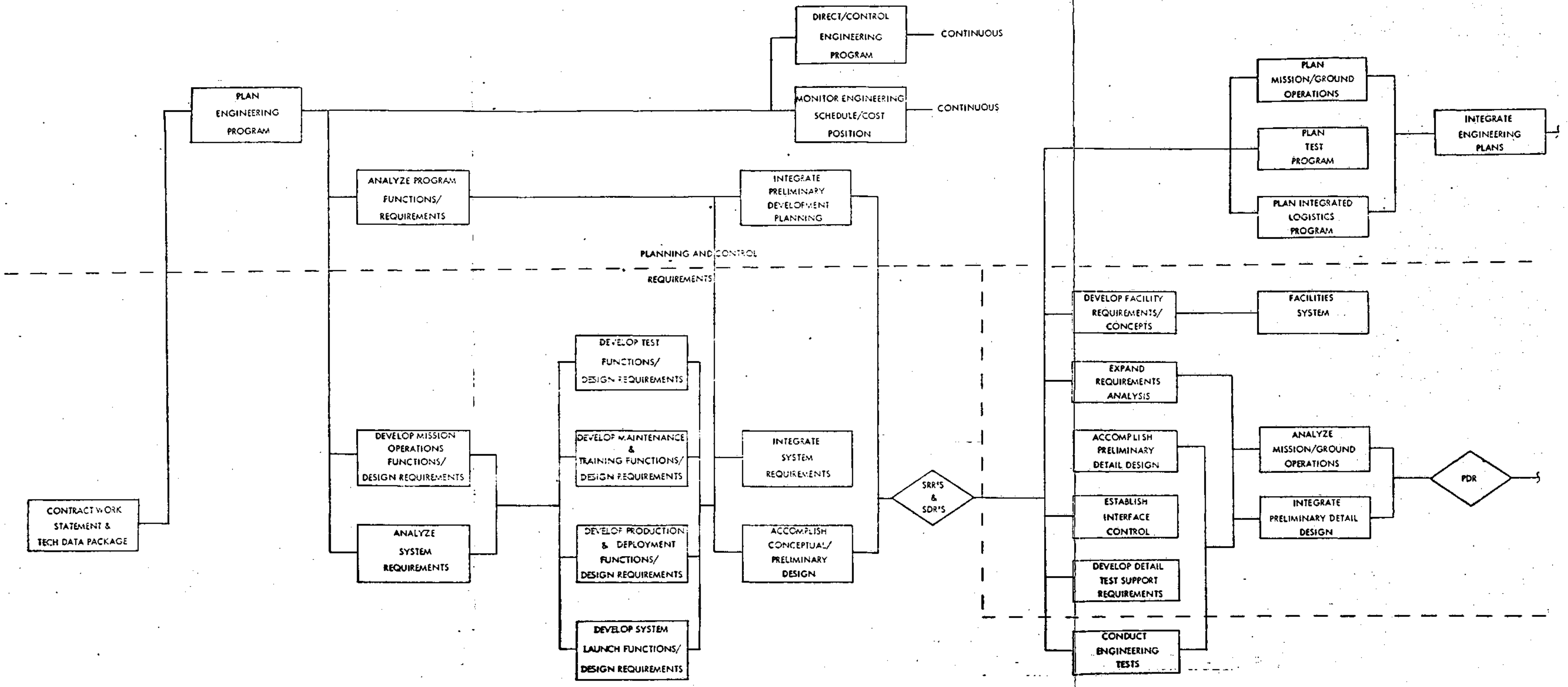
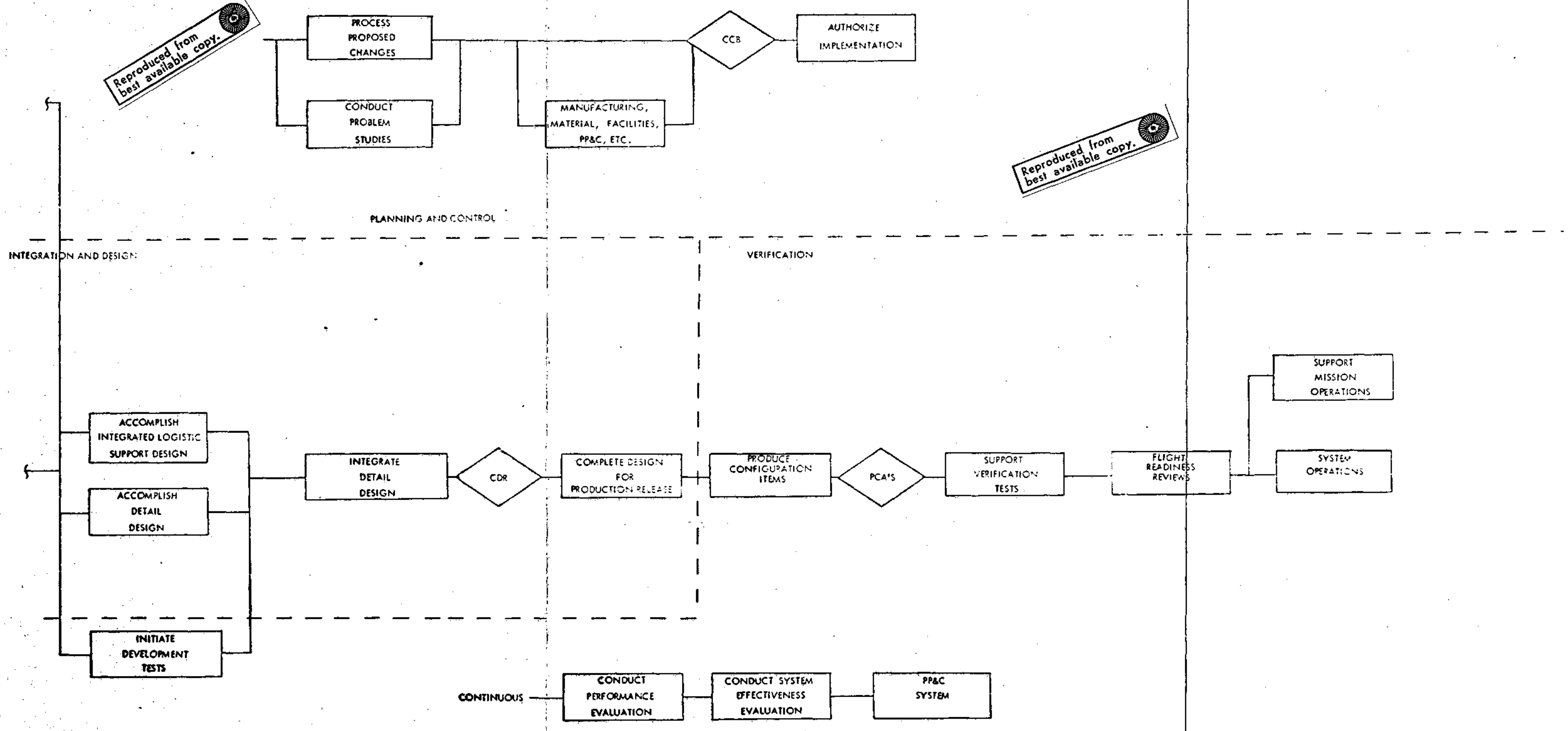


Figure 3-3. Engineering Process Logic (Prior to Preliminary Design Review)



Reproduced from best available copy.

Reproduced from best available copy.

Figure 3-4. Engineering Process Logic (After Preliminary Design Review) criteria, and the preparation and maintenance of development specifications for the ESS. Requirements definition will be established for design, test, reliability, safety, maintainability, and transportability. Studies and analyses will be conducted to optimize the ESS system design and to provide system/design cost effectiveness to optimize ESS system costs. The contractor will prepare test procedures and test plans for conduct of required tests.

The contractor will provide a system reliability and safety program to define requirements for failure mode effects and criticality analysis, hazard analysis, failure and corrective action reporting, a preferred parts program, and certification testing. The contractor will also implement safety procedures and conduct a general safety program in support of Engineering, Test, and Operation.

4.1.3 Systems Integration

The ESS contractor will ensure that the integration activities listed below are performed as required.

1. Prepare CEI specifications to assure compatibility with shuttle system specifications.

2. Integrate all internal vehicle subsystems to assure their relative compatibility as well as the vehicle compatibility with requirements as defined in the CEI specification.

3. Analyze and negotiate main engines/ESS physical and functional ICD's.

4. Prepare and negotiate physical and functional ICD's for vehicle/facility and GSE/facility interfaces.

5. Expand GSE/facility requirements to cover special needs of test programs at the operational site and requirements of other locations used for development testing.

6. Establish ESS requirements for use of the Tracking and Data Relay Satellite (TDRS), i.e., those which can influence its physical/functional characteristics or its scheduled availability.

4.1.4 Flight Technology

A flight technology program will be established that will include orbital flight mechanics. This activity will include support to mission analysis and mission planning at the program level; establishment of data requirements, flight procedures, simulation and/or training programs; and definition of requirements for testing and analysis of test data. Ascent performance analysis for the ESS following separation from the booster will be conducted. The contractor will generate detailed ESS parameter histories, mission timelines, and control requirements.

Parametric studies will be conducted to define the ESS performance capability for variations in entry state vector, vehicle aerodynamics and mass loading parameters, environmental conditions, and systems and vehicle design limits. The contractor will provide performance data to aid in definition of system and vehicle requirements. Design trajectories will also be generated.

Studies will be conducted to fully define the ESS abort characteristics throughout the launch phase of the ESS missions.

The contractor will define the aerodynamic configuration design requirements and the flight performance characteristics. Stability and control design criteria will be established for all mission phases, and an airloads analysis will be performed. The contractor will define ESS rigid body airloads and distribution data and will plan and conduct a wind tunnel program to provide data for the ESS. The contractor will provide aerodynamic requirements for flight test and aerodynamic analysis of flight test data.

The contractor will conduct aerodynamic heating analysis, thermal protection analysis, and thermal control analysis to define requirements for the design and testing of the ESS TPS and thermal control subsystems.

The contractor will define flow-field models to support the definition of the aerodynamic heating environment and aerodynamic heating prediction models.

The contractor will also provide thermal design criteria and integrated thermal control requirements for subsystem and subsystem component design.

4.2 SUBSYSTEM DESIGN AND DEVELOPMENT

The ESS contractor will be responsible for all engineering effort and materials required to design, develop, and certify all the ESS subsystems and the integration of the subsystems into the vehicle. As stated previously, existing S-II, shuttle, and Apollo designs will be utilized to the optimum extent.

A combined vehicle sizing will be performed with the booster contractor to finalize the configuration of the ESS and modifications to the booster vehicle. Design functions will provide initial vehicle and subsystem configurations. These configurations will be refined in preparation for development testing and updated following completion of development testing.

Preliminary design effort will be provided to generate CEI Part I Specification data, preliminary procurement specifications, block diagrams and schematics, functional descriptions, and process specifications. Parts lists, weights, volumes, equipment locations, and interface data will also be provided.

Detailed development plans and schedules will be established and implemented. The ESS contractor will provide data, reports, drawings, specifications, and charts for PDR's and CDR's.

Detailed design effort will be provided to generate CEI Part 2 Specification data, detailed engineering drawings, ICD's, subsystem test and checkout specifications, procurement specifications, and analytical design and test data. Development and certification test programs, ground and flight simulation tests, mockups, and laboratory breadboards will be included. Test requirements, test plans, data, data evaluation, and test reports will be provided for all major development tests and analyses.

ESS engineering activities supporting the manufacture and test of the vehicle and support equipment will also be provided. Information for spare parts lists, flight handbooks, and repair/maintenance manuals will be provided.

The specific unique design requirements and criteria for the subsystems are defined in the following paragraphs.

4.2.1 Structural Group

The preliminary structural design will be based on the initial sizing and wind tunnel testing, and the main propulsion engine physical and performance requirements contained in the ESS/engine interface control document (ICD) and the payload configuration (ICD). Development of the docking subsystems are required to support rendezvous with the orbiter (ICD).

The areas of interest in the structural and mechanical group consist of body structure, thermal protection, and docking. The following engineering effort and requirements are specific to the structural subsystems.

Body Structures

The contractor will provide structural static test articles and conduct tests to demonstrate achievement of the following objectives: (1) that permanent set will not occur in the structures at limit loads; (2) that structures will not fail at ultimate loads; (3) that structural, thermal, and pogo analysis data correlate with test data; and (4) that the capability to withstand design loads and temperatures will include, but not be limited to, maximum-Q alpha and maximum axial acceleration.

The contractor will perform structural analyses and trade studies to verify primary structural load paths, select materials, and identify stiffened skin configurations and frame spacings. Structural sizes and overall vehicle section properties will be verified. The contractor will also conduct development/qualification type structural testing.

Structural analysis and test will also be provided to define/verify the interface requirements for booster/ESS interface and separation systems, payload/ESS interface, orbiter/docking interface and system, and the ESS/main engine interface.

The contractor will perform structural dynamic analyses to determine loads, deflections, and/or structural system stability for all ESS mission phases from prelaunch through deorbit. Studies will be conducted to examine flexible body dynamic loads due to prelaunch operations, liftoff, separation, boost, orbital maneuvers, docking. Stability studies will be performed for pogo and static aeroelasticity. Predictions and calculations of shock, vibration, and acoustic environments will be made; and design and test criteria will be developed. Calculations will be supported by dynamic model tests for evaluating vehicle modes, ground wind effects, and buffet/flutter boundaries. Analyses will support detailed designs on the major structural subsystems. The contractor will plan and initiate development-type test programs and define requirements for the ground test program required for evaluation of structural dynamics studies.

The ESS contractor will also establish a weight and mass properties and volumetric control program for the ESS vehicle.

Thermal Protection

The contractor will provide the test requirements and conduct development tests on the thermal protection system (TPS) to develop utilization criteria for the external insulation.

Docking

To permit recovery in orbit of high-value components from the ESS by the orbiter, the ESS will utilize the basic shuttle docking system. This will significantly reduce the development effort which otherwise would be required. A flexible body loads analysis will be performed for all expected ESS docking conditions. In addition, verification tests will be conducted of all the docking loads; these will be performed on the full-scale test article.

4.2.2 Avionics Group

The integrated avionics subsystem (IAS) for the ESS will be a hybrid system combining the most attractive components or systems from the Saturn S-II, the Apollo CSM, or the Shuttle programs. This approach has been taken to provide a cost-effective program and to advance derivatives to the state-of-the-art being employed by the Shuttle Program for flight vehicles and the support equipment required to develop, check out, service and launch the vehicles.

The integrated avionics subsystem will consist of the following elements: (1) guidance, navigation, and control (GN&C); (2) data and control management (DCM); (3) communications; (4) electrical power distribution (EPD); (5) electrical control (EC); (6) instrumentation; and (7) software. These elements are developed through the component assembly stages into subsystem and integrated tests. After completion of the avionics subsystems tests, the combined avionics/non-avionics testing, culminating in wet and dry flight demonstration testing and launch simulation, will be initiated.

Emphasis will be placed on using the Shuttle Program Avionics Subsystems Integration Laboratory (ASIL) for development of the software for the ESS and for integration of functions and verification of avionics and non/avionics interfaces. (Also, the Hydraulics/Controls Laboratory will be required to develop end-to-end flight control testing into propulsion section.)

The following requirements and engineering effort pertain to the integrated avionics subsystem.

Guidance, Navigation, and Control Subsystem

The function of the GN&C subsystem is to determine the position, velocity, attitude, and attitude rate of the vehicle; to compute desired changes to any or all of these vehicle states in accordance with internally-stored or alterable computer programs; and to provide control signals to the propulsion systems for commanding those changes. The basic GN&C equipment (without redundancy) consists of (1) an inertial measuring unit (IMU), (2) a rate gyro set, and (3) interfacing electronic control units.

The navigation equipment senses vehicle inertial changes and provides this information to the data and control management (DCM) computer. The guidance and navigation software operates on the received data and generates the control signals which command changes in the vehicle attitude or state vector in accordance with preplanned mission objectives. Other inputs from non-GN&C hardware (tracking and communications) contribute to the solution of the navigation problem for determining partial vehicle state vector parameters. Primary functions of the separate GN&C assemblies to be verified are as follows:

1. Inertial measuring unit — Verify the system attitude measurement capability. Verify the system acceleration measurement capability.

2. Rate gyros — Verify the capability to measure attitude rates of change.

3. Electronic control units — Verify the capability of the units to adequately perform in accordance with the design transfer function.

Data and Control Management Subsystem

The data and control management subsystem (DCM) is the central integrating agent for all ESS vehicle subsystems. The subsystem consists of the hardware and the software to implement the following: (1) configuration control and sequencing, (2) guidance and navigation computation, (3) flight control, (4) data storage, (5) data acquisition and distribution, (6) checkout and fault isolation, and (7) self-management.

All elements function together to address storage, obtain and store information, process arithmetic and logical data, execute sequential instructions, process interrupts, and initiate communications between storage and the input/output devices.

The DCM subsystem requires considerable software to process command/response data and perform the other tasks necessary for vehicle operation. Adaptation of modular software developed for similar functions on the Shuttle Program and development of the specialized software for ESS demands will require a major share of the integration task. Use of the Avionics Systems Integration Laboratory reconfigured to the ESS will enhance rapid verification of modular block utilization and verification of the ESS dedicated software.

General requirements of subsystems components are as follows:

1. Central Processing Unit (CPU) — Verify ability of system to address storage, collect and store data, process equations, execute sequential instructions, and process interrupts.

2. Input/output units (I/O) — Verify the ability to process transfer of data between the CPU's and all ACT/LRU's via the data bus and to devices controlled by dedicated hardwire system.

3. Data bus — Verify the capability of the bus to interconnect all elements of the IAS and the IAS with other ESS subsystems, between the ESS and the shuttle booster, and between the ESS and the ESE.

4. Storage units — Verify the ability to store and retrieve data located in the main memory sections within specified time limits.

5. Software — Verify that the software modular units are compatible with the DCM system and are acceptable for ESS usage. Verify that supplemental programs bridge the configuration gap between the shuttle and ESS requirements.

Communications Subsystem

The communications subsystem will have the capability of transmitting and receiving all radio frequency information necessary to accomplish the basic ESS mission by providing telemetry data, turnaround ranging data, and receiving updata and range safety commands. The subsystems serve the functions of the following four data links: (1) data bus communications, (2) telemetry communications, (3) updata communications, and (4) range safety communications.

The approach and rationale to be used in the communications system test program was developed to preclude constraint of total systems by incompatible requirements. Those components and subsystems requiring development will be subjected to analytical tests to ensure compatibility with the vehicle requirements and systems. The particular items requiring tests of an analytical nature are the antenna systems, telemetry, and the data storage equipment. The antenna systems tests are model tests to verify proper location of the antennas to ensure coverage in all directions with respect to the vehicle. The telemetery development program will require breadboard tests to ensure interlacing of the engine data with the data bus extracted information and priority channels using worst-case phase and capacity parameters. The data storage equipment will require tests similar to the telemetry system to assure storage adequacy during periods of high data transmission.

Component level tests are conducted on all items prior to utilization in the communications systems at a level sufficient to ensure that the design parameters are met. The subsystem and combined subsystem tests will be conducted on a completed vehicle.

Program Software

The contractor will provide design, development, production, and operational effort in support of breadboards, simulators, and the Avionics System Integration Laboratory. The computer software will include that required for all elements of the avionics subsystem group, including GN&C, communications, data and control management, power distribution and controls, and ground systems software.

Tests will be performed to verify designs and analyses and to demonstrate system operation and performance. Tests will be structured to validate software modules before incorporation in operational hardware.

Electrical Power Distribution Subsystem

The electrical power subsystem is the ESS energy source and distribution network required to support the load demands of the IAS for the 24-hour mission life. The ESS employs batteries to supply electrical energy for the 24-hour mission. The power system supplies energy for the main, instrumentation, heater and recirculation/EAS distribution systems.

Control of the internal/external power source will be by 200-ampere transfer switches with hardwire and data bus control. Monitoring devices to verify stage current levels will function as a part of the failure detection and isolation methods.

Conversion capability for ac power needs will be supplied from the recirculation/EAS bus system, utilizing inverters to provide the necessary voltage/current/frequency requirements.

Electrical Control Subsystem

The electrical control subsystem (ECS) is the interfacing agent between avionic and non-avionic subsystems. The ECS requirements derive from the requirements for operation of the mechanical subsystems, since the ECS interfaces directly with the following: (1) main engine, (2) auxiliary propulsion, (3) engine actuation, (4) pressurization, (5) propellant feed, (6) propellant management, (7) separation control, and (8) safing.

The functional requirements for sequencing, timing, response times, analog and discrete measurements, redundancy criteria, and software requirements are established within each of the subsystems noted. These requirements drive back into the DCM subsystem for software programming and equipment sizing. These same requirements will also define checkout and fault isolation (COFI) techniques as well as tolerances for subsystems operations.

The power conditioning, distribution and control system will perform all required power conversion, distribution, control, and regulation, and will provide fault protection.

The contractor will conduct laboratory tests to verify operation of individual circuits. The system will be verified by tests in the ASIL.

Instrumentation Subsystem

The instrumentation subsystem will provide for the acquisition, processing, and storage of operational and test data. The equipment will include all sensors and signal conditioning equipment that is not an integral part of the individual subsystem.

The contractor will perform development tests to verify the operation of the individual measurement systems. The equipment will then be tested as a part of the avionics subsystem tests.

Avionics Integration

The contractor will perform design analyses and tests to ensure that the integrated Avionics subsystem elements perform in accordance with the design requirements, not only to verify the equipment but to confirm that the subsystem also satisfies all interfaces. In performing this task the contractor will define and demonstrate a test program that will provide confidence in the avionics design approach. This test program is encompassed in the Avionics Subsystem Integration Laboratory. Tests will be performed to demonstrate the integrated system operations and performance. Test requirements for the final integration tests are to prove the compatibility of the avionics with other vehicle subsystems.

4.2.3 Propulsion Group

The propulsion group consists of the main propulsion subsystem (MPS) and the auxiliary propulsion subsystem (APS). The main propulsion system (MPS) design will be based on ICD 13M15000B and characteristics supplied by the main engine contractor and space shuttle orbiter development. The final configuration for the auxiliary propulsion subsystem (APS) will be based on guidance and control design requirements and space shuttle orbiter development. The development of the MPS and the APS will be phased to provide flight articles for installation, as required.

The following requirements and engineering effort are unique to the propulsion and power generation group.

Main Propulsion Subsystem (MPS)

The MPS consists of liquid hydrogen and liquid oxygen tankage, pressurization and venting provisions, propellant utilization and gaging provisions, propellant distribution provisions, and rocket engines.

The rocket engines will be provided to the ESS contractor as government-furnished equipment (GFE). Engine performance, when provided with propellants under conditions as specified in space shuttle vehicle engine Interface Control Document, 13M15000B, will be in consonance with requirements delineated in the CEI specification. The ESS contractor will be responsible for engine/vehicle integration. Should incompatibilities exist between the engine ICD, 13M15000B, and the vehicle performance requirements; or should any engine/vehicle physical incompatibilities occur, the contractor will recommend corrective action to NASA. The ESS contractor will provide technical representation to the engine contractor's facility to coordinate engine-vehicle interfaces. Engine contractor test data will be made available to the ESS contractor for review and analyses to provide early identification of integrated engine/vehicle system problems.

The ESS contractor will conduct a static firing test on the first two expendable second stages at a NASA Static Firing Test Facility to demonstrate or verify the following objectives:

1. Capability to inert the propellant tanks, feed, recirculation, pressurization, and engine systems

2. Capability to precondition vehicle propellant systems for propellant loading

3. Capability to load propellants

4. Capability of the pressurization system to provide minimum ullage pressure and net positive suction head (NPSH) under operating conditions

5. Capability of the propellant recirculation system to meet minimum engine propellant inlet requirements

6. Capability of the thrust vector control (TVC) system to perform satisfactorily throughout the complete range of operating requirements

7. Capability of the ground servicing equipment to satisfactorily check out, service, and safe the vehicle systems

8. Satisfactory performance of all systems under static firing conditions

9. Capability of all vehicle systems to withstand acoustic environments

10. Functional capability of propellant depletion/engine cutoff sequence

11. Thrust structure compliance, structure dynamics, and ascertained load paths

The contractor will utilize the basic space shuttle components and assemblies of the auxiliary propulsion subsystem (APS) (OMS and ACPS) as developed by the shuttle. The APS will consist of liquid hydrogen and liquid oxygen propellant tankage, tank pressurization and venting provisions, propellant gaging provisions, propellant distribution provisions, and rocket engines.

The ESS contractor will conduct static firing development tests on the APS to achieve or demonstrate the following objectives:

1. Capability to render inert and precondition the propellant tanks and feed systems of the APS

2. Capability of the propellant gaging systems to perform satisfactorily throughout all required operating ranges

3. Compatibility of auxiliary propulsion subsystem with various elements of the integrated avionics subsystem

4. Compatibility and satisfactory interface performance of the integrated OMS/ACPS

5. Capability to supply required pressurant to APS propellant tanks

6. Capability of vent system to control tank pressure

7. Ability to provide propellants to the pump inlets at required conditions

Subsystem testing of an integrated ESS OMS will be accomplished during development testing. The test will be performed at the shuttle test facility. Some modification of the shuttle test facility will be required due to differences in the ESS and shuttle subsystems. During the MPS static firing test, the APS will be tanked and subjected to boost environmental conditions.

4.2.4 Ground Support Equipment and Facilities Design

The contractor will provide requirements and engineering effort specifically for the support equipment and facilities required at all geographic sites.

ESS support equipment will include equipment which is common to the booster and designated in the commonality list. The ESS contractor will integrate the ESS unique and payload specific support equipment into the shuttle system.

Program support equipment requirements will be reviewed in terms of vendor needs, manufacturing and assembly needs, acceptance checkout needs, and needs of the operational program. This review will assure that support equipment costs will be minimized by commonality of design, allocation of quantities, and scheduling of units.

Support equipment includes the items necessary for launch, handling, checkout, transportation, service, training, and software related to these items. The type of support equipment and the design requirements for such equipment will be determined from analysis of the requirements for the shuttle system vehicles, their maintenance requirements, and facilities and interfacing equipment. The special needs of the test program will also be considered. The types of equipment include the following: (1) facilities and facility equipment, (2) in-process manufacturing equipment, (3) special laboratory equipment, (4) handling, servicing, test, checkout, and launch support equipment (except for payload), (5) packaging design and equipment, (6) standard support equipment, (7) commercial equipment, (8) government-furnished equipment, (9) equipment from prior programs, (10) on-board support equipment (not permanently installed), and (11) training equipment.

The contractor will perform the following tasks for each support equipment category:

1. Determine detailed design requirements based on analysis of the specification requirements, airborne subsystem detailed design requirements, interfacing equipment, facilities design details, and maintenance requirements.

2. Review the detailed design requirements for ESS support equipment to determine which items should become common with booster support equipment.

3. Conduct design studies to establish detailed approaches and solutions that meet the requirements of performance, safety, reliability, producibility, quality verification, maintainability, cost, and schedule — consideration will be given to use of existing surplus equipment, existing designs, and commercial standard equipment.

4. Prepare for and participate in preliminary design reviews (PDR) and critical design reviews (CDR).

5. Perform the detailed support equipment design which includes the preparation of layouts, block diagrams, schematics and production drawings, and specifications.

6. Determine development test requirements for the support equipment.

7. Provide technical coordination and assistance as required.

8. Provide technical data, manuals, test procedures, and acceptance criteria.

9. Modify software developed on the Shuttle/Orbiter program as required to support the ESS and maintain the software necessary to program the function and operation of programmable elements of the support equipment subsystems. The software will include but not be limited to ground computer programs for checkout, data reduction and processing, mission planning, flight operations, management information and control simulation. Specialized software required to configure, program, operate, and maintain other ground equipment items will also be provided. The contractor will also develop and implement an integrated data system for preparation and control of support equipment subsystem software and software-related data.

10. Identify the unique software required to meet the requirements of the support equipment subsystem specifications and present the purpose, application, and design approach at the support equipment subsystem PDR for each element of software. To accomplish objectives of the software development, the contractor will perform the following tasks:

    a. Determine detail programming requirements and criteria, based on analysis of the requirement specifications, and equipment design details

    b. Perform the actual coding of the programs and complete documentation of the programs will be prepared

    c. Maintain the programs and program documentation through the flight operations phase

4.3 MAJOR TEST ARTICLES, MOCKUPS, AND MODELS

The approach and rationale for the test and development of the ESS test articles, MPS and APS, is that maximum use of S-II and shuttle hardware and facilities will be used to minimize ESS facility and test hardware requirements.

Major test articles, mockups, and models that will be provided for the development of the ESS are listed in the following subsections. These are defined in more detail in the Preliminary Test Plan.

4.3.1 Structural Static Test Article - Body Structure

This article will consist of the total vehicle structure with simulated subsystems as required. Tests will demonstrate that permanent set does not occur at limit loads, that the structure will not fail at ultimate loads, and that the structure can sustain loads. The test will also provide structural stiffness data to support POGO analysis. Ultimate loads will be demonstrated prior to first flight.

4.3.2 Thrust Structure Test Article

This article will consist of the thrust structure, aft skirt, and OMS engine support. In addition to the verification of structural integrity, other objectives are as follows:

1. To determine stress and deflection influences of separate engine and actuator loads

2. To determine required precant angle of orbiter engines because of structural deflections

3. To verify the analytical methods used to predict stress levels and deflections

4. To determine effect of load peaking at the structural interfaces

4.3.3 Avionics Subsystem Integrated Laboratory (ASIL) Test Articles

The ASIL will include all ESS software and sufficient power generation equipment to supply power and simulated or actual interfaces with other vehicle subsystems. The tests will verify compatibility between avionics subsystems and interfacing subsystems. Testing will be phased to support static testing as required.

4.3.4 Structural Dynamics Models

These models will be used in wind tunnels for structural dynamic analysis verification. They will include models for flutter, buffet, ground winds, and aerodynamic noise.

4.3.5 Aerodynamic/Thermal Models

These models will be used as development tools to support finalization of aerodynamic vehicle shapes and TPS design.

Preceding page blank

5.0 POTENTIAL TECHNICAL PROBLEMS

This section provides a description, in both engineering management and design terms, of potential technical problems and alternatives planned to minimize the impact, if the problems occur. Technical risk assessment and problem solution techniques are compatible with Shuttle Program requirements.

5.1 THERMAL PROTECTION SUBSYSTEM

The thermal protection system proposed for the ESS booster must be capable of withstanding acoustics, flutter, and shock wave impingement. Precise analysis for these design conditions is presently beyond the state of the art.

Wind tunnel and acoustic tests will be performed on representative test panels to verify the basic design concepts. The data from these tests will be evaluated, and modifications will be made to the TPS design for both the acoustic and shock requirements as required. Aerodynamic flutter may require panel stiffening with an attendant weight increase.

The accomplishment of these tests is proposed for the ESS; however, a proposal has been submitted to accomplish this testing on a separate change order. If this task is approved, state-of-the-art information will be available prior to design release of the ESS.

5.2 STRUCTURES (SUPPORT POINT LOAD DISTRIBUTION)

The system proposed for support of the ESS on the shuttle booster imposes local loads on the ESS structure. This type of loading is significantly different than all previously developed support systems. Present day technology is exhibited in the use of Saturn V type support where the loads are uniformly distributed through the vehicle skirts. Further development and analysis is required for the new attach system to demonstrate vehicle structural integrity. A detailed internal loads analysis will be performed to establish skirt structural sizing. This internal load distribution analysis will provide adequate confidence in the design to permit final structural verification in the proposed test program.

PRECEDING PAGE BLANK NOT FILMED

5.3 POGO INSTABILITY

POGO-type instabilities have been encountered on most large liquid propellant rocket powered boost vehicles. The ESS vehicle fits this category and, therefore, must be considered for the POGO phenomenon. The ESS/booster combination is further complicated by the lack of symmetry of the mated vehicles.

Since the same basic POGO problem exists on the shuttle orbiter/booster combination, the data obtained during the Shuttle Program will be evaluated and applied to the ESS for the mated flight period.

It is planned to use the stiffness characteristics obtained from the static tests of the modified ESS thrust structure to partially verify the modeling used for that structure. The LO_2 feedline dynamics will be determined by analysis using finite element techniques. The engine transfer function and pump termination impedance will be considered the responsibility of the engine contractor and is to be furnished by the NASA. The above technique when coupled with the knowledge gained on the S-II program is considered adequate for defining ESS POGO susceptibility. The static firings will be used to verify, in part, the structure/feedling/engine interaction. This will require adequate low frequency and closely coupled instrumentation, therefore, no special tests related to ESS POGO are planned other than those required by the engine contractor to define the engine transfer function and pump termination impedance.

SECTION IV

TEST PLAN

Preceding page blank

CONTENTS

Section		Page
IV	TEST PLAN	4-1
	1.0 INTRODUCTION	4-1
	2.0 SCOPE	4-3
	3.0 PROGRAM SUMMARY	4-5
	3.1 ESS Test Program	4-5
	3.2 Structural Dynamics Testing	4-8
	3.3 Wind Tunnel Test Program	4-8
	3.4 Electromagnetic Compatibility Test Program	4-9
	3.5 Major test Article Summary	4-9
	4.0 TEST PHILOSOPHY AND CRITERIA	4-11
	4.1 Development Testing	4-12
	4.2 Qualification Testing	4-14
	4.3 Acceptance Testing	4-18
	5.0 REQUIREMENTS	4-21
	5.1 Subsystem Requirements	4-21
	5.2 Vehicle Level Requirements	4-111
	6.0 APPROACH AND RATIONALE	4-119
	6.1 Overall Test Program	4-119
	6.2 Mated ESS/Booster	4-123
	7.0 COMMONALITY/COST ERFECTIVENESS	4-125
	8.0 SUPPORT REQUIREMENTS	4-127
	8.1 Avionics Subsystems Integration Laboratory (ASIL)	4-127
	8.2 Post—Manufacturing Checkout	4-127
	8.3 Static Firing	4-128
	9.0 REUSABLE SHUTTLE BOOSTER AND SEPARATION STRUCTURE	4-129
	9.1 General Description	4-129
	9.2 Requirements	4-129
	9.3 Test Approach and Rationale	4-129
	9.4 Test Configuration	4-131
	9.5 Test Hardware Requirements, Separation Structure	4-132
	10.0 Glossary	4-133

PRECEDING PAGE BLANK NOT FILMED

Preceding page blank

ILLUSTRATIONS

Figure		Page
4-1	Certification Approach	4-17
4-2	Main Propulsion Subsystem Elements	4-24
4-3	Main Propulsion Subsystem Schematic	4-25
4-4	Main Propulsion Subsystem Test Logic And Constraint Network	4-31
4-5	Auxiliary Propulsion Subsystem Elements	4-34
4-6	Auxiliary Propulsion Subsystem Schematic	4-35
4-7	Auxiliary Propulsion Subsystem Test Logic And Constraint Network	4-40
4-8	ESS Structural Configuration	4-42
4-9	Structure Subsystem	4-43
4-10	LH_2 Tank Structure	4-44
4-11	LO_2 Tank Structure	4-45
4-12	ESS Thrust Core Structure	4-47
4-13	Structure Test Logic And Constraint Network	4-51
4-14	Static Test Setup	4-56
4-15	Thrust Structure Test Setup	4-57
4-16	Insulation Erosion Barrier Installation	4-65
4-17	Insulation Test Logic And Constrain Network	4-67
4-18	Electrical Power Subsystem Hardware Hierarchy	4-70
4-19	EPS Block Diagram	4-71
4-20	EPS Test Logic And Constraint Network	4-75
4-21	Data and Control Management Subsystem	4-77
4-22	Data and Control Management Subsystem Block Diagram	4-78
4-23	Data and Control Management Subsystem Test Logic and Constraint Network	4-81
4-24	Guidance, Navigation, and Control Subsystem Hardware Hierarchy	4-83
4-25	GN&C Subsystem Block Diagram	4-84
4-26	GN&C Subsystem Test Logic and Constraint Network	4-86
4-27	Communications Subsystem	4-88
4-28	Communications Subsystem Block Diagram	4-89
4-29	Communications Subsystem Test Logic and Constraint Network	4-93

PRECEDING PAGE BLANK NOT FILMED

Figure | Page

4-30 Electrical Control Subsystem Hardware Requirements 4-95
4-31 Electrical Control Subsystem Block Diagram 4-96
4-32 Electrical Control Subsystem Test Logic and Constraint Network 4-100
4-33 Instrumentation Subsystem 4-102
4-34 Typical Instrumentation Circuit 4-102
4-35 Test Program Schedule 4-120
4-36 ESS Test Logic and Constraint Network 4-122

TABLES

Table		Page
4-1	Major Test Article Summary	4-10
4-2	Functional Criticality	4-15
4-3	Main Propulsion Subsystem Certification Requirements	4-27
4-4	Auxiliary Propulsion Subsystem Certification Requirements	4-37
4-5	Structural Subsystem Certification Requirements	4-48
4-6	Structural Subsystem Acceptance Checkout Requirements	4-54
4-7	Structural Subsystem Dynamic Certification Requirements	4-61
4-8	Test Hardware Requirements Structural Subsystem	4-62
4-9	Structural Requirements Structural Tests	4-63
4-10	Insulation Subsystem Certification Requirements	4-66
4-11	Electrical Power Subsystem Certification Requirements	4-73
4-12	Data and Control Management Subsystem Certification Requirements	4-79
4-13	GN&C Subsystem Certification Requirements	4-85
4-14	Communications Subsystem Certification Requirements	4-91
4-15	Electrical Controls Subsystem Certification Requirements	4-97
4-16	Instrumentation Subsystem Certification Requirements	4-103
4-17	Phase C/D Wind Tunnel Certification Requirements	4-106
4-18	Wind Tunnel Test Categories	4-107
4-19	Candidates for Phase C/D Wind Tunnel Facility Utilization	4-110

SECTION IV. TEST PLAN

1.0 INTRODUCTION

The ESS test plan defines the ESS test program, relates that test program to the test requirements delineated in the ESS contract end item specification and the development test requirements definable during this phase, and identifies test flows and constraints. Facility and support equipment requirements are also defined for ESS development, qualification, and acceptance testing. Since the booster is from the space shuttle operational inventory, only mated ESS/booster test requirements are included in this plan.

2.0 SCOPE

The ESS test plan describes the preliminary concepts of the Phase C/D testing to be conducted on the ESS vehicle, subsystems, assemblies, and components. The final plan for ESS testing will be generated during Phase C.

The overall preliminary ESS test program summary is presented in Section 3.0 and defines the levels of testing to be performed on the subsystems and the completed vehicle.

Section 4.0 presents the development, qualification, and acceptance test philosophy and criteria.

Test requirements are presented in Section 5.0. In the first subsection, requirements for each of the individual vehicle subsystems have been defined. The second subsection itemizes the integrated requirements.

The method to be utilized in generating the final test plan and the means by which the ESS test requirements will be satisfied under the philosophy and criteria are presented in Section 6.0, Approach and Rationale. Included in this section are the overall ESS test logic and constraint network and the test schedule.

Major areas of commonality between the ESS and the S-II and the ESS and the Space Shuttle Program are delineated in Section 7.0. This section also includes other detailed actions to be taken to maximize test program cost-effectiveness.

The support requirements for integrated testing in the Avionics Subsystems Integration Lab (ASIL) in post-manufacturing checkout (PMC), and at the static firing facility, are denoted in Section 8.0.

A glossary of terms is presented in Section 9.0 to provide concise definitions of test phraseology and words used in this document.

PRECEDING PAGE BLANK NOT FILMED

Preceding page blank

3.0 PROGRAM SUMMARY

3.1 ESS TEST PROGRAM

The test program for the ESS is an outgrowth of the design verification requirements. The ESS mission dictates the design functional and environmental requirements, and from these the verification requirements are defined and will be delineated in the contract end item (CEI) specification. The verification requirements are analyzed and the test logic and constraints are prepared for each subsystem and for the overall program. The test program, including approach and rationale, is then optimized to assure it will be both cost-effective and that the ESS vehicle is ready to perform the designated missions. Selection of S-II or shuttle-orbiter-developed components will be a major consideration during Phase C. Component level testing will be developed as components are selected. This plan approaches the ESS testing at three hardware levels: subsystem, combined subsystems, and vehicles.

3.1.1 Subsystem Level Testing

Subsystem level development testing (e.g., data and control management, auxiliary propulsion) will require close coordination between test and design functions. It will be sufficiently flexible to encourage functional efficiency and maintainability in design, cost-effectiveness in material selection, and optimization of fabrication and nondestructive test and inspection techniques. Each development test and the results will be documented for analysis and retained for subsequent retrieval. This test data will include objectives, conditions, support, and hardware limitations relative to production equipment.

Qualification testing for functional Criticality I hardware will be performed at certified vendor or contractor labs or customer-approved test facilities. Test procedures will follow a standardized format and will reference the system or CEI specification and the test logic constraint network.

Each ESS subsystem is presented in a separate subdivision of Subsection 5.1 and includes a description of the subsystem and its major functional elements, design issues and certification requirements, test approach and rationale, and support requirements for the respective tests.

PRECEDING PAGE BLANK NOT FILMED

3.1.2 Combined Subsystem Level Testing

Major tests for the integration of specific subsystems and their integration with interfacing subsystems are summarized in the following paragraphs.

3.1.2.1 Avionics/NonAvionics Test Program

The data and control management subsystem and its complementing software is integrated in an Avionics Subsystem Integration Laboratory (ASIL) with the following: guidance, navigation and control; power; communications and instrumentation; and nonavionics subsystem interfaces. Support equipment, procedures, and test and operational software will also be integrated in this laboratory. These tests, in conjunction with the integration tests on the flight vehicles, will eliminate the need for a special ESS integration vehicle.

3.1.2.2 Auxiliary Propulsion Subsystem Integrated Test Program

The orbit maneuvering and attitude control propulsion subsystems share a common propellant and pressurization system. Integration tests will verify the subsystem capability to perform hot firings at simulated altitudes. A cryogenic tanking test prior to the vehicle main propulsion firing will demonstrate the propellant system/support equipment ability to service and control propellants. Dry gimbaling tests will be used to verify the thrust vector control acceptance requirements of the orbit maneuvering propulsion subsystem.

3.1.3 Vehicle Level Testing

Since the ESS program does not economically justify a dedicated all-systems test vehicle, several design verification requirements will be verified on the first operational vehicle. Vehicle level requirements will be satisfied during three test phases as detailed in Subsection 5.2. The three phases are summarized below.

3.1.3.1 Post-Manufacturing Checkout

Upon completion of assembly and in-line manufacturing acceptance tests, such as leak checks and continuity and megger tests, each subsystem will undergo a functional acceptance test during post-manufacturing checkout (PMC). The PMC will culminate in an integrated, noncryogenic, simulated flight test designed to verify that all subsystem interfaces are correct and that no extraneous interactions exist.

3.1.3.2 Static Firing Test Program

The first two vehicles will be static-fired at the launch operations site, utilizing the space shuttle orbiter support fixture, engine exhaust aspirators, and modified flame deflector.

One test will be conducted on each vehicle. Subsequent to the static firings, each of the vehicles will be subjected to a post-static-firing checkout prior to final acceptance by the customer. All vehicles subsequent to the first two will receive final acceptance after PMC and will be transported directly to the operational site.

The static firing of the first two vehicles was selected as the most cost-effective means to provide the necessary evaluation of the integrated main propulsion system, including engines, tanks, feed lines, pressurization, avionics, and controls. GSE compatibility, static firing/launch support equipment, facilities, procedures, and software will all receive final certification during these tests. Fit and functional compatibility of interfacing subsystems such as structures and propulsion will also be demonstrated. Major objectives of the test are to verify:

1. Capability of the propellant recirculation system to meet minimum engine propellant inlet requirements.

2. Capability of the pressurization system to provide minimum ullage pressure and net positive suction head (NPSH) under required operating conditions.

3. Capability to precondition vehicle propellant systems for propellant loading.

4. Capability of the thrust vector control (TVC) system to perform satisfactorily throughout the complete range of operating requirements.

5. Capability to inert the propellant tanks, feed, recirculation, pressurization, and engine systems.

6. Capability of the ground servicing equipment to satisfactorily check out, service, and safe the vehicle systems.

7. Satisfactory performance of all systems under static firing conditions.

8. Capability of vehicle systems to withstand acoustic environments.

9. Functional capability of propellant depletion/engine cutoff sequence.

10. Thrust structure compliance, structure dynamics, and ascertained load paths.

3.1.3.3 Mated Flight Vehicle Testing

When the first vehicle arrives at the operational site, it will be mated to the space shuttle booster in the horizontal mode. The mated vehicles will then be subjected to a mated horizontal dynamic test program primarily to determine structural modes. Subsequent to this test program, the vehicles will be demated and will proceed through their respective prelaunch and launch operations. The data generated by the dynamic test program will be utilized to establish the flight control program parameters.

Although the first flight of the ESS program will be operational, final verification of several design issues will be accomplished. These issues are detailed in Subsection 5.2.

3.2 STRUCTURAL DYNAMICS TESTING

Structural dynamics tests are designed to investigate three primary areas: aeroelasticity and dynamics loads, POGO, and shock/vibration/acoustics. One of the major dynamic test programs is the ground vibration test on the flight vehicle to verify analytically determined vehicle modes and damping characteristics. POGO involves a coupling of the structural subsystem with the main propulsion subsystem; therefore, these tests will be designed to obtain data for confirmation of analysis. Test data are also required to support POGO suppression development. Static firing tests of single engines by the engine contractor, using a simulated ESS LO_2 feedline, will provide data on the behavior of the feedline/pump/engine with and without a suppression device. Finally, flight vehicles will be instrumented to ascertain that no POGO tendencies are present. Shock, vibration, and acoustic test programs are planned to validate predicted dynamic environments and to determine response of local structure and equipment for confirmation of design criteria. Initial aerodynamic noise predictions are checked by wind tunnel model tests. Rocket engine noise will be measured in static firing tests of individual engines. Acoustic data from booster cluster firings will be utilized to confirm predicted liftoff noise levels and in-flight measurements for other vibro-acoustic environments.

3.3 WIND TUNNEL TEST PROGRAM

Wind tunnel testing will be conducted to obtain data for analysis and development of design criteria and for substantiation of analytically predicted performance design environment. The Phase C/D wind tunnel test program has been planned as a continuation of the testing accomplished during Phase B. The main categories for wind tunnel testing are aerodynamics, heat transfer, and structural dynamic tests. Aerodynamic wind tunnel tests will be conducted for individual ESS as well as mated ESS/booster configurations. Aerothermodynamic wind tunnel tests will initially employ paint models to determine constant temperature contours. Subsequently larger-scale models will be used to acquire more detailed temperature and heating rate data by means of thermocouple instrumentation. Structural dynamic wind tunnel tests will provide air vehicle design data and validate the analytical methods used to calculate dynamic response and flutter margins.

ESS and booster dynamic models will be used both individually and in a mated configuration to study "launch vehicle" structural dynamics in other than the liftoff flight region.

3.4 ELECTROMAGNETIC COMPATIBILITY TEST PROGRAM

Verification of electromagnetic compatibility (EMC) represents testing activity at all hardware levels from the component to the complete vehicles. During the initial development phase, EMC tests will be performed on new subsystem equipment as well as additional tests if necessary on "off-the-shelf" black boxes. The results of these tests will be utilized in establishing requirements for subsequent subsystem and combined subsystem level tests. Electromagnetic interference (EMI) susceptibility identification and corrections will be implemented in the Avionics Subsystem Integration Laboratory, the hydraulics test stand, the static firing program, and ultimately the flight vehicles. EMC/EMI evaluation at the vehicle level will be performed during post-manufacturing checkout at the final assembly area and finally during preflight operations.

3.5 MAJOR TEST ARTICLE SUMMARY

As a result of the maximization of S-II and shuttle-orbiter-developed components and assemblies, a minimum number of major test articles are required by the ESS test program. Test article requirements are detailed in Subsection 5.1 and are summarized in Table 4-1.

Table 4-1. Major Test Article Summary

AVIONICS SUBSYSTEMS INTEGRATION LABORATORY (ASIL)
The ESS avionics group will be developed in the space shuttle program ASIL. The following ESS avionics subsystems will be both developed individually and integrated in the ASIL: 1. Electrical power subsystem 2. Data and control management subsystem 3. Guidance, navigation, and control subsystem 4. Communications subsystem 5. Electrical controls subsystem 6. Instrumentation subsystem The ASIL will also be integrated with a hydraulics laboratory to provide thrust vector control development for main propulsion and orbit maneuvering subsystems (OMS).
BODY STRUCTURE TEST ARTICLE
The body structure test article will be subjected to the applicable portions of the structural test program. This article is comprised of three major structural assemblies: forward skirt, LH_2 tank, and aft skirt.
THRUST STRUCTURE TEST ARTICLE
The thrust structure test article will also be subjected to the applicable portions of the structural test program. This article is comprised of the thrust structure, aft skirt, and OMS engine support assemblies.
AUXILIARY PROPULSION SUBSYSTEM (APS)
The APS will be developed in the Space Shuttle Orbiter APS test facility. The ESS APS components will be the same as those in the Orbiter APS, however fewer in number. Utilization of the Orbiter APS test facility results in significant cost savings.

4.0 TEST PHILOSOPHY AND CRITERIA

It is intended that ESS component, subsystem, and system testing be developed as an integrated program; i.e., test requirements for an individual element will be tailored based on that element's operational requirements. All testing to be performed from development, qualification, acceptance, manufacturing in-process, and operational checkout through flight will be considered. The test program will thus allow maximum use of all test data in satisfying certification requirements, which should accomplish the basic objective of achieving adequate confidence at minimum cost. The test data will also be used for the development of checkout procedures, the establishment of trends, and in the resolution of anomalies.

All equipment, both flight and GSE, shall be certified for flight (or operational use) by an assessment of previously identified analyses and test results from development, qualification, acceptance, off-limit, checkout, and other special tests. Qualification as a part of certification is required for critical components only.

Early developmental testing will necessarily require a highly flexible approach so that hardware configuration and operating and checkout procedures are optimized. As final component and subsystems configurations are selected, development testing will become more rigorous and acceptance test requirements and approaches will be determined and proven, as will operating software, checkout concepts, maintenance approaches, and interfacing ground support equipment (GSE). At the other end of the scale, acceptance testing will require rigorous control, inspection, and documentation from the outset to assure that all elements of the ESS program, including software, procedures, and GSE, meet the specified requirements (performance, functional, configuration, etc.) and that no manufacturing defects exist.

The test program is structured to satisfy the development and verification "issues" or requirements that are identified during design and development. The establishment of a procedure for positive and early identification of these "issues" or requirements is thus critical to test program planning and implementation. These verification requirements will be based on the most critical operational or mission requirement and will be traceable to corollary specification requirements.

Test procedures and equipment utilized for component and subsystems testing at subcontractor, supplier, and prime contractor plant locations will be standardized insofar as possible. To the extent that it is practicable and cost-effective, test plans and procedures will be based on the use of highly flexible and multipurpose ground support test equipment. For manufacturing in-process and other appropriate testing, the onboard checkout capability will be utilized to the maximum extent practical.

Special life-cycle testing (other than structural fatigue) for the accumulation of statistical reliability data will be accomplished by exception. This data will normally be obtained by acquiring operating time data and failure trends throughout the development, qualification, acceptance, and operational phases of the program. The integrated test program approach will provide for accumulation of this data during the process of satisfying other test requirements without the implementation of special tests. Nondestructive test techniques shall be utilized to the maximum extent in this regard.

Wind tunnel testing will be conducted as necessary to establish reasonable confidence in the capability of the configuration to satisfy program requirements. Data and related information should be acquired from wind tunnel tests of appropriately designed subscale models. Test conditions shall be representative of the flight modes of ascent and separation. Flight conditions shall be simulated within the practical limits of existing facilities, including applicable Mach and Reynolds numbers, vehicle attitudes, and booster aerodynamic control surface positions. Maximum utilization will be made of government-owned wind tunnel facilities and identification of specific requirements.

4.1 DEVELOPMENT TESTING

Development testing is that testing conducted to select and prove the feasibility of design concepts. Development testing is concerned with engineering evaluations of hardware, software, and manufacturing processes and techniques for the purpose of acquiring engineering data, identifying sensitive parameters, evaluating the development configuration performance, and providing the necessary confidence that the hardware will meet the specification requirements and the manufacturing process will produce an acceptable product. Development testing encompasses materials selection and characterization, process evaluation, design feasibility determination, and overall vehicle design and configuration verification, including that for major test article and model tests.

4.1.1 Development Testing Criteria

1. Development of checkout and maintenance plans and procedures will be accomplished during subsystem development and will be verified during the operational phase of the program.

2. Early subsystem integration with the software will be a key test program goal.

3. Overstress testing, when required for operational analysis or design and manufacturing verification, may be conducted at the completion of the development program utilizing development hardware. Overstress and off-limit conditions include both increased time at qualification levels and increased severity of the applied stress or condition as applicable.

4. Acceptance tests, procedures, equipment, and test levels shall be proven and verified during development testing.

5. Where new materials or existing materials under new conditions are to be used, adequate testing shall be performed to statistically identify material property values.

6. Application of nondestructive testing techniques shall be proven and verified during the development test program.

7. EMI/EMC testing will be accomplished primarily at the component or subsystem level and data will be accumulated for subsequent installed subsystem susceptibility assessment. This will be accomplished as part of the manufacturing "in-process" test and integrated vehicle checkout activity.

4.1.2 Development Test Requirements

For flight hardware which is to undergo development testing, test requirements shall encompass the following as a minimum:

1. Verification of design and performance capability, including redundancy.

2. Verification of ability to meet mission requirements with adequate design margin.

3. Integration of each component and subsystem with other components, subsystems, facilities, and support equipment.

4. Verification of processes, procedures, equipment, and test levels for manufacturing, acceptance testing, maintenance, checkout, and operational phases of the program.

5. Determination of significant failure modes and effects.

6. Determination of the effect of various combinations of tolerances and drift of design parameters.

7. Determination of the effect of combinations and sequences of environments and varying stress levels.

8. Identification of safety hazards, parameters, requirements and procedures.

9. Wind tunnel testing utilizing models, major vehicle segments, components, etc. shall be performed in support of ascent trajectory analyses, stability and control verification, abort performance evaluation, loads analyses, and flight performance predictions.

10. Verification of ability to detect malfunctions or degradation of designed-in redundant elements at the highest practical level of assembly.

11. Establishment of requirements for developmental and operational instrumentation during the early phases of the program.

4.2 QUALIFICATION TESTING

The basic objective of qualification testing is the acquisition of quantitative and qualitative data verifying specified performance in specified environments to establish confidence that the test article will perform its design function with the required design margin. Qualification testing consists of a series of functional and environmental tests conducted on production hardware with formal rigor, including a calibrated facility and instrumentation, inspection coverage, approved test plan, and approved test report. A failure or anomaly encountered during qualification testing requires positive corrective action agreed to by both contractor and customer.

The requirement for qualification testing will be based on the functional criticality of the subsystem and will be performed on all hardware which, in event of failure, could result in loss of crew or vehicle (Criticality I as indicated in Table 4-2).

For the purposes of determining whether qualification testing is or is not required, the provision of redundant identical components or subassemblies (only) is not a sufficient cause for lowering the criticality. Functional criticality should be based on an assessment of the likelihood of continued functional performance after incurring any credible failure due to a single or combined stress or environment. True functional redundancy is represented by a completely alternate system or redundant method of performing

Table 4-2. Functional Criticality

Criticality	Potential Effect of Failure	Tests
I	A. Loss of life of crew member(s) (ground or flight). Also includes safety and hazard warning systems for primary operating systems whose failure could potentially cause loss of life of crew members.	Full qualification with testing rigors.
	B. Loss of vehicle.	
II	A. Immediate (safe) termination of the mission flight.	Certification by test data accumulation. Selected items may undergo qualification testing with management approval.
	B. Loss of primary or secondary mission objectives.	
III	Launch scrub or delay.	Certification.

NOTE: Functional criticality is a loss of function due to a single stress or environment which negates redundancy because of packaging or adjacent location. Determination of functional criticality requires knowledge of packaging and location (inboard profile).

the required function; however, functional redundancy can also be satisfied by redundant components if the postulated stress or environment resulting in the failure does not affect all redundant components. Determination of functional criticality must be based on failure modes and effects analyses (FMEA) in addition to packaging and location assessment.

Hardware whose failure would result in loss of primary or secondary mission objectives or launch scrub or delay shall generally be certified flightworthy by an assessment of previously identified data from design analysis and test during development, acceptance, off-limit, and checkout, in lieu of rigorous qualification testing. In these cases, a more rigorous development and acceptance test program will generally be required to satisfy these certification test requirements. Figure 4-1 depicts the test flow associated with this certification concept.

Exceptions to the general guideline above will be identified by the contractor for state-of-the-art or extremely high-cost (or other) components. A prime consideration in this regard is overall program cost-effectiveness. In some cases the total program cost of fabricating and qualification testing the component may be less than the potential consequences of foregoing qualification testing.

4.2.1 Qualification Testing Criteria

1. Qualification testing may be waived when equipment is selected which has been previously qualified to the level required for the proposed ESS application. Adequate substantiation of configuration control, inspection, fabrication methods, facility certification, etc. must be submitted with supporting rationale to the contracting agency for approval of the waiver.

2. Hardware which could potentially result in loss of crew or vehicle shall receive a qualification test in the specified environments. Environments selected shall be the worst-case condition (ground or flight) that the hardware is expected to experience in its service life plus the design margin.

3. Qualification test levels must include verification of design margins.

4. All qualification test specimens shall be processed through specified acceptance testing prior to qualification test.

5. Successful testing of qualification hardware must be completed prior to first use in flight.

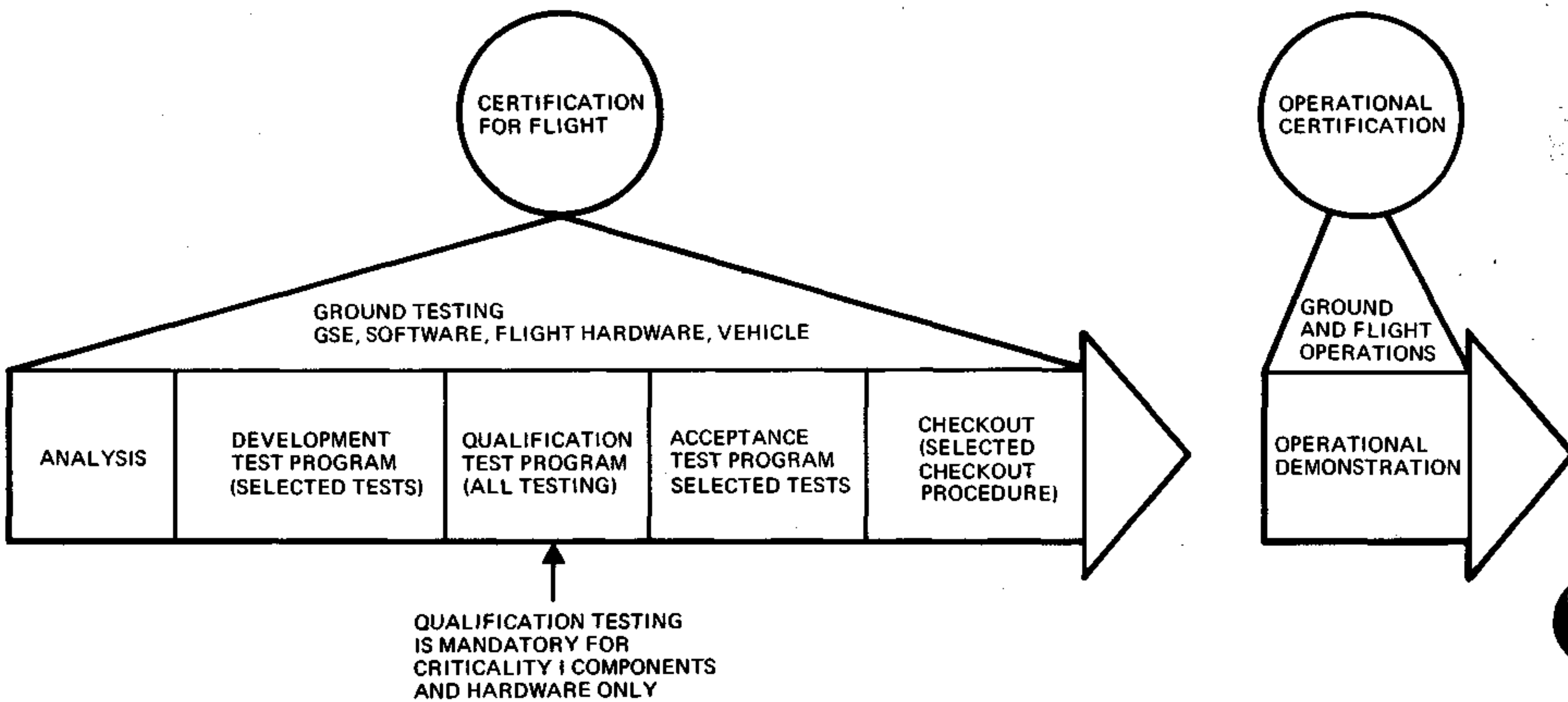


Figure 4-1. Certification Approach

6. Where redundancy in design exists, qualification tests shall assure that each redundancy is verified.

7. Qualification tests shall be performed under strict control of environments and test procedures. Adjustment or tuning of qualification test hardware is not permitted during test unless it is a normal in-service operation.

8. The test sequence during qualification testing shall follow the same order, where practicable, in which the environment will be encountered by the flight hardware.

9. Qualification test hardware shall be of the same configuration as flight hardware.

10. Requalification shall be required when:

    a. Design or manufacturing processes are changed to the extent that original testing is invalidated.

    b. Inspection, test, or other data indicate that a more severe environment or operational condition exists than that to which the equipment was originally qualified.

    c. Manufacturing source is changed.

4.3 ACCEPTANCE TESTING

Acceptance testing is designed to verify that hardware produced by production methods under quality control procedures and ready for delivery to its next assembly or usage point, complies with specifications, is free from defects, and is capable of performing in conformance with stated contractual requirements. Acceptance tests begin with vendor tests at the component/subassembly, assembly, and subsystem level and continue through demonstration at the time of vehicle delivery (or turnover) and customer acceptance.

Where appropriate, acceptance tests at the component/subassembly level shall include environmental testing. Environment test levels shall be equivalent to mission requirements or a level sufficient to screen defects. The contractor shall make recommdnations concerning which items of hardware should be considered for environmental acceptance testing. These tests shall be designed to detect manufacturing flaws, workmanship errors, and incipient failures which are not readily detectable by normal inspection.

Acceptance testing at the subsystem level (installed in the vehicle) shall include a demonstration of alternate/redundant modes of operation, together with malfunction switching logic, by exercise of subroutines inherent to the data control and management system. Whenever possible, alternate/redundant path checkout capability by malfunction simulation shall be an inherent subsystem checkout feature and be accomplished without disturbing the flight configuration.

4.3.1 Acceptance Testing Criteria

1. Acceptance of vendor-supplied equipment shall take place at the manufacturing source, insofar as is practical. Acceptance tests at the component/subsystem level will provide the necessary quality/inspection and testing rigor to assure that functional pre-installation testing will be minimized.

2. Alternate or redundant path checkout shall be required on deliverable components, subsystems, and systems.

3. Electromagnetic compatibility (EMC) will be established at the design level and verified in the normal test and checkout sequence. Integrated tests in the development and acceptance cycle will verify that no electromagnetic interference (EMI) exists.

4. Components or subassemblies built by the prime end item contractor, or not source inspected and accepted, shall be subject to the same acceptance requirements specified for vendor acceptance testing.

5. Each measured parameter for acceptance testing shall have a specified tolerance band of acceptability bracketing the nominal value.

6. End item support equipment shall be accepted by a functional test according to specification. Where appropriate, each first article of an end-item model shall also have an environmental acceptance test tailored to its expected "in-use" external environment under worst-case conditions. The test will be for a duration sufficient to disclose functional/environmental exposure deficiencies.

7. Excessive shelf life prior to installation may require repeat acceptance testing for items designated age-sensitive or delicate. These items shall have specified the maximum handling requirements or shelf life before retest.

8. An integrated checkout of the ESS end item shall be conducted subsequent to final assembly. This checkout shall confirm that the vehicle has been manufactured and tested in accordance with engineering documentation and approved shop practices.

9. Operational site acceptance testing shall verify the various vehicle interface requirements, including ESS/booster separation, communication and data functions, and integrated vehicle pneumatic, propellant, purge, and power compatibility with ground support equipment and launch facilities.

10. A facility verification program will be conducted to demonstrate acceptability of facilities and facility systems. Physical and functional compatibility with the ESS vehicle interface requirements will be verified.

11. System/subsystem performance evaluation (while installed on or in the flight vehicle) shall utilize operational (natural) signals as stimuli insofar as possible.

12. Retest may be required whenever:

    a. The test was not performed in accordance with approved specification or procedure.

    b. Test equipment malfunctions or operator errors occur.

    c. Modifications, repairs, replacement, or rework of the article or material occur after completion of testing.

    d. Periodic intervals for retest shall be established on articles or materials subject to drift or degradation due to storage or handling.

    e. The number of retests shall be limited and based on the limited life of the equipment.

13. GFE used to support and/or perform tests shall be maintained, calibrated, and controlled by the contractor. GFE that becomes part of deliverable end item hardware shall be tested and controlled as part of that end item.

5.0 REQUIREMENTS

5.1 SUBSYSTEM REQUIREMENTS

This section of the ESS test plan contains the certification requirements and the approach to satisfying the requirements for each ESS subsystem. Specific items included in each subsystem section are:

1. Subsystem description
2. Hardware breakdown
3. Subsystem schematic
4. Certification requirements
5. Test approach and rationale
6. Test logic and constraint network.

A brief description of each subsystem is provided to establish a reference baseline configuration upon which certification requirements and test hardware are based. A subsystem hardware breakdown also furnished reflects, in general, the work breakdown structure and established hardware levels.

Certification requirements are tabulated for each subsystem. In addition to development and qualification, requirements associated with subsystem acceptance are included. Since the S-II and shuttle orbiter components and assemblies are to be utilized as much as possible, many certification requirements will have been satisfied on those programs. Those actions are denoted by the symbols "S-II" and "SS." For requirements where S-II or orbiter assemblies are modified for the ESS, the symbols "S-II(P)" and "SS(P)" are used. These symbols indicate that the requirements have been partially satisfied but that additional testing is required for the ESS. To provide consistency in developing the test plan and visibility to the reader, the verification methods employed have been categorized as follows:

<u>Category 1—Verified by Engineering Analysis</u>. This includes design and technical analyses of a less formal nature than computer programs. Also included are engineering studies such as comparison of component characteristics and operational environment for qualification by similarity.

Category 2—Verified by Computer Program or Math Model. This includes computer simulations and noncomputer mathematical model representations of the flight hardware and its interactions with the physical environment. These models/programs are usually constructed at the subsystem, combined subsystems, or vehicle level.

Category 3—Verified by Component Level Testing. This includes testing of individual components such as valves, regulators, lines, and black boxes.

Category 4—Verified by Assembly Level Testing. This includes testing of individual assemblies or combinations of two or more components from the same or different assemblies within a subsystem.

Category 5—Verified by Subsystem Testing. This includes testing of the complete subsystem or testing that involves a combination of elements of the subsystem. A subsystem is defined as Level 5 of the WBS.

Category 6—Verified by Combined Subsystems Testing. This includes testing that involves elements from two or more subsystems where the purpose of testing includes verification of interaction or interfaces of the subsystems. A typical example is the avionics/nonavionics testing. Tests that include only ACTs or power/control cabling interfaces are not classified as combined subsystems tests.

Category 7—Verified by Ground Test or Flight of the Vehicle. This includes tests conducted in the mated mode or on single-element mode during prelaunch operations, mated ascent, ESS ascent, or on-orbit operations.

A test logic and constraint (TLC) network is developed from the tabulation of certification requirements and implementation methods. The network (1) shows the level of testing from components through flight vehicle, (2) presents the classification of testing (i. e., development, qualification, acceptance), and (3) represents an initial "top-level" subsystem flow sequence. During Phase C/D, the network will be expanded to reflect detailed constraints at all levels of testing activity. Although included in the subsystem section, it is intended that the certification requirements, the TLC network, and accompanying approach and rationale summary cover the entire subsystem spectrum from component development through vehicle acceptance. Based on the constraints and flow sequence established in the TLC network, test article and subsystem development schedules will be defined. The schedule and test article requirements will establish additional requirements for test facilities and support equipment. The test article, facilities, support equipment, and required software will be tabulated for each subsystem section during Phase C.

These data can subsequently be utilized for development of integrated test program schedules and for program cost data.

The manufacturing in-process phase of acceptance testing covered in the subsystem section consists of (1) cleanliness verification and external-internal leak checks and (2) verification of wire harness installation consisting of bus isolation, insulation resistance, and high potential and electromagnetic compatibility checkout. Component acceptance checkout will be a function of fabrication acceptance requirements. Subsystem installation will be functionally verified to the extent necessary to detect installation anomalies. Specific checkout peculiar to each subsystem is presented in the individual subsystem sections.

5.1.1 Main Propulsion Subsystem

Subsystem Description

The main propulsion subsystem (MPS) provides the second stage propulsion required to boost the vehicle into a transfer orbit of 66 by 100 nautical miles following separation from the shuttle booster. The subsystem includes all lines, valving, etc. required to support main engine burn. It does not include the associated propellant tankage which is primary vehicle structure or the electrical controls and instrumentation which are considered to be part of the integrated avionics subsystem. The MPS test plan does not include test of the engines since they are GFE, but does include vehicle/engine integration testing. The MPS elements are shown in Figure 4-2. The subsystem is shown schematically by Figure 4-3.

The ESS main propulsion subsystem employs two pump-fed engines burning LO_2 and LH_2 at a nominal mixture ratio of 6 to 1. The engines are in accordance with ICD 13M15000B. Each engine generates 632,000 pounds of thrust at altitude. The engines are equipped with a retractable nozzle which provides an expansion ratio of 150 to 1 when extended.

Propellants are fed to the engines from the propellant tanks by vacuum-jacketed feed ducts. Preconditioning of the engine is accomplished by recirculating fuel and oxidizer through the feed ducts and engine back to the propellant tanks via the recirculation return lines. The pressure differential for flow is provided by motoring each engine LH_2 boost pump with a small electric motor and by natural convection augmented by helium-injection in the LO_2 system. A regulated helium supply is utilized for the necessary valve actuation. Helium from the helium injection supply will be used to charge the POGO suppression accumulators mounted at each LO_2 pump inlet. The propellant tanks will be filled and drained through individual stage-mounted LO_2 and LH_2 fill and drain valves.

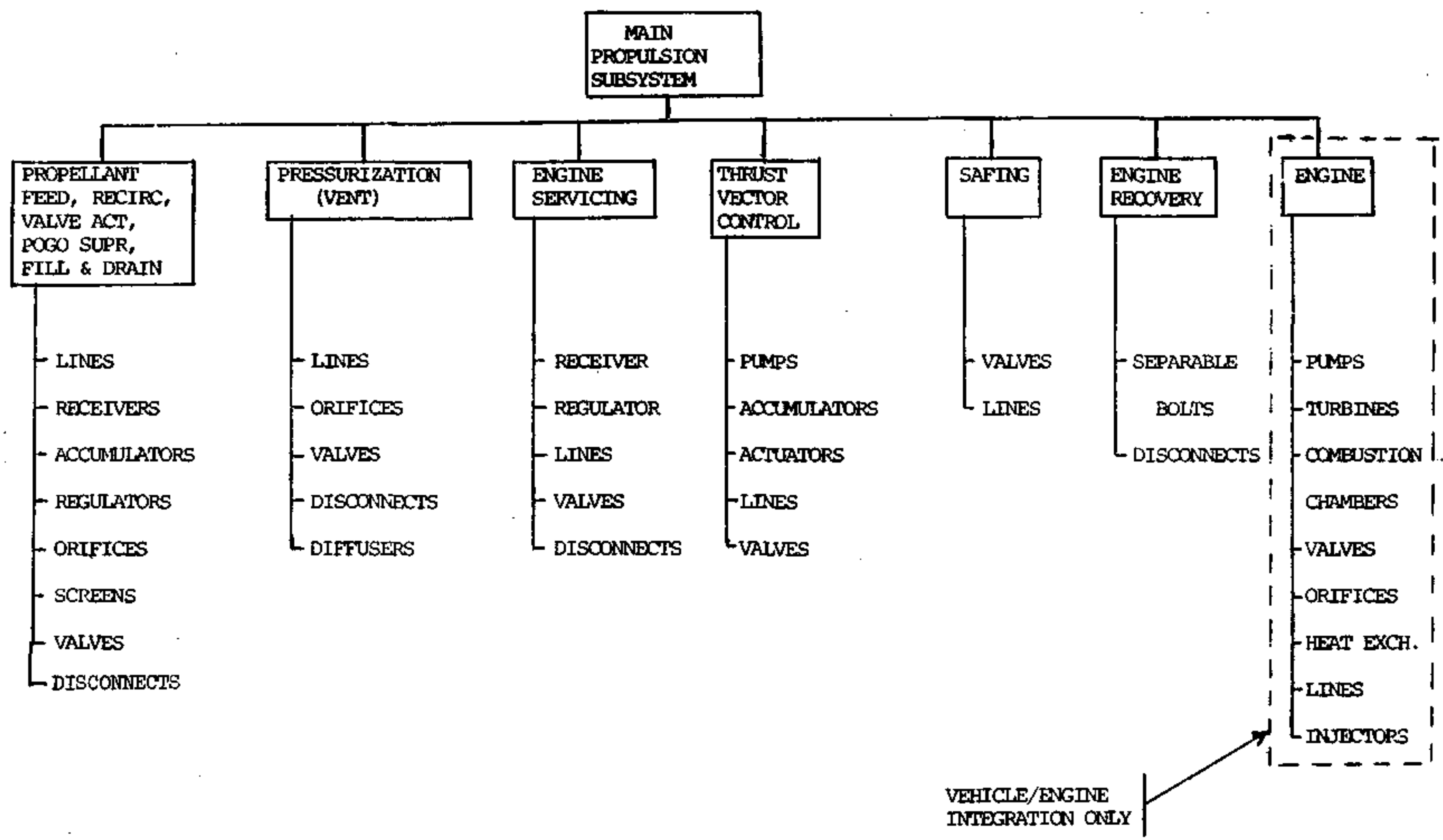


Figure 4-2. Main Propulsion Subsystem Elements

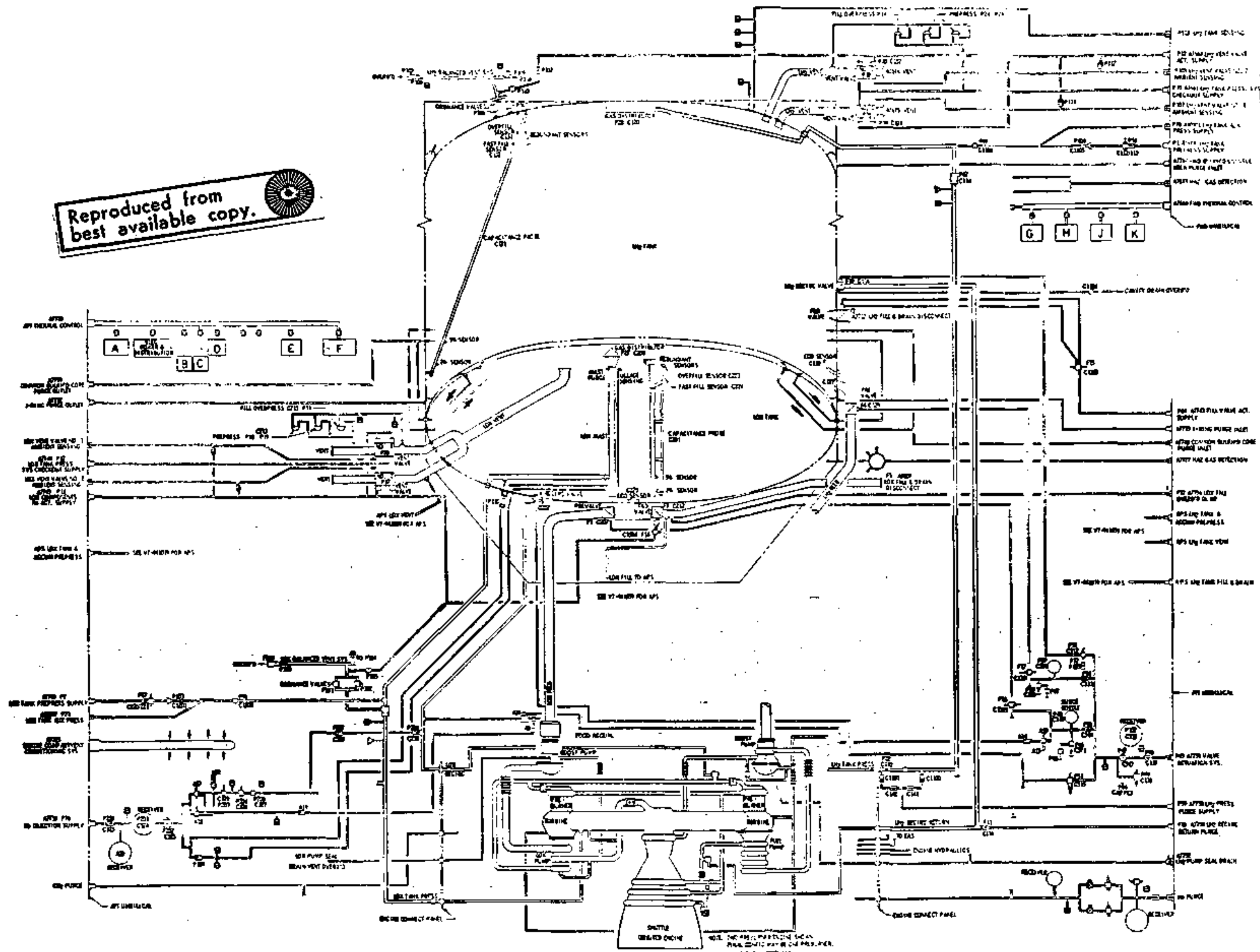


Figure 4-3. Main Propulsion Subsystem Schematic

Reproduced from best available copy.

The propellant tanks are prepressurized with helium on the ground. During main engine burn, tank pressure is maintained by tapping GH_2 and GO_2 from the engines. GH_2 is tapped off after being expanded through the thrust chamber tubes; GO_2 is taken from the engine LO_2 pump outlet and routed through an engine-supplied heat exchanger. Flow control is provided by stage orifices. Two vent and relief valves are mounted in parallel on each main propellant tank. Ground-supplied helium will provide the necessary valve actuation during propellant loading operations. The engines will be serviced by a stage-supplied helium bottle and regulator in flight. A ground-supplied nitrogen purge will also be used. The stage will provide a fuel pump drain line and a hydraulic power supply for the retractable nozzle.

A hydraulic engine actuation system will gimbal the main engines for thrust vector control (TVC). Subsequent to main engine burn the main propellant tanks will be safed by parallel-mounted, ordnance-actuated valves which allow the tanks to be vented through a nonpropulsive vent assembly.

Following the ESS delivery of payload, the main engines will be recovered. This will be accomplished by separating the recoverable components with separable bolts and then utilizing the shuttle orbiter for the recovery operation. Sealing disconnects will be installed in the hydraulic lines to prevent hydraulic oil from contaminating the engines.

Subsystem Test Requirements

The main propulsion subsystem test requirements are delineated in Table 4-3.

Approach and Rationale

The MPS test logic and constraint network is given in Figure 4-4. The MPS is significantly affected by the fact that the main propulsion engines are being developed and qualified for the space shuttle program, and it is also anticipated that other shuttle components will be utilized on the ESS. Consequently, the test approach is quite similar to the shuttle approach.

Certification of the MPS will begin at the component level where most components will be subjected to critical environments (cryogenic shock and vibration) and durability testing to that extent required to assure a sufficiently high degree of success at the subassembly and assembly level. Concurrent with component development, development breadboard assemblies of the pressurization and propellant distribution systems will be tested to ascertain functional and dynamic response characteristics at the assembly level before interfacing with the main propulsion engine (MPE).

Table 4-3. Main Propulsion Subsystem Certification Requirements

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
	A. OPERATIONAL REQUIREMENTS							
1.	Verify component accessibility							SII (P)
2.	Verify ability of components and engine to withstand acoustic and vibration	X		SII (P)				SS (P)
3.	Verify adequacy of base heating thermal protection of components and engine	X	X	SII (P)				X
4.	Verify ability of MPS to withstand boost environment	X		SII (P)				SS (P)
5.	Verify ability to start engines in boost environment	X						SS (P)
6.	Verify ability to engage and disengage umbilicals			SII (P)				X
7.	Verify ability to leak test			SII (P)				SII (P)
8.	Verify ability to functional test			SII (P)				SII (P)
9.	Verify ability to purge and inert	X		SII (P)				SII (P)

NOTES

X	To be accomplished by ESS Program
S-II	Accomplished on S-II Program
S-II(P)	Partially accomplished on S-II Program
SS	To be accomplished on the Space Shuttle Program
SS(P)	To be partially accomplished on the Space Shuttle Program

Table 4-3. Main Propulsion Subsystem Certification Requirements (Cont)

No.	Requirement	Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
10.	Verify MPS/GSE compatibility	X						SII (P) SS (P)
11.	Verify capability to extend/retract engine nozzle under flight loads	X						SS (P)
12.	Verify engine/stage compatibility from 50 to 109% of thrust	X						X
13.	Verify engine/stage compatibility during 5.5 to 6.5 mixture ratio excursion	X						X
	B. PROPELLANT FEED ASSEMBLY REQUIREMENTS							
1.	Verify ability to provide engine start NPSP requirements	X						X
2.	Verify ability to monitor and maintain vacuum jacket conditions			SII (P)				SII
3.	Verify POGO suppression	X	SS (P)					SS (P)
4.	Verify tank isolation capability	X		SII (P)				SII (P)
5.	Verify ability to fill main tanks within 2-hour servicing time	SII						SII
6.	Verify ability to drain tanks	SII						SII
7.	Verify capability of depletion cutoff to protect engines	X						X
8.	Verify satisfactory heat leak rates	X						SII (P) SS (P)

Table 4-3. Main Propulsion Subsystem Certification Requirements (Cont)

No.	Requirement	Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
	C. PRESSURIZATION ASSEMBLY REQUIREMENTS							
1.	Verify ability to meet engine mainstage NPSP requirements	X	X					X
2.	Verify capability of vent system to maintain tank pressure	SII						SII
3.	Verify prepressurization capability	SII						SII
4.	Verify vent system capability to vent tanks	SII						SII
	D. ENGINE SERVICING ASSEMBLY REQUIREMENTS							
1.	Verify ability to supply in-flight helium at ICD pressure and flowrate	SS (P)		X				SS (P)
2.	Verify ability to vent fuel pumps without excessive backpressure	X						X
3.	Verify GN_2 purge supply adequacy	X						SS (P)
4.	Verify capability to fill/drain hydraulic fluid	X						SS (P)
	E. THRUST VECTOR CONTROL ASSEMBLY REQUIREMENTS							
1.	Verify ability to dry gimbal with sufficient clearance	X						X
2.	Verify engine alignment	X						X
3.	Verify capability to gimbal engines over angular rate and response range	X		X	X			X
	F. SAFING ASSEMBLY REQUIREMENTS							
1.	Verify ability to safe the main propellant tanks				SII			

C-3

Table 4-3. Main Propulsion Subsystem Certification Requirements (Cont)

No.	Requirement	Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
	G. ENGINE RECOVERY ASSEMBLY REQUIREMENTS							
1.	Verify ability to sever all connections	X		X	X			
2.	Verify manipulator arm/removal clearance	X						X

(Certification Category spans columns 1–7.)

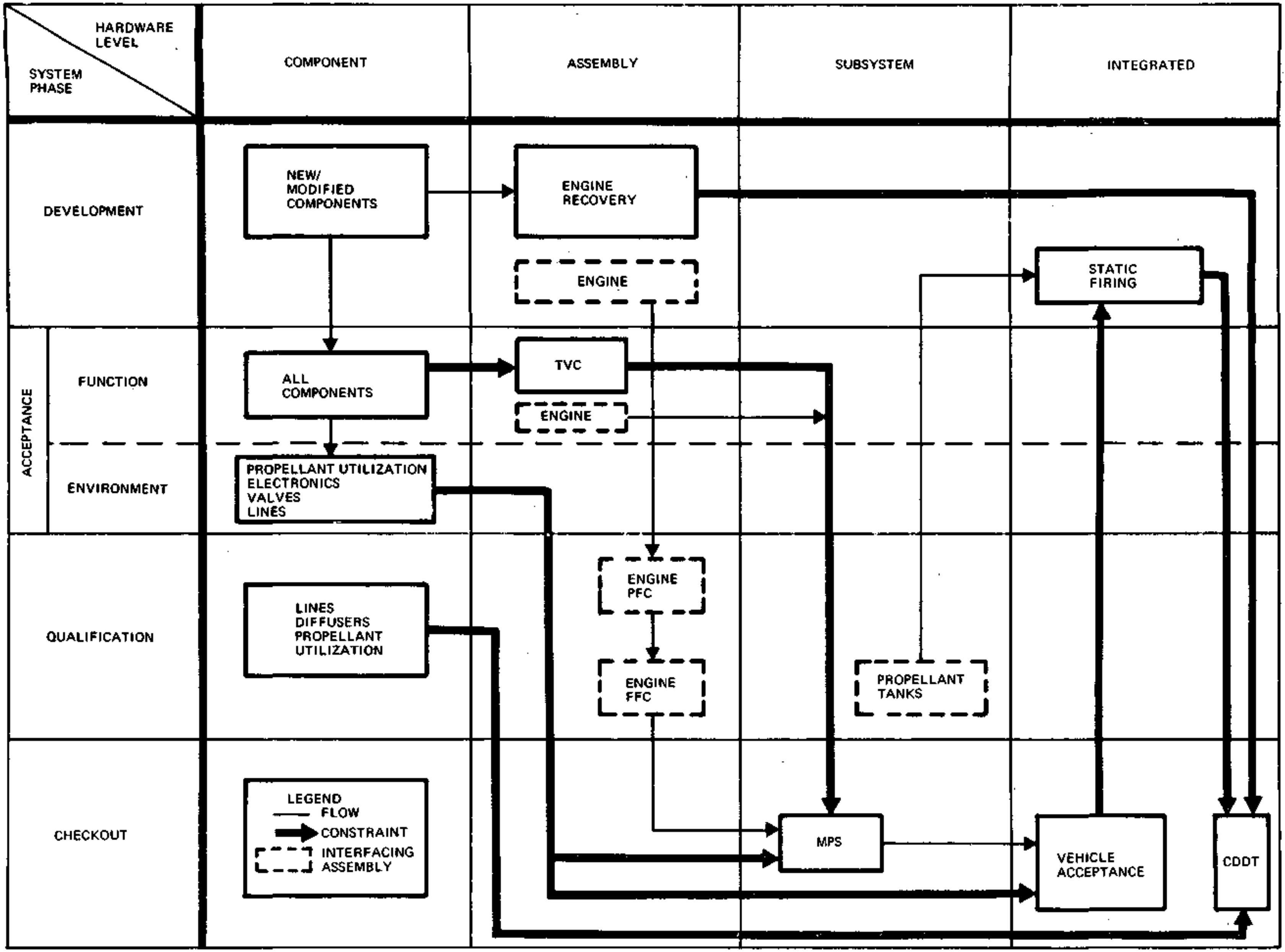


Figure 4-4. Main Propulsion Subsystem Test Logic and Constraint Network

Interface compatibility of the propellant distribution and pressurization systems with the MPE will be accomplished during development and qualification testing of the MPE by the MPE contractor. Testing will be accomplished under sea-level and simulated-altitude conditions. Overall MPS compatibility will initially be demonstrated during combined subsystem testing of the vehicle during post-manufacturing checkout. Final MPS certification will be achieved from the static firing program on the first two vehicles.

Support Requirements

The support requirements for the main propulsion subsystem at the vehicle level are summarized in Section 8.0 of this document.

Support requirements will be listed for component development, acceptance, and qualification when components are selected and requirements established. These requirements will be satisfied by the component vendor either at the vendor's facility or at a subcontracted laboratory. In-house component testing will be accomplished in existing laboratory and test facilities where only minor fixture changes would be required.

For assembly testing, two distinct test setups are needed. The development testing of the engine recovery assembly will require a facility where the recovery system panels can be set up, the separable bolts fired, and separation verified. Support equipment will be minimal, consisting primarily of a mounting fixture and the electronics necessary to send a firing command.

For acceptance testing of the TVC, a breadboard setup (including pump drive and simulated engine mass) such as utilized on the Saturn S-II Program will be needed. The test fixture for the shuttle orbiter TVC system can be used with little or no modification.

5.1.2 Auxiliary Propulsion Subsystem

Subsystem Description

The auxiliary propulsion subsystem (APS) provides the capability for orbital maneuvers and for roll control during boost with one main engine out. For the lighter payloads, such as space tug or RNS, a serial burn of the OMS engines will achieve the prescribed orbit after boost with one main engine out. The APS may be divided into two basic elements: orbit maneuvering and attitude control.

The orbit maneuvering element supplies velocity increments necessary for changing orbits, rendezvous, and de-orbit. Two engines, each developing 10,000 pounds of thrust, are used for orbit maneuvering. The attitude control element provides proper attitude during on-orbit periods when the main or orbit maneuvering engines are not running, braking thrust for rendezvous, and roll control with an engine out. Fourteen thrusters, each developing 2100 pounds of thrust, are used for attitude control.

The two orbit-maneuvering engines are mounted at Positions II and IV with the thrust chamber exit at the same station as the main propulsion engines. The engines burn LO_2 and LH_2 at a mixture ratio of 6 to 1 and deliver a nominal specific impulse of 454 seconds. The expansion ratio is 255 to 1 and the nominal chamber pressure is 800 psia.

The 14 attitude control thrusters are mounted on the moldline of the stage with 7 each at Positions I and III. The 14 thrusters are allocated as follows: two for yaw, two for braking thrust, two for longitudinal acceleration, and eight for pitch and roll. The large number of pitch and roll thrusters is dictated by a one main engine out condition. The thrusters burn gaseous oxygen and hydrogen at a mixture ratio of 4 to 1 and deliver a nominal specific impulse of 425 seconds. The expansion ratio is 20 to 1 and the nominal chamber pressure is 300 psia.

The APS cryogenic propellants are stored in four series-fed LH_2 tanks and an LO_2 tank located inside the main engine thrust cone. The propellants are fed to a turbopump and gas generator package.

The propellants for the orbit maneuvering engines are fed directly from the turbopumps to each engine. In the attitude control mode, the propellants are fed from the turbopumps through heat exchangers into accumulators. The propellant is then fed to the thrusters from the accumulators. The attitude control thrusters may be fired in any combination selected by the GN&C. The turbopumps do not operate continuously during attitude control thruster operation but only as required to maintain accumulator pressure.

The APS cryogenic propellant tanks are pressurized by tapping oxygen and hydrogen from the attitude control accumulators for prepressurization (the accumulators are initially charged on the ground), and from the orbit maneuvering engines during steady state operation. Flow control is provided by regulators. LH_2 from the APS tanks is flowed through coils around the feed ducts and turbopumps to maintain subcooled liquid hydrogen and oxygen at the pump inlets at all times. To assure liquid at the tank outlet, propellant retention is provided by internal screens.

A hydraulic actuation system will gimbal the orbit maneuvering engines for TVC. Power for the hydraulic pump will be provided by batteries.

Figure 4-5 represents the APS elements. The subsystem is shown schematically in Figure 4-6.

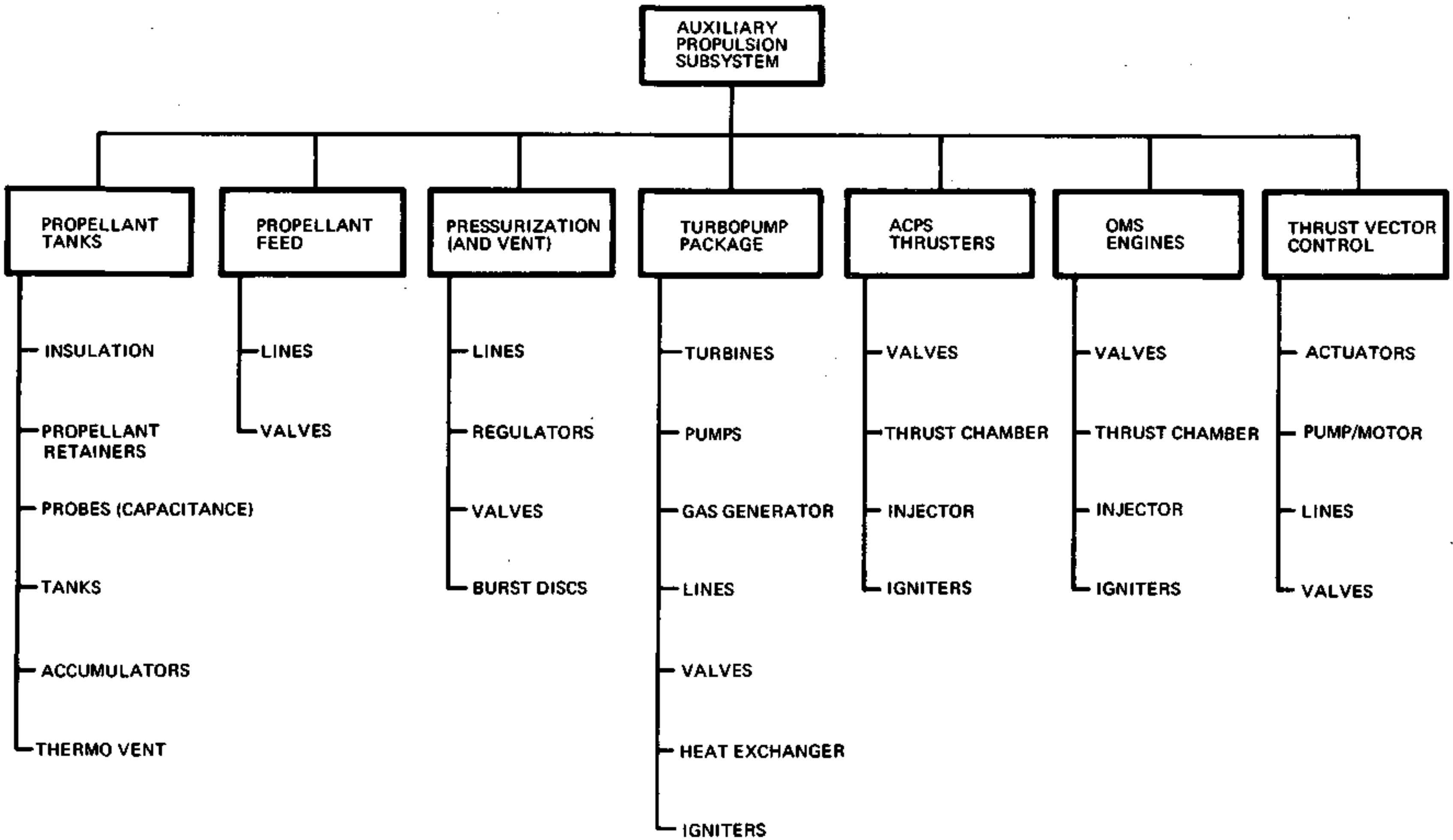


Figure 4-5. Auxiliary Propulsion Subsystem Elements

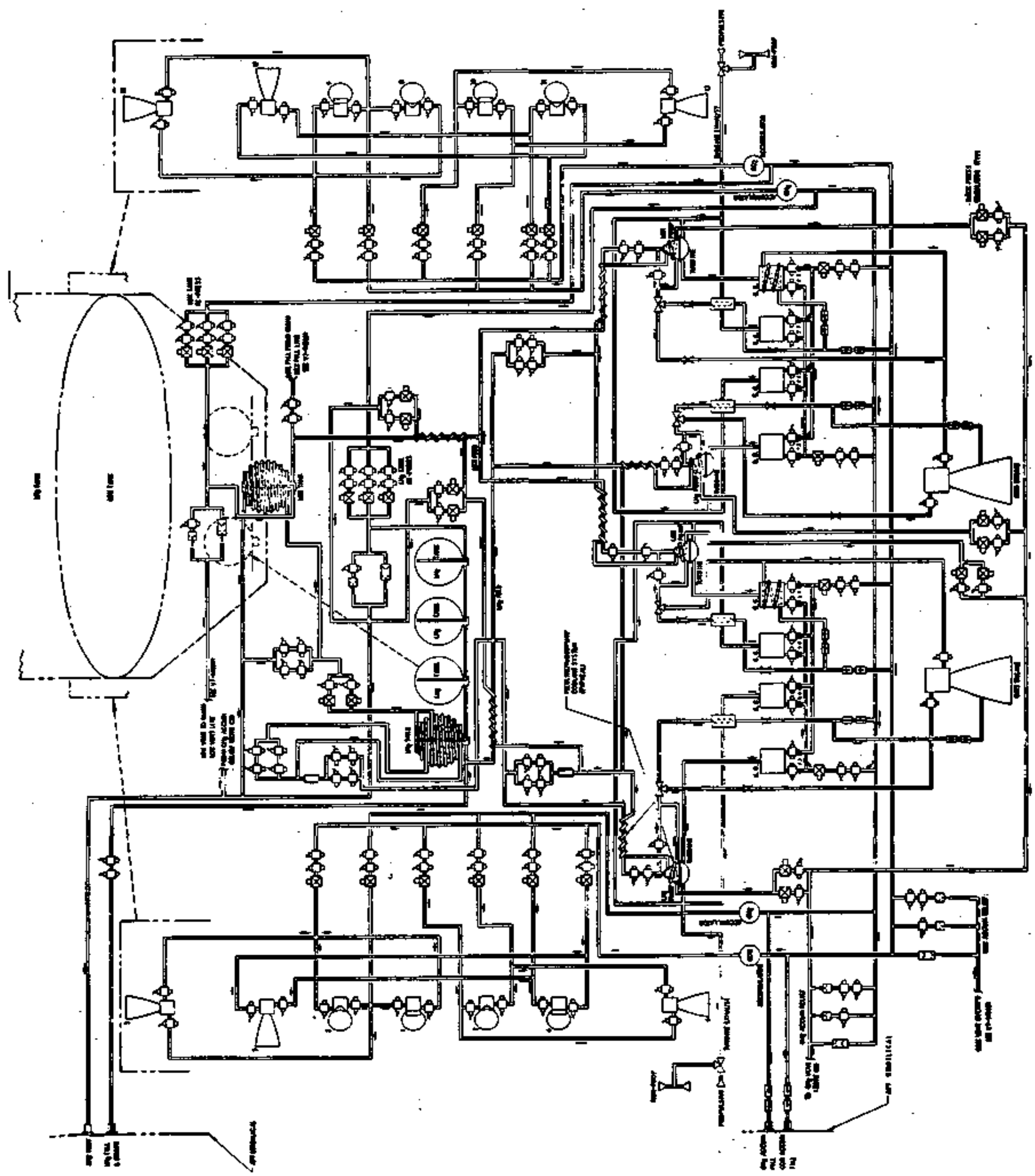


Figure 4-6. Auxiliary Propulsion Subsystem Schematic

Subsystem Test Requirements

The auxiliary propulsion subsystem test requirements are delineated in Table 4-4.

Approach and Rationale

The approach and rationale for the auxiliary propulsion subsystem development is shown by the APS test logic and constraint network (Figure 4-7).

The test approach is dictated by the shuttle program as the ESS will utilize the basic space shuttle components and assemblies. The ACPS thrusters, OMS thrust chambers, gas generators, valves, regulators, and heat exchangers will be developed in the shuttle program. The ESS APS will require some development as the line and tank configurations will differ from the shuttle. The propellant retention device will be developed in the shuttle program. The changes required to adapt the subsystem to ESS are not significant enough to preclude use of the space shuttle APS test facility for ESS testing.

Support Requirements

The support requirements for the APS certification are summarized in Section 8.0 of this document.

Support requirements will be listed for component development, acceptance, and qualification when components are selected and requirements established.

These requirements will be satisfied by the component manufacturer either at his facility or at a subcontracted laboratory. In-house component testing will be accomplished in existing contractor laboratory and test facilities with only minor fixture changes required. Most component development and qualification will be accomplished on the Space Shuttle Program.

Assembly testing will be accomplished on each hydraulic actuation system. The system is acceptance-tested on a breadboard setup with a simulated chamber mass. A test fixture will be required. Assembly testing of the turbopump and GG package will be accomplished by the manufacturer.

Subsystem testing of an integrated ESS APS will be accomplished during development testing. The test will be performed on the shuttle APS test article. Some modification of the shuttle test article will be required because of differences in the ESS and shuttle subsystems.

Table 4-4. Auxiliary Propulsion Subsystem Certification Requirements

No.	Requirement	Certification Category: Analysis (1)	Computer/Model (2)	Component (3)	Assembly (4)	Subsystem (5)	Comb. Subsystem (6)	Flight Vehicle (7)
	A. OPERATIONAL REQUIREMENTS							
1.	Verify component accessibility							X
2.	Verify ability of subsystem to operate	SS (P)				X	SS (P)	SS (P)
3.	Verify capability to withstand vibration and acoustic effects from main propulsion operation	X		SS (P)				SS (P)
4.	Verify capability to withstand base heating environment	X	X	SS (P)				SS (P)
5.	Verify ability to withstand space environment	X		SS (P)				SS (P)
6.	Verify ability to leak and functional test	X		SS (P)		X	SS (P)	SS (P)
7.	Verify capability to purge and inert	X		SS (P)		X	SS (P)	SS (P)
	B. PROPELLANT FEED AND TANK ASSEMBLY REQUIREMENTS							
1.	Verify absence of coupling effect with structure and pump (pogo)	X	SS (P)			X		
2.	Verify capability of propellant retention devices to maintain liquid at the pumps in zero g.	SS (P)			SS (P)			SS (P)
3.	Verify propellant tank structural capability to withstand flight environment	X		X				

NOTES

- X — To be accomplished on ESS program
- SS — To be accomplished on the space shuttle program
- SS(P) — To be partially accomplished on the space shuttle program

Table 4-4. Auxiliary Propulsion Subsystem Certification Requirements (Cont)

No.	Requirement	Certification Category						
		Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
4.	Verify ability to provide required conditions at pump inlets	X				X		X
5.	Verify ability to fill propellant tanks within 2-hour service time	X				X		X
6.	Verify ability to drain propellant tanks	X				X		X
7.	Verify capability to evacuate and monitor vacuum-jacketed lines			SS (P)		SS (P)		SS (P)
8.	Verify capability of thermo vent to vent only gas under zero g conditions	X		SS (P)		SS (P)		SS (P)
	C. PRESSURIZATION ASSEMBLY REQUIREMENTS							
1.	Verify ability to meet pump NPSH requirements	X	X			SS (P)		SS (P)
2.	Verify capability of vent system to maintain tank pressure	X		SS (P)		SS (P)		SS (P)
3.	Verify capability of prepressurization	X				X		X
4.	Verify ability to vent tanks	X	X			SS (P)		SS (P)
5.	Verify engine-out capability	X	X			SS (P)		
	D. THRUST VECTOR CONTROL ASSEMBLY							
1.	Verify ability to dry gimbal with sufficient clearance	X						X
2.	Verify engine alignment	X						X
3.	Verify capability to gimbal engines over rate and response range	X		SS (P)	SS (P)			SS (P)

Table 4-4. Auxiliary Propulsion Subsystem Certification Requirements (Cont)

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
	E. ENGINE REQUIREMENTS							
1.	Verify capability to deliver the rated thrust (10,000 pounds) at minimum Isp (451.4 seconds)	X			SS	SS (P)		
2.	Verify multiple start and duration capability	X			SS	SS (P)		
	F. THRUSTER REQUIREMENTS							
1.	Verify capability to deliver rated thrust (2,100 pounds) at minimum Isp (425 seconds)	X			SS	SS (P)		SS (P)
2.	Verify multiple start (pulse mode) capability	X			SS	SS (P)		SS (P)
3.	Verify capability to deliver minimum impulse bit (210 lb-sec)	X			SS	SS (P)		SS (P)

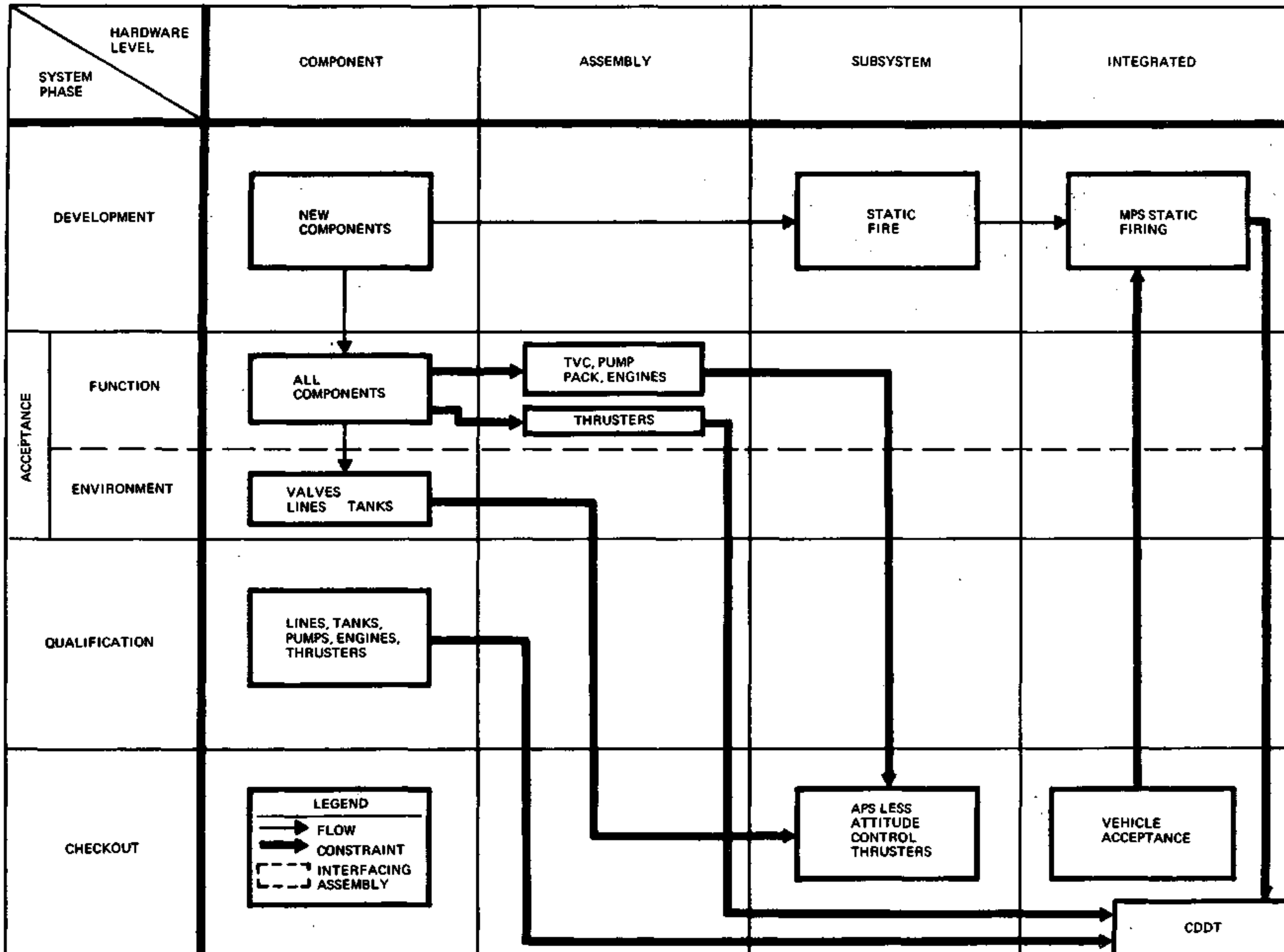


Figure 4-7. Auxiliary Propulsion Subsystem Test Logic and Constraint Network

5.1.3 Structures Subsystem

Description

The ESS structure consists of five major subassemblies: a forward skirt, an LH_2 tank, an LO_2 tank, an aft skirt, and a thrust structure (see (Figures 4-8 and 4-9).

The forward skirt structure is of skin-stringer-frame construction extending from ESS Station 719 to Station 856. The skirt structure includes a bolting flange and mating face at Station 856 for attachment to the payloads. A support structure is provided at Station 828 for attachment to the booster separation system. The skirt is subjected to aerodynamic and inertia loads as well as internal cavity differential pressure loads. The forward attach point reacts the radial load applied by the aerodynamic and inertia loads.

The LH_2 tank consists of a cylindrical wall extending from Station 297 to Station 723 and a forward bulkhead extending from Station 723 to Station 856. The tank wall incorporates integral stiffening members in both the longitudinal and circumferential directions to react the aerodynamic and inertia loads applied from the payload (see Figure 4-10). The entire tank wall is composed of five cylindrical sections joined by circumferential fusion welds. Each cylinder section is made up of four equal panels joined by vertical fusion welds. Two fuel feed outlets are provided in the second cylinder. The forward bulkhead is fabricated of 12 equal gore segments with a 36-inch access door located in the center. It is joined to the tank wall by a circumferential fusion weld. Skin gauges for both the tank wall and bulkhead are determined from the internal tank pressure.

The LO_2 tank is essentially a shell of revolution composed of a forward bulkhead assembly common to the LH_2 tank and an aft bulkhead (see Figure 4-11). The common bulkhead is an adhesive-bonded sandwich assembly employing facing sheets and fiberglass/phenolic honeycomb core. The forward facing sheet terminates in the J-ring section welded to the LH_2 tank wall. Waffle-stiffened gore sections are used in the aft facing to provide shell stability under collapse pressures. In addition to the collapse pressure, the common bulkhead is designed to withstand the LO_2 tank burst pressure. The aft LO_2 bulkhead is made up of 12 waffle stiffened gore segments, a dollar closeout, and the sump. An access door is provided in one of the gore panels above the dollar section. The door, approximately 23 inches in diameter, is attached by bolts to an integral land provided in the gore panel. The bulkhead must withstand the inertia head pressure variations generated during the boost and burn phase.

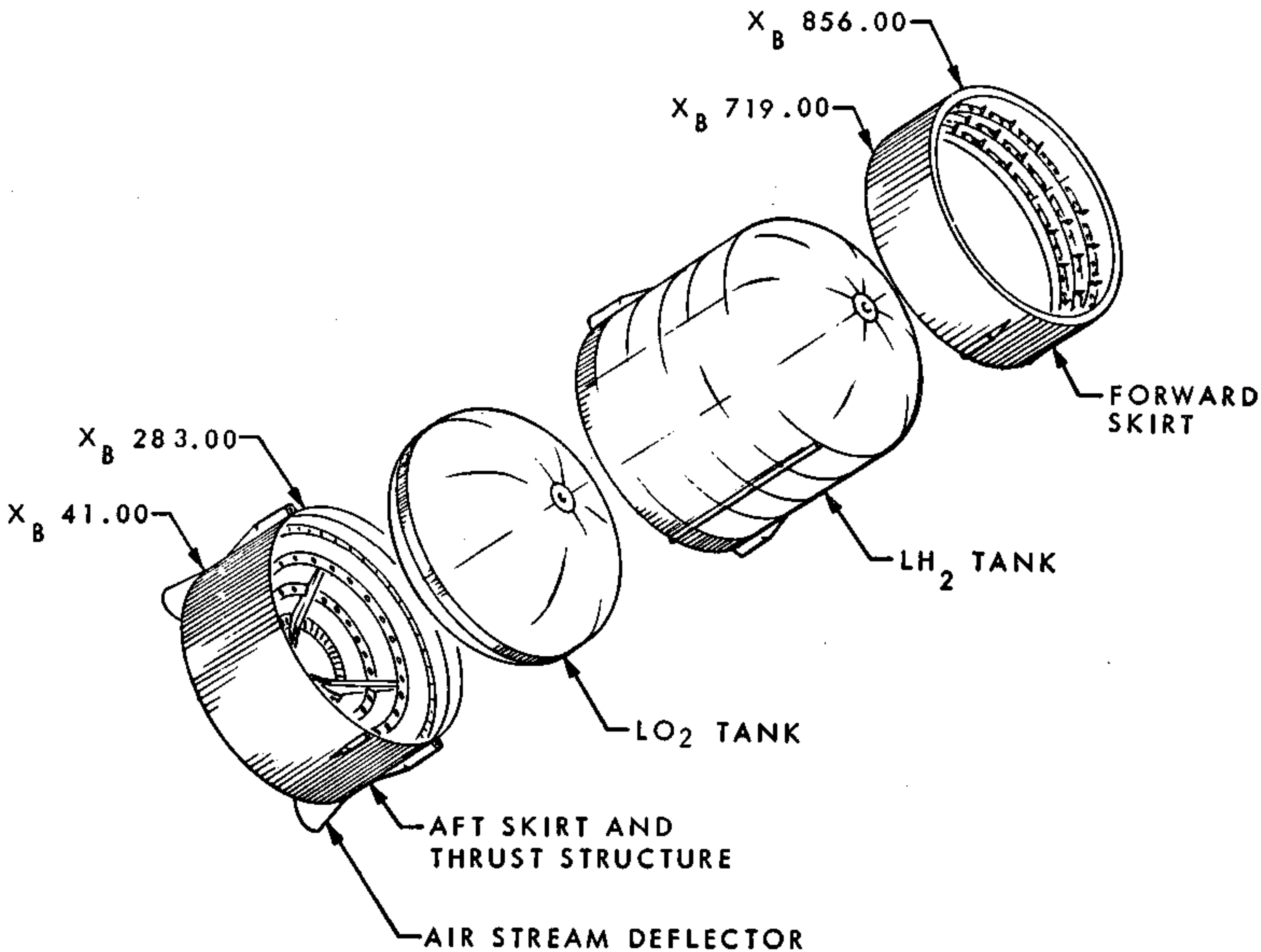


Figure 4-8. ESS Structural Configuration

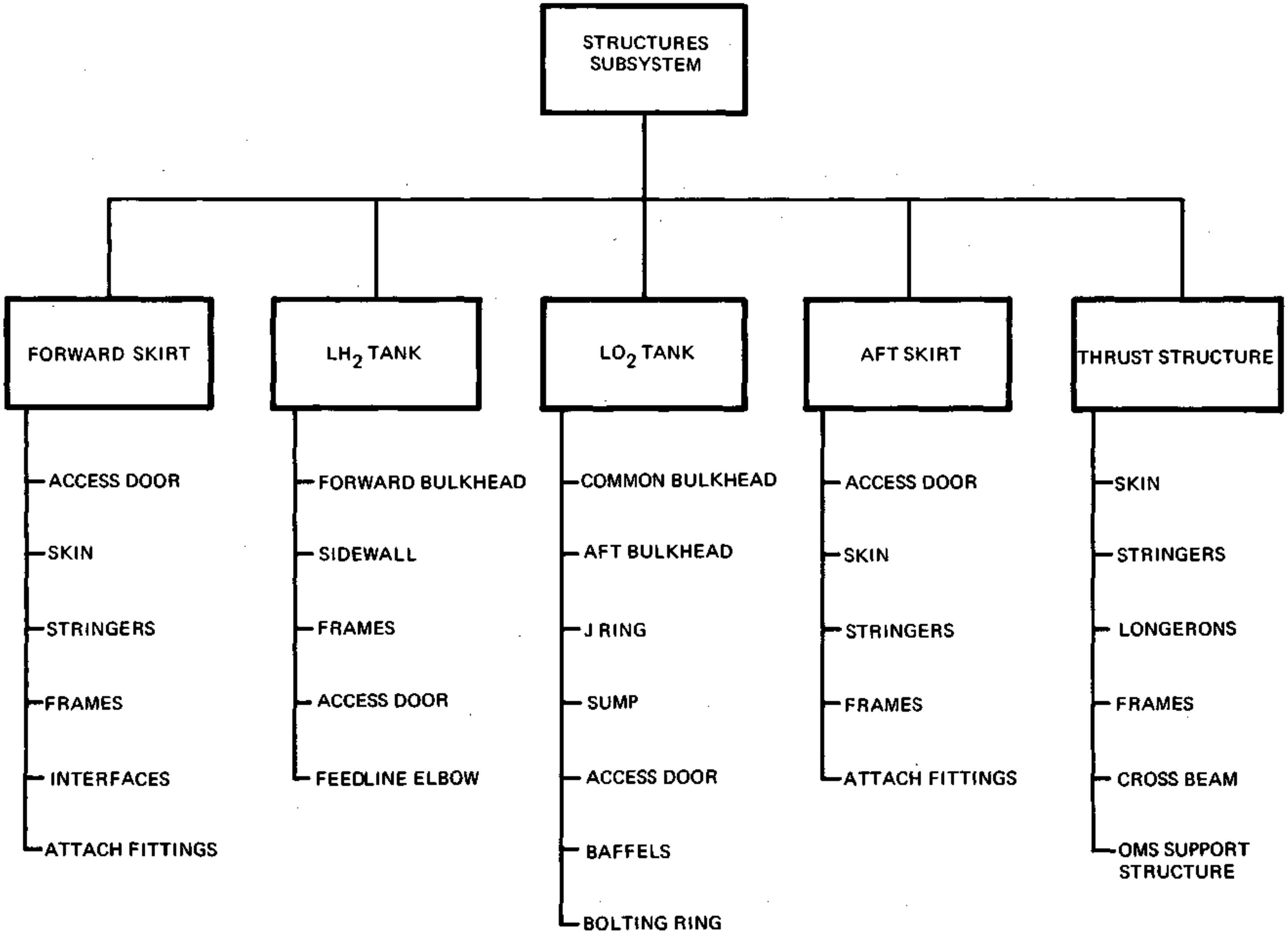


Figure 4-9. *Structure Subsystem*

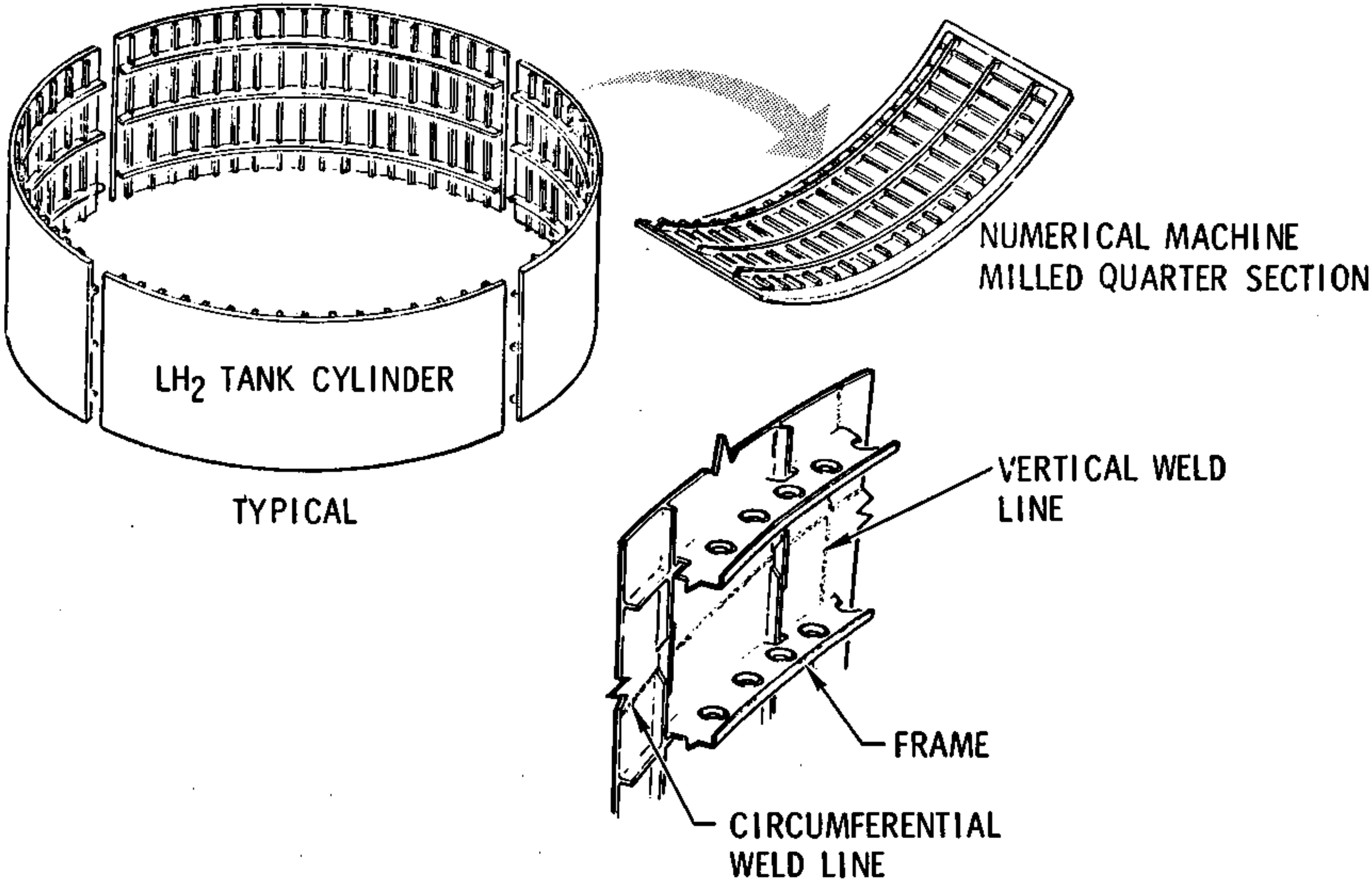


Figure 4-10. LH_2 Tank Structure

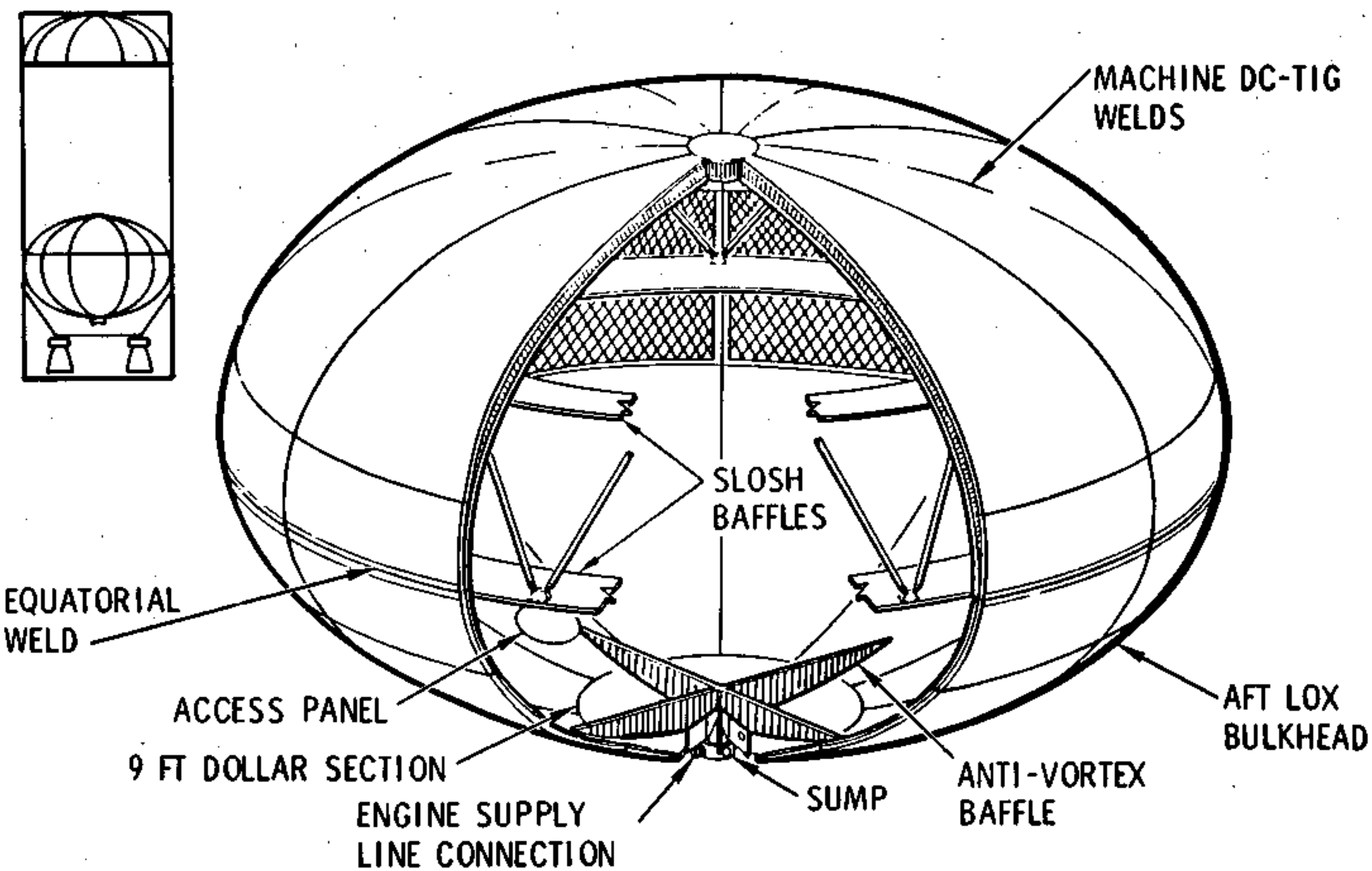


Figure 4-11. LO_2 Tank Structure

The aft skirt is a conventional semi-monocoque shell structure extending from Station 41 to Station 283. The aft skirt structure attaches to the bolting ring at Station 283. The conical thrust structure assembly is joined to the aft skirt at Station 174.5. Two air stream deflectors are attached to the aft skirt at Station 41 and extend aft to Station -30. The skirt structure must transmit the vehicle aerodynamic and inertia loads to two fittings extending aft from Station 174.5 to Station 28.

The ESS thrust structure is a semi-monocoque shell assembly in the form of a conical frustum extending from Station 44 to Station 174.5 (see Figure 4-12). The primary function of this assembly is to support the two shuttle orbiter engines and their associated systems. The conical shell also serves to support the five APS propellant tanks and the OMS engines. The thrust structure is required to accept the loads associated with thrust from the two main engines including thrust vector control. The structure is designed to withstand the loads resulting from full deflection of the engine at emergency power levels and with one engine out.

Requirements

The structural integrity of the primary structure will be established by analysis and verified by tests under a number of selected critical load conditions. The static test verification requirements will include all of the requirements listed in Table 4-5.

Structural dynamic testing involves elements of the structure, flight control, and propulsion systems. The test specimens range from scaled models to the complete vehicle. The test configuration definition is dependent upon the specific objectives to be satisfied.

Approach and Rationale

The structural and dynamic testing program is arranged to provide timely information and the support required for each phase of the design, fabrication, and analysis effort from material selection, manufacturing process optimization, to final structural design verification and end product acceptance. The structural and dynamic testing program will include the following: material and process testing, structural development testing, and acceptance, and qualification testing as depicted in Figure 4-13.

Material and process testing will be performed as required to evaluate, characterize, select, and substantiate the selection of materials; and evaluate, characterize, select, and substantiate the processing of materials for use in

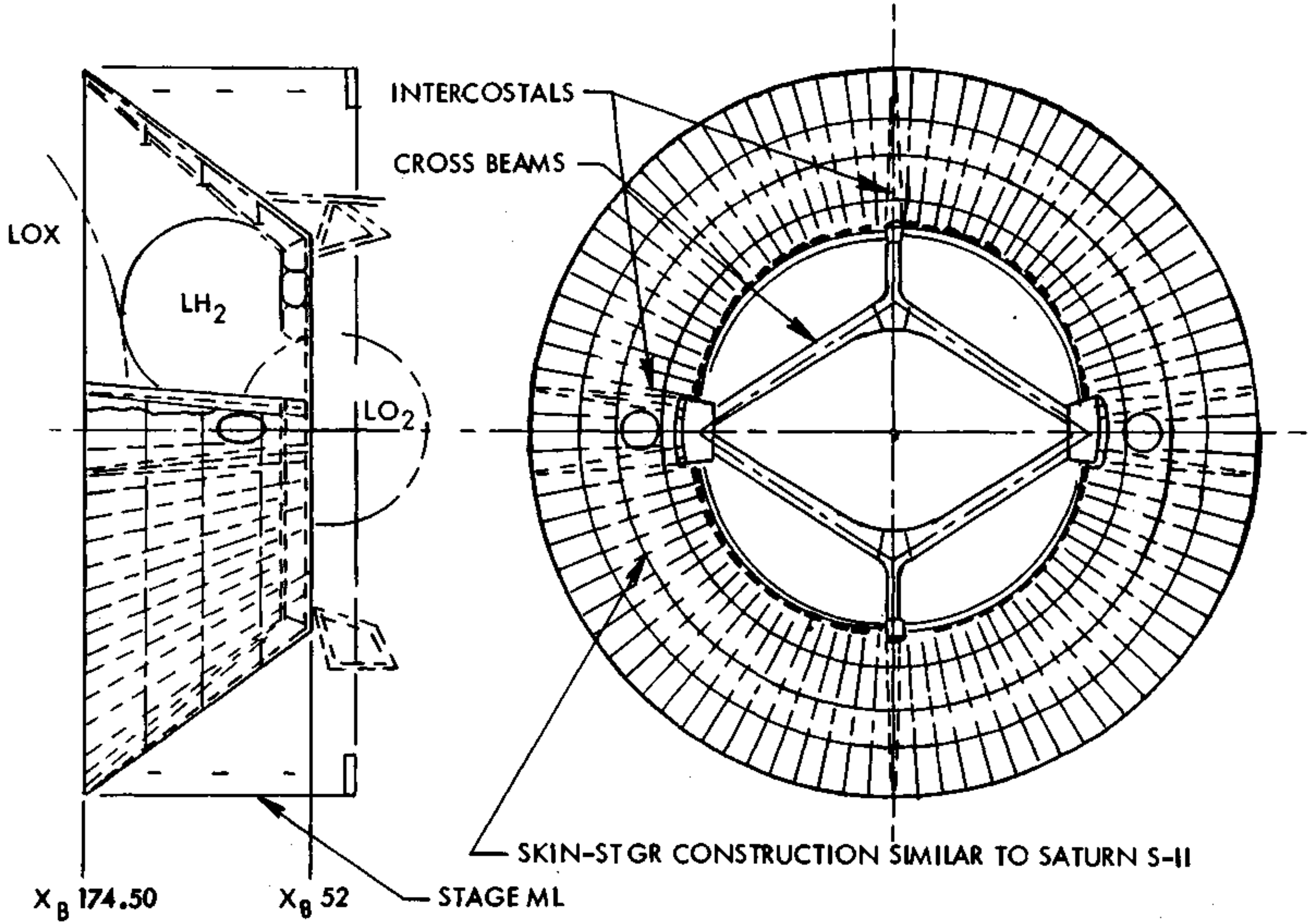


Figure 4-12. ESS Thrust Cone Structure

Table 4-5. Structural Subsystem Certification Requirements

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
	A. GENERAL TEST REQUIREMENTS							
1.	Ability of the structure to sustain design (limit) loads with no detrimental deformation	X	X					X
2.	Ability of the pressure vessel structure to sustain 1.10 X design loads without yielding (0.2 percent offset)	X	X			X		
3.	Ability of the structure to sustain ultimate loads (design loads X F.S.) without rupture or collapse	X	X			X		
4.	For structures which depend on non-destruction inspection for safe-life assurance, verify that the inspection techniques are adequate to detect critical defects				SII	SII		
5.	Ability of the structure to withstand dynamic effects without impairing structural or functional adequacy	X	X				X	
6.	Functional adequacy of all mechanical component support structure after complete life spectrum load history	X	X			X		
7.	Extensional, shear, rotational, and bending stiffness of entire body structure	X	X					X
8.	Items 1 through 7 are to be verified under true or simulated environmental effects, where applicable (cryogenic or heat)							X
	B. FORWARD SKIRT REQUIREMENTS							
1.	Structural integrity and spring constants of the forward attach fittings and local support structure	X	X			X		

NOTES

X — To be accomplished by ESS program

SII — Accomplished on S-II program

Table 4-5. Structural Subsystem Certification Requirements (Cont)

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
2.	Structural integrity of the forward skirt/payload interface		X	X		X		
3.	Structural integrity of the forward skirt under internal skirt pressure, internal tank pressure, inertial loads, and thermal environment	X	X			X		
4.	Structural integrity of the skirt/tank joint under critical aerodynamic inertial and pressure loads	X	X	X		X		
	C. LH_2 TANK REQUIREMENTS							
1.	Structural integrity of the LH_2 tank with forward skirt under critical aerodynamic, inertial, TPS, and internal pressure	X	X				X	
2.	Ability of the LH_2 tank to withstand maximum design internal pressure after sustaining complete life spectrum loading	SII					SII	
3.	Structural integrity of the feedline elbows under critical internal pressures	X					X	
4.	Ability of the LH_2 tank to withstand proof pressure							SII
5.	Structural integrity of the LH_2 tank with LO_2 tank and aft skirt under critical aerodynamic, inertial, and other pressures	X	X				X	
	D. LO_2 TANK REQUIREMENTS							
1.	Structural integrity of the LO_2 tank with the LH_2 tank and aft skirt under critical aerodynamic, inertial, and internal pressure	X	X				X	
2.	Structural integrity of the sump under critical internal pressure	X		X				
3.	Ability of the LO_2 tank to withstand design internal pressure after sustaining complete life spectrum loading	SII					SII	
4.	Ability of the LO_2 tank to withstand proof pressure							SII
5.	Structural integrity of the common bulkhead under critical burst and collapse pressure	SII					SII	

Table 4-5. Structural Subsystem Certification Requirements (Cont)

No.	Requirement	Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
	E. AFT SKIRT REQUIREMENTS							
1.	Structural integrity and spring constants of the aft attach fittings and local attach structure	X	X				X	
2.	Structural integrity of the aft skirt under critical aerodynamic inertial and thermal environment	X	X				X	
3.	Structural integrity of the aft skirt with the thrust structure under critical engine loadings and thermal environment	X	X				X	
4.	Structural integrity and spring constants of the aft skirt/docking adapter structure	X	X				X	
	F. THRUST STRUCTURE REQUIREMENTS							
1.	Structural integrity and spring constants under critical engine thrust loads and thermal environment	X	X				X	
2.	Structural integrity and spring constants of OMS engine support structure	X					X	

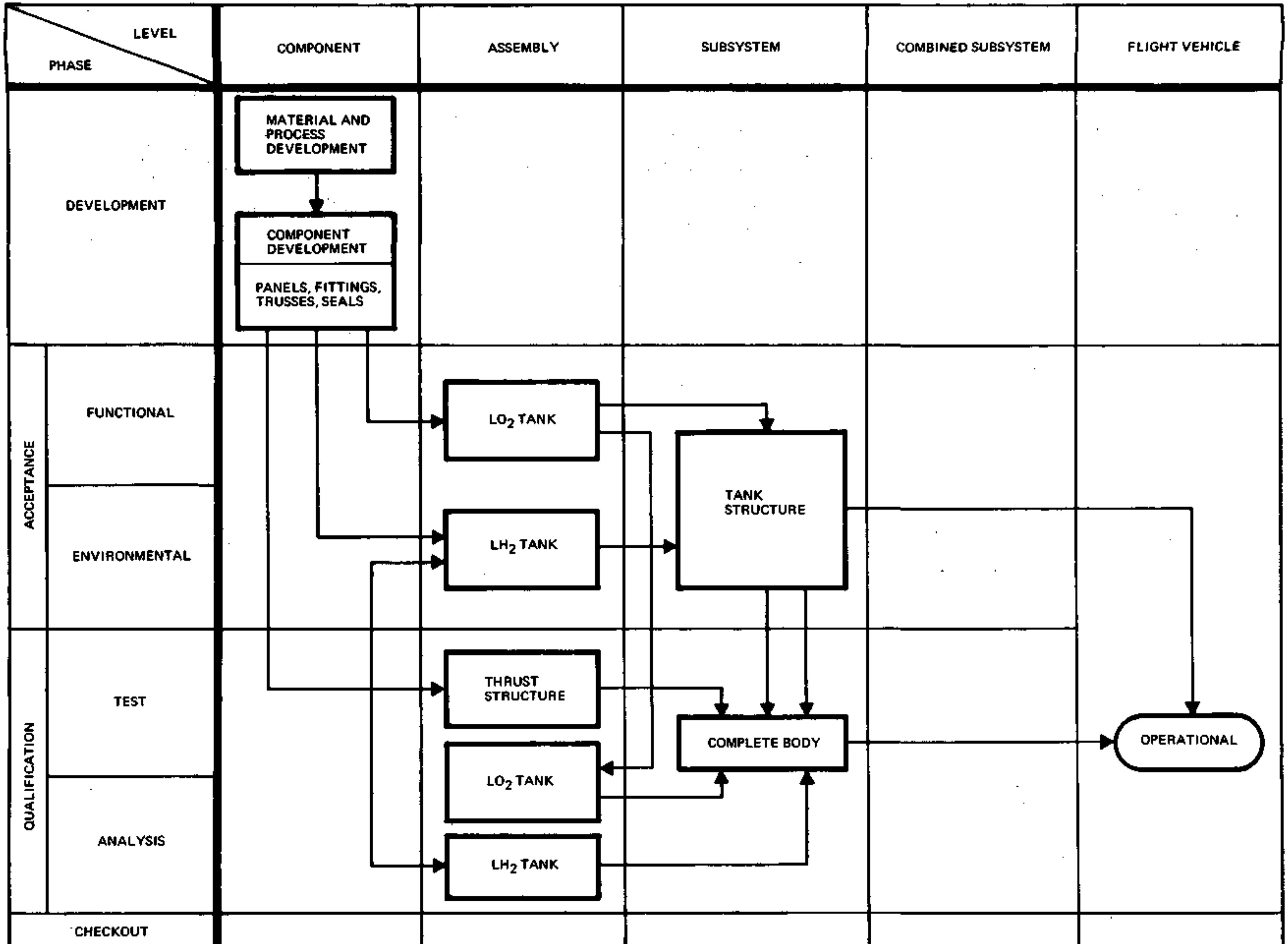


Figure 4-13. Structures Test Logic and Constraint Network

the structural subsystem. Areas to be investigated (applicable to this subsystem) include the following:

1. The ability of seals, sealants, lubricants, and grease materials to function under mission requirements for temperature, pressure, loads, and exposure time

2. The flammability, toxicity, smokability, and outgassing characteristics of candidate materials

3. Performance of thermal control coatings under boost exposure

4. Compatibility of materials in contact with each other in environments which may result in degradation in properties

5. Effects on structure system of corrosion with regard to useful life of candidate materials

6. Optimization of special welding techniques verified by mechanical and non-destructive tests

7. Fabrication techniques for producing extremely large, integrally reinforced and contoured tank panels and contoured J rings

8. Fracture mechanics design data to predict the critical flaw size and flaw growth under sustained and cyclic loading for structural materials

9. Physical and mechanical properties of ESS materials which have not been previously established

10. Joining methods for candidate alloys for ESS structural and thermal requirements

11. Development, design, fabrication, and verification of an external insulation for the ESS thermal protection system

12. Demonstration of thermal performance, structural integrity, and materials compatibility of orbit maneuvering cryogenic tankage insulation.

Structural development testing will be performed to provide test data on critical or difficult to analyze areas early in the program. This will provide knowledge of internal load distribution in configuration complexity, load path redundancy, or high load dissipation. This early testing will aid in minimizing weight and reduce the risk of premature failure of the major structural test articles. Major development test areas include:

1. Booster attach fittings and load diffusion structure

2. Heat shield/flex curtain attachment to support structure.

Acceptance testing, primarily of the pressurized structure, is designed to demonstrate the flight worthiness of each delivered article. By pressurizing the structure sufficiently in excess of the maximum limit (or operational) design pressure, the successful completion of the test and subsequent non-destructive inspection will give the required high confidence in the capability of the structure to undergo the required life spectrum loading without compromise to mission requirements.

Acceptance testing will include the following:

1. LH_2 tank acceptance testing will consist of bulkhead and feedline elbow hydrostatic proof testing plus pneumastatic proof testing of the vehicle prior to systems installation. Tests will be conducted at room temperature with pressures adjusted for material property differences between test and operational temperatures.

2. LO_2 tank acceptance testing will consist of hydrostatic proof tests of the aft bulkhead and aft facing sheet of the common bulkhead plus pneumastatic proof tests of the complete tank assembled with the vehicle. The forward facing sheet of the common bulkhead will be subjected to low pressure helium leak tests. The common bulkhead acceptance tests also will include a vacuum decay test prior to mating with the aft bulkhead, burst and collapse proof tests during the full-stage pneumastatic test, and a helium purge check.

3. The completed stage acceptance tests will consist of circumferential rotation tests to detect loose particles that may remain after final assembly. Acceptance test requirements are summarized in Table 4-6.

Qualification testing will demonstrate the vehicle structural integrity and compliance with design criteria by testing under the most critical load and environmental conditions. Safe-life capability of the LH_2 and LO_2 tanks will be certified by subjecting the structure to pressure-cycling before ultimate load application.

The sequence of testing and the selection of test article configuration is designed to gain the most critical information as soon as possible while attempting to minimize program risk and testing costs. Maximization of S-II

Table 4-6. Structural Subsystem Acceptance Checkout Requirements

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
1.	LH_2 tank forward bulkhead hydrostatic proof tests			X				
2.	LH_2 feedline elbow hydrostatic proof tests			X				
3.	LH_2 tank pneumastatic proof tests						X	
4.	LO_2 tank aft bulkhead hydrostatic tests			X				
5.	Common bulkhead aft facing sheet hydrostatic proof tests			X				
6.	LO_2 tank pneumastatic proof tests (burst and collapse common bulkhead)						X	
7.	Common bulkhead forward facing sheet helium leak tests				X			
8.	Common bulkhead/J ring helium purge check						X	
9.	Complete vehicle circumferential rotation tests							X

experience and data accumulated on the S-II full scale, common bulkhead test tank (CBTT), and the mini-articles greatly decreases the structural testing and test article requirements. The most significant decrease in testing results from the use of LH_2 rather than LN_2 in the LH_2 tank during the initial cryogenic tests.

It is highly desirable that the major vehicle structure be tested in the vertical position to facilitate simulation of propellant acceleration forces. The test article must be suspended from the booster attach fittings to maintain structural continuity and duplicate flight hardware load diffusion characteristics in these highly loaded regions. A segment of the payload aft skirt structure or the tug transition cone must be attached to the forward skirt to duplicate the internal load distribution. The resulting configuration is a test article that is more than 75 feet in height.

The thrust structure assembly will be tested with the aft skirt to reduce test complexity and minimize catastrophic failure potential.

The following list defines the test articles and testing required for qualification:

1. Forward skirt, tank structure, and aft skirt sections contained in Article A (see Table 4-6 and Figure 4-14). This test will be conducted in the vertical position supported at the booster attach fittings. The LH_2 tank will be filled with LH_2 and the LO_2 tank filled with LN_2 to duplicate operational temperatures. Forward and aft skirt temperatures will be duplicated with bonded strip heaters or heat lamps. Influence coefficient tests will provide verification of analytical stiffness matrices for the ESS body structure and booster attach fittings. The body structure will be loaded to limit load followed by an ultimate load test for all critical load conditions. Ultimate pressure tests of the LH_2 and LO_2 tank will not be required because of verification on the S-II Program.

2. Thrust structure, aft skirt, and OMS engine support are contained in Article B (see Table 4-6 and Figure 4-15). Testing on this specimen may be conducted in either the vertical upright position or inverted, depending on test facility selection. In addition to the verification of structural integrity, the objectives of this test are (1) determine the stress and deflection influences of individual engine and actuator loads, (2) determine required precant angle of the orbiter engines caused by structural deflections, (3) verify the analytical methods used to predict stress levels and deflections, and (4) determine the effect of load peaking at the structural interfaces.

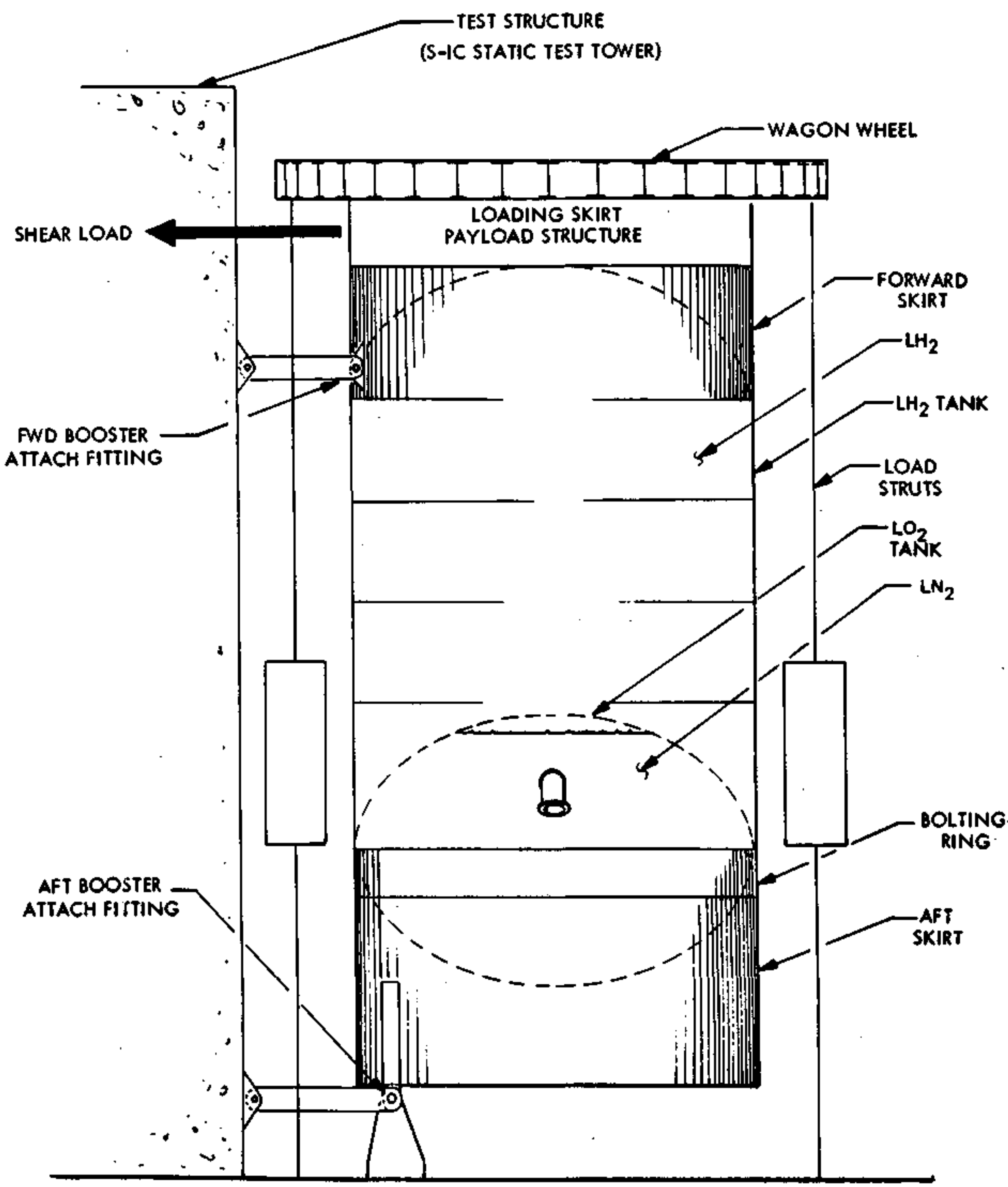
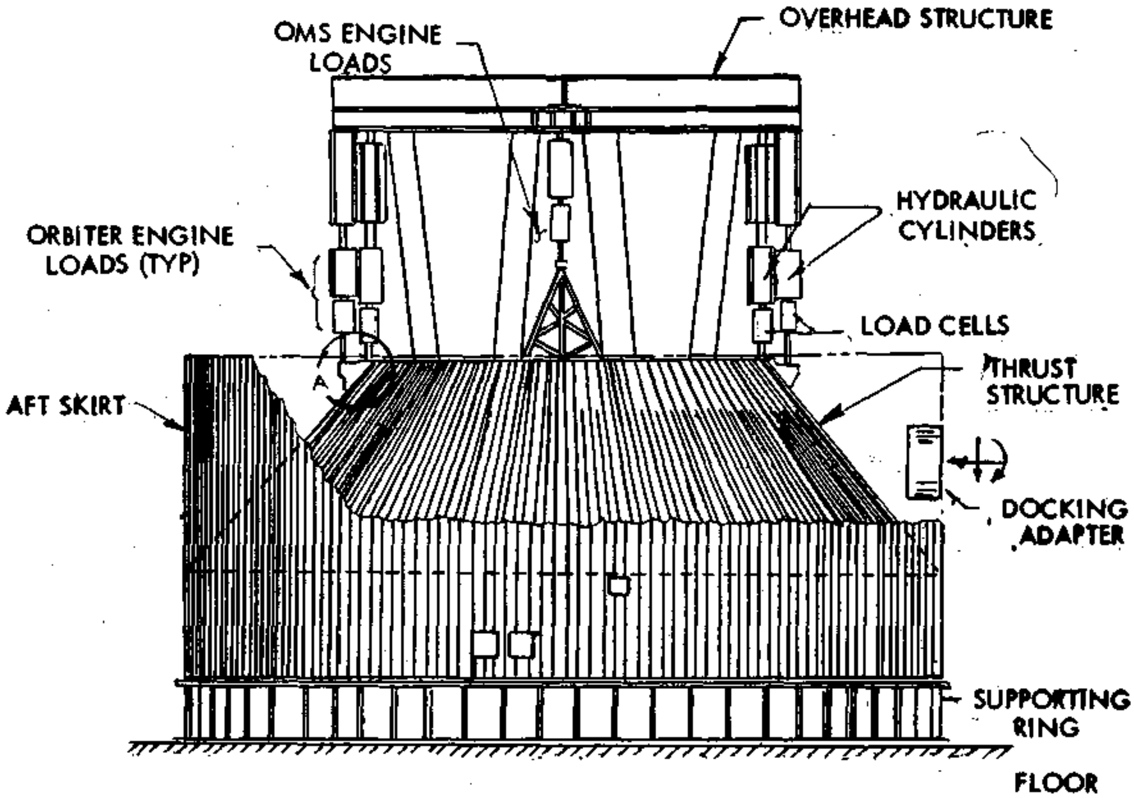
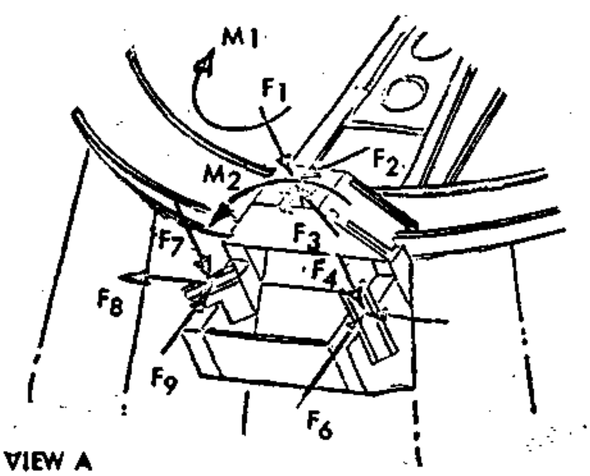


Figure 4-14. Static Test Setup





VIEW A
ORBITER ENGINE
AND ACTUATION
LOAD APPLICATION

Figure 4-15. Thrust Structure Test Setup

It will be required to duplicate the operational thermal environment during the ultimate test conditions. Testing will be conducted in three phases: influence, limit load, and ultimate load. During the influence phase testing, tests will be conducted to determine engine attach and actuator attach influence coefficients and the thermal stresses generated by the operational environment. The next phase will apply all of the test load conditions to limit load. The final phase will see selected critical load conditions taken to the ultimate level with the thermal environment. Additionally, critical components or attach fittings such as the APS tank supports or OMS engine attachments will be tested on this specimen.

Structural dynamic tests are performed to satisfy several objectives, i. e., provide design environments, provide data for analytical modeling, confirm results of analytical studies, confirm structural and functional integrity, and verify that no adverse coupling exists between the structure/ flight control/propulsion systems which could impair structural integrity or performance. The ESS structural dynamic test requirements are intended to maximize the use of information gained on the Saturn S-II program and that which will be generated as a part of the space shuttle program. The following discussion categorizes the various elements required to adequately define the structural dynamic behavior of the ESS, and the means that will be employed to acquire the definition.

Structural Modes

The structural modes of vibration are required for the formulation of vehicle body loads, component and component support design, and determination of pogo susceptibility. Since the pogo phenomenon is a coupling of the structure and propulsion systems, it is necessary to define the feedline and engine dynamics.

The resolution of the Saturn S-II pogo problem resulted in a high degree of confidence in the ability to construct a mathematical model of the structure so that representative structural modes of vibration are obtained. This was achieved by representing the dry structure by a series of springs and masses; finite element modeling was used for the thrust structure and the bulkheads were represented as an axisymmetric hydroelastic model. The characteristics of the overall model were verified by static firings, special ground tests involving LO_2 tank dynamic behavior, and flight results.

For ESS design, it is planned to utilize the analytical modeling techniques developed on the S-II program to define the modes of the booster and ESS. The dynamic characteristics of the attached system will be analytically determined and the coupled ESS/booster modes of vibration will be determined by component mode synthesis. It is not planned to conduct any special verification tests which are solely ESS oriented; rather, it is planned to extrapolate from the model and full scale tests to be conducted as a part of the regular space shuttle program. Modes generated in this fashion will be used to determine vehicle loads for prelaunch, launch release, rebound, boost, separation, and ESS boost.

Pogo

The study of the pogo phenomenon will be limited to the ESS MPS burn period. The modeling of the structure will be accomplished as previously outlined. It is planned to use the stiffness characteristics obtained from the static tests of the modified ESS thrust structure to partially verify the modeling used for that structure. The LO_2 feedline dynamics will be determined by analysis using finite element techniques. The engine transfer function and pump termination impedance will be considered the responsibility of the engine contractor to be furnished by NASA. This technique, when coupled with the knowledge gained on the S-II program, is considered adequate for defining ESS pogo susceptibility. The static firings will be used to verify, in part, the structure/feedline/engine interaction. This will require adequate low-frequency, close-coupled instrumentation. Therefore, no special tests related to ESS pogo are planned other than those required by the engine contractor to define the engine transfer function and pump termination impedance.

Component Support

Initial component design and associated support structure will be based on analytical models. The complexity of the model, e.g., simple spring mass system or finite element techniques, will be dependent upon the type of structure involved. The adequacy of design will be verified by qualification testing of those components designated as Criticality I. The nature of these tests will be dependent upon the component; however, test specimen size could range from the component level to the thrust structure with the massive APS tanks attached. The latter will be similar to the high force test program, with the test verifying structural integrity in the low-frequency regime. For those components which are carryovers from the S-II program, it is planned to limit any retest to those items for which a change in environment can possibly impair the original qualification status of the item.

Acoustic and Vibration Environmental Definition

The structural response caused by rocket engine noise, boundary layer noise, and interference effects will initially be determined by extrapolation techniques utilizing data from prior programs. It is planned to use clustered engine firings, static firings, and flight data which are generated as a part of the space shuttle program to verify the predicted rocket engine noise level for the ESS. The aerodynamic boundary layer noise will be determined by extrapolation from previous programs with the wind tunnel tests and flight program of the space shuttle program and ESS program as a basis for verification. The interference effects introduced by the proximity of the two bodies will initially be determined by analytical and extrapolation techniques. The wind tunnel tests, a part of the space shuttle program, will provide the basis for modifying the predicted environment. The structural response to the several sources of noise excitation will initially be determined by analytical and extrapolation techniques.

The knowledge gained on the S-II program and the tests planned for the space shuttle program are considered sufficient to obtain a definition of the ESS noise environment; therefore, no special tests unique to the ESS are planned for this purpose.

Structural dynamic test requirements are listed in Table 4-7. The requirements are based on the assumption that considerable information can be extracted from the space shuttle program and be applied to the ESS program, therefore eliminating dual test requirements.

Test hardware requirements are summarized in Table 4-8 and test support requirements are listed in Table 4-9.

Table 4-7. Structural Subsystem Dynamic Certification Requirements

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
	A. STRUCTURAL DYNAMIC TESTS							
1.	Structural modes	X SII(P)	X SII(P)	X			X(P) SS(P)	X(P) SS(P)
2.	Feedline dynamics	X	X			SS(P)	X(P)	X(P)
3.	Engine transfer functions	GF				GF(EF)	X(P)	X(P)
4.	Vibration and acoustic environment	X SII(P)	X SII(P)	SS(P)		X(P) SS(P)	X(P) SS(P)	X(P) SS(P)
5.	Component and component support design	X SII(P)	X SII(P)				X(P)	X(P)

NOTES

X	To be accomplished on ESS program
X(P)	To be partially accomplished on ESS program
SII	Accomplished on S-II program
SII(P)	Partially accomplished on S-II program
SS	To be accomplished on space shuttle program
SS(P)	To be partially accomplished on space shuttle program
GF	Government furnished
GF(EF)	Government furnished engine firing data

Table 4-8. Test Hardware Requirements Structural Subsystem

No.	Test Article Description	Quantity
A	Forward skirt, LH_2 tank, LO_2 tank, aft skirt, and approximately six feet of payload skirt structure	1
B	Aft skirt, thrust structure and OMS support structure, docking adapter structure, OMS tanks or dummy representation may be mounted to the thrust structure for dynamic tests	1
C	Required support bracketry for above specimens TBD, dependent upon qualification program test requirements	

Table 4-9. Requirements Structural Tests

Facilities

- Structural test laboratory
- LH_2 test stand for body structure
- LN_2 storage/transfer equipment
- LH_2 storage/transfer equipment
- Helium storage/transfer equipment
- Electrical power - 60 Hz, 3 Ø, 120 v, 440 v, 28 vdc
- Materials laboratory
- Vibration facility - up to 400,000 force capability
- Hydraulic power supply
- Acoustic test facility - 75,000 to 100,000 cubic-foot chamber

Support Equipment

- Miscellaneous load application devices (for various size, shape specimens - tension, torsion, compression)
- Miscellaneous environmental test equipment
- Heat application devices
- Load, strain, temperature, vibration, microphone measuring/recording systems
- Data acquisition systems
- Capability for computer-controlled test and data acquisition

Software

- Programs to implement data acquisition, processing, recording, data evaluation

5.1.4 Insulation

Description

The ESS insulation system consists of spray foam or other fragile insulation material, a shingled aero-shear barrier, and ablative coatings.

Spray foam is applied over the entire LH_2 tank sidewall and forward LH_2 bulkhead to maintain minimum heat leak for the cryogens during ground hold and launch. Protection of the spray foam on the LH_2 tank sidewall is provided by aero-shear barriers. These aero-shear barriers are approximately 5 feet by 5 feet square honeycomb panels with polyimide facing sheets (Figure 4-16). The panels are sized to allow reasonable gapping at the edges (about 0.5 inch) and shiplapped for a smooth outer surface. The barrier panels are bolted through the spray foam into local hard spots on the tank sidewall.

Local hot-spot protection is provided by an ablative coating in the critical regions.

Requirements

The integrity of the spray-on foam insulation (SOFI) thermal protection system will be established by analysis; however, precise acoustic, flutter, and shock wave analysis are presently beyond the analysis state-of-the-art and will require confirmation by testing. The test verification requirements will include all of the items listed in Table 4-10.

Approach and Rationale

The approach to the development program is to perform influence coefficient development testing on a full scale 66-inch panel to determine edge fixity effects of single-point panel attachments. These data are then used to modify the flutter computer program which is in turn used to analytically size the panel mounting bolt pattern to meet flutter requirements. From processing and materials properties monostrain data, the panel is analytically sized to withstand altitude pressure bleed-off and mechanical vibration loads at elevated temperatures. Tests will then be performed to determine optimum processing; and four full-scale panels will be fabricated for tests. The panels will be subjected to mechanical vibration, pressure bleed-off loads, acoustic excitation, transonic wind-tunnel flutter and shock tests and environmental exposure. The successful completion of these tests will verify the panel design. Figure 4-17 represents the insulation test logic and constraint network.

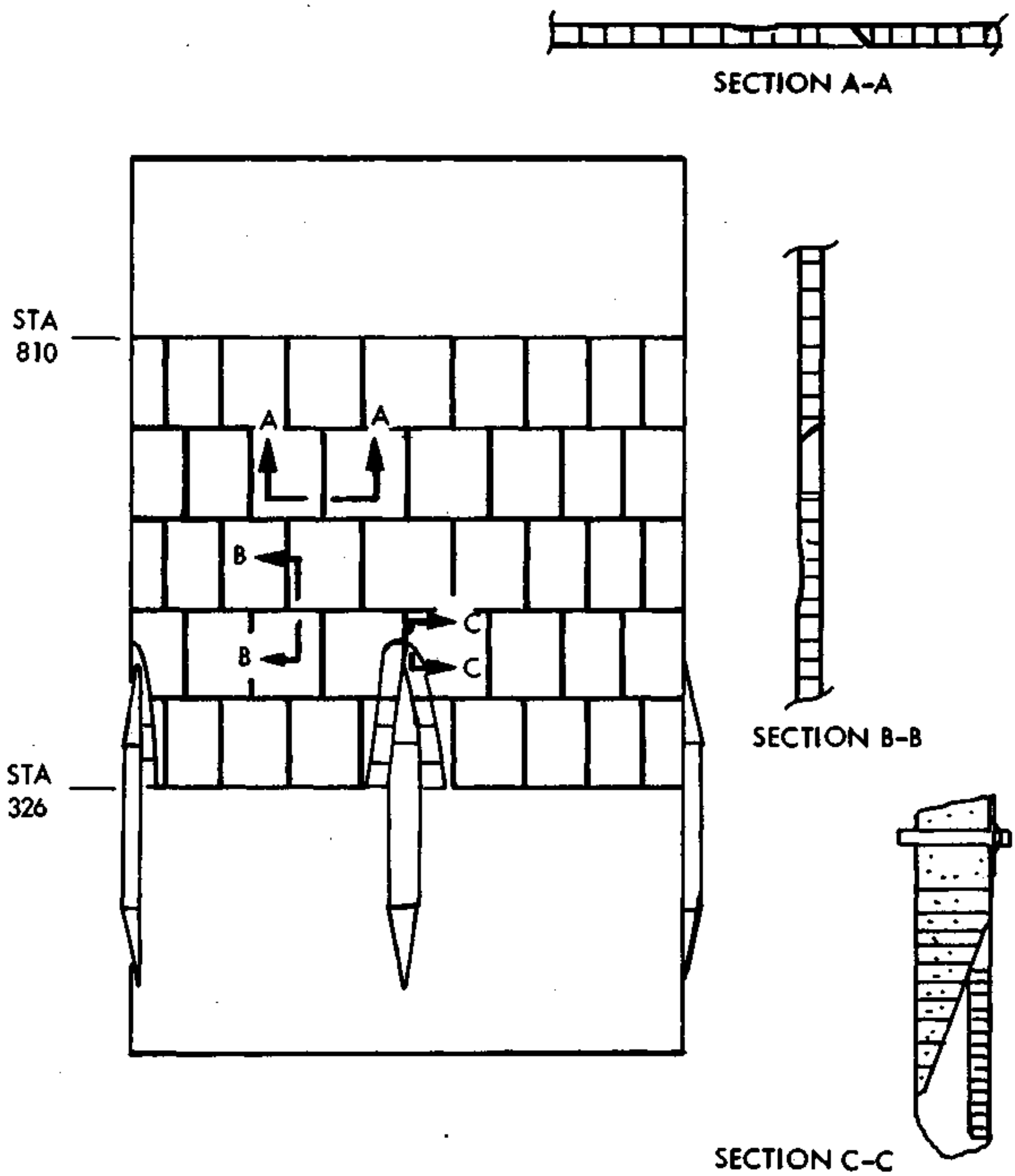


Figure 4-16. Insulation Erosion Barrier Installation

Table 4-10. Insulation Subsystem Certification Requirements

No.	Requirement	Certification Category: Analysis 1	Computer 2	Computer Test 3	Acoustic Test 4	Wind Tunnel 5	Vibration Test 6	Weatherometer 7	Pressure Test 8
1.	Ability to withstand internal burst pressure due to altitude change	X		X					X
2.	Ability to withstand aerodynamic erosion during earth to orbit launch			X		X			
3.	Ability not to flutter during earth to orbit boost	X	X			X			
4.	Ability to withstand shock wave pressure front during boost	X				X			X
5.	Ability to withstand aerodynamic temperature heating profile during boost	X		X					
6.	Ability to withstand acoustic sound pressure levels from engine firing and aerodynamic flow				X	X			
7.	Ability to withstand mechanical vibration from engine firings	X	X	X			X		

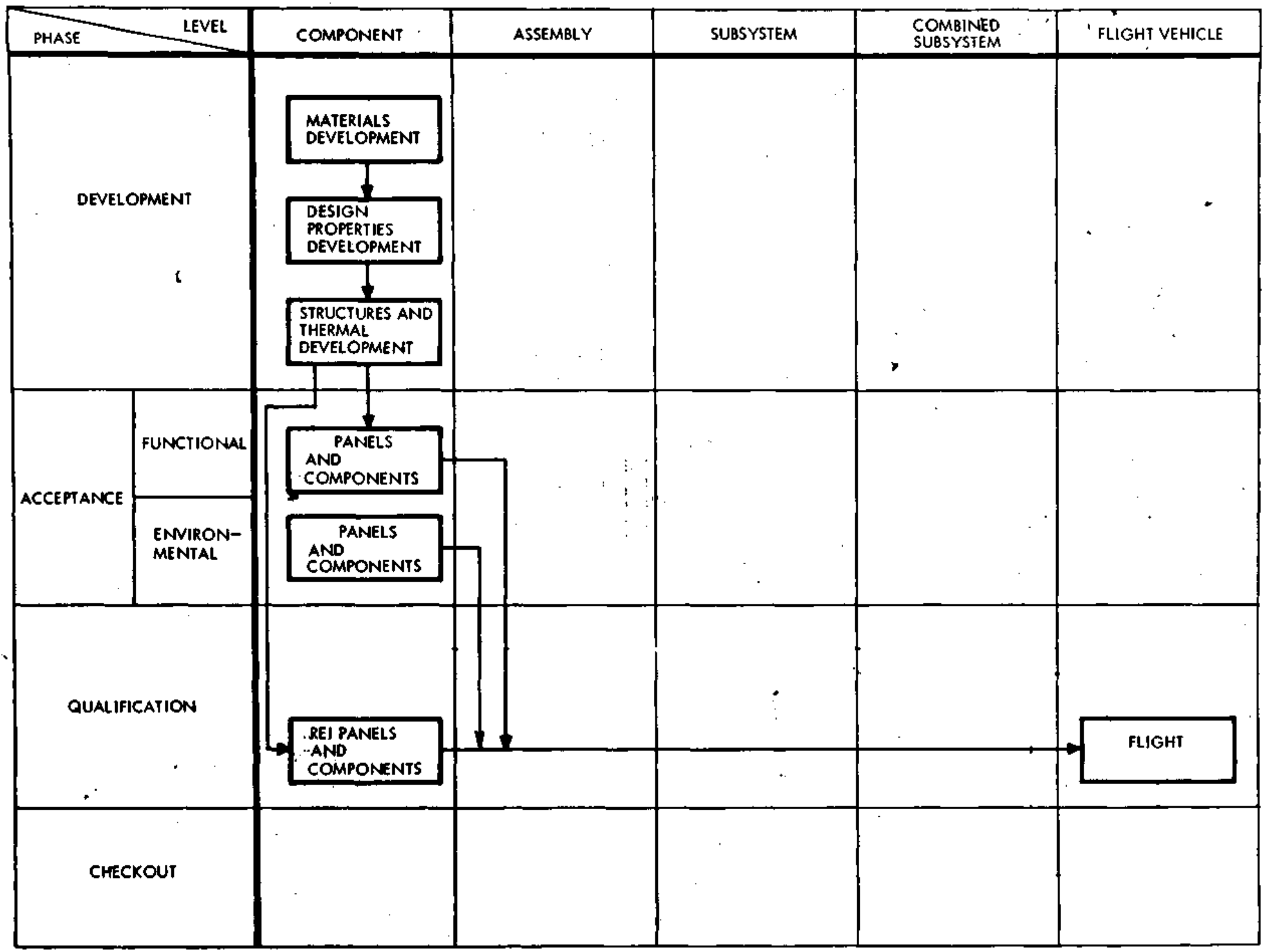


Figure 4-17. Insulation Test Logic and Constraint Network

The following test program will be performed to demonstrate the flight adequacy of full-scale panels when subjected to simulated flight environment.

1. Four full-scale polyimide panels and two titanium panels will be tested in a supersonic wind tunnel to compare the flutter test data to analysis and to certify design adequacy or provide data for design modification. The aerodynamic flow in this test will be controlled to provide uninterrupted flow over the panel.

2. The panels tested above will be subjected to a representative aerodynamic shock wave profile rather than uninterrupted flow to determine panel response in a protuberance region of the stage. This test is to be accomplished as a follow-on to the flutter test to determine whether shock waves will induce flutter.

   Successful completion of the tests will certify the panels' adequacy to withstand the aerodynamic boost shock profile.

3. Altitude pressure bleed-off tests will be performed on a full-scale panel to determine the pressure decay rate through the panel and around the overlapping edges. Data from this test will be used to calculate the burst pressure time history profile during launch to aid the structural sizing of the aero-shear barrier.

4. Acoustic sound pressure tests will be performed on two full-scale polyimide panels and two full-scale titanium panels. The test will be performed to determine acoustic response levels, acceleration levels, and amplitude and amplification factors. Upon completion of the tests, the panel will be certified for the nominal flight pressure profile. The data obtained will also lead to the identification of the maximum tolerable acoustic level.

5. Mechanical vibration tests and instrumentation calibration will be performed on one polyimide panel to determine model response and panel dynamic characteristics. The test panels will be obtained from the panels fabricated for 1 or 4 above, depending on schedule requirements. Reciprocal influence calibration tests will be performed to support 1 and 2 above. The completion of these tests will certify the aero-shear barrier for ground and flight induced vibration and will serve to calibrate accelerometer instrumentation for the flutter tests of 1 above.

6. Small-scale panels shall be subjected to weather environment testing such as sun, rain, humidity, salt spray, and fungus. The test cycles will conservatively simulate the stage life-cycle requirements to demonstrate panel adequacy when subjected to these elements.

7. Tests representing all foreseeable processing variables such as temperature tolerance, pressure tolerance, humidity, cleanliness, cure time, and material properties, will be performed to assure product manufacturing quality and to furnish design allowables. Assessment tests of these types will be performed on the basic polyimide sandwich panels fabrication. Upon completion of this effort, new process specifications suitable for manufacturing production will be prepared. The necessary additional material properties test are to be included in this effort.

8. The phenolic block hard spots, which support the erosion barriers on the LH_2 tanks, are bolted to blind bosses. Spray foam is then applied to the tank around the hard spots. Due to the exothermic process, cryopump cavities can occur. Twenty small panels with hard spots will be subjected to a simulated cryopump test (using LN_2) to assure design adequacy.

Support Requirements

Aerodynamic flutter and shock wave testing must be accomplished in a wind tunnel larger than 10 feet. Candidate facilities are Ames Laboratory, WADD, and Tullahoma. Altitude bleed-off testing, materials properties, vibration testing, environmental testing, processing and hard spot cryopumping tests can be accomplished in the NR laboratories at Downey. Acoustic sound pressure testing can be accomplished in the NR Los Angeles Division Laboratories.

5.1.5 Electrical Power Subsystem

Subsystem Description

The electrical power subsystem is the expendable second stage (ESS) energy source and distribution network required to support the load demands of the integrated avionics system (IAS) for the 24-hour mission. Figure 4-18 depicts the IAS electrical power hardware elements. The subsystem is shown schematically in Figure 4-19.

The ESS employs 17 batteries to supply electrical energy for the 24-hour mission. This provides 6100 ampere hours of energy for ESS use.

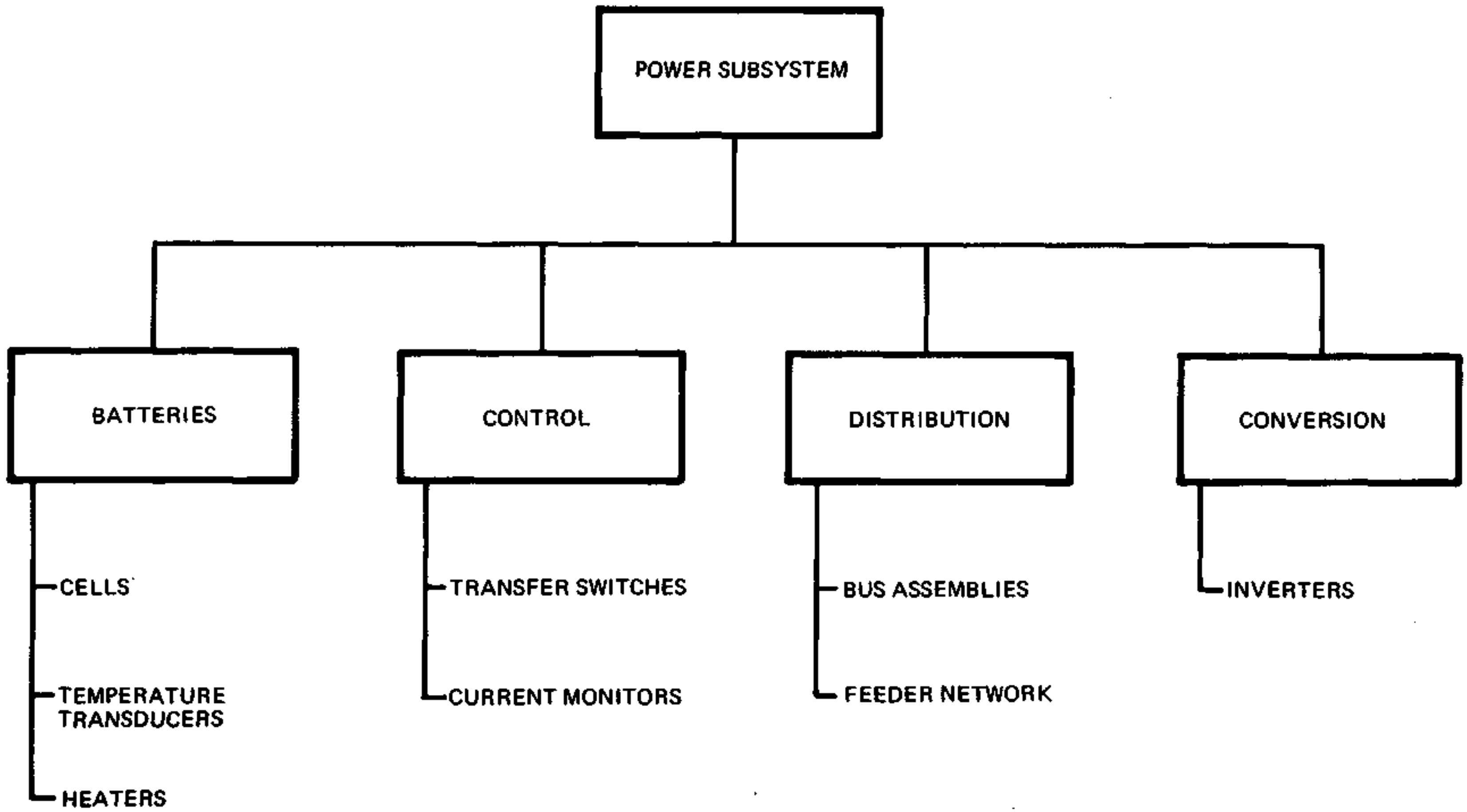


Figure 4-18. Electrical Power Subsystem Hardware Hierarchy

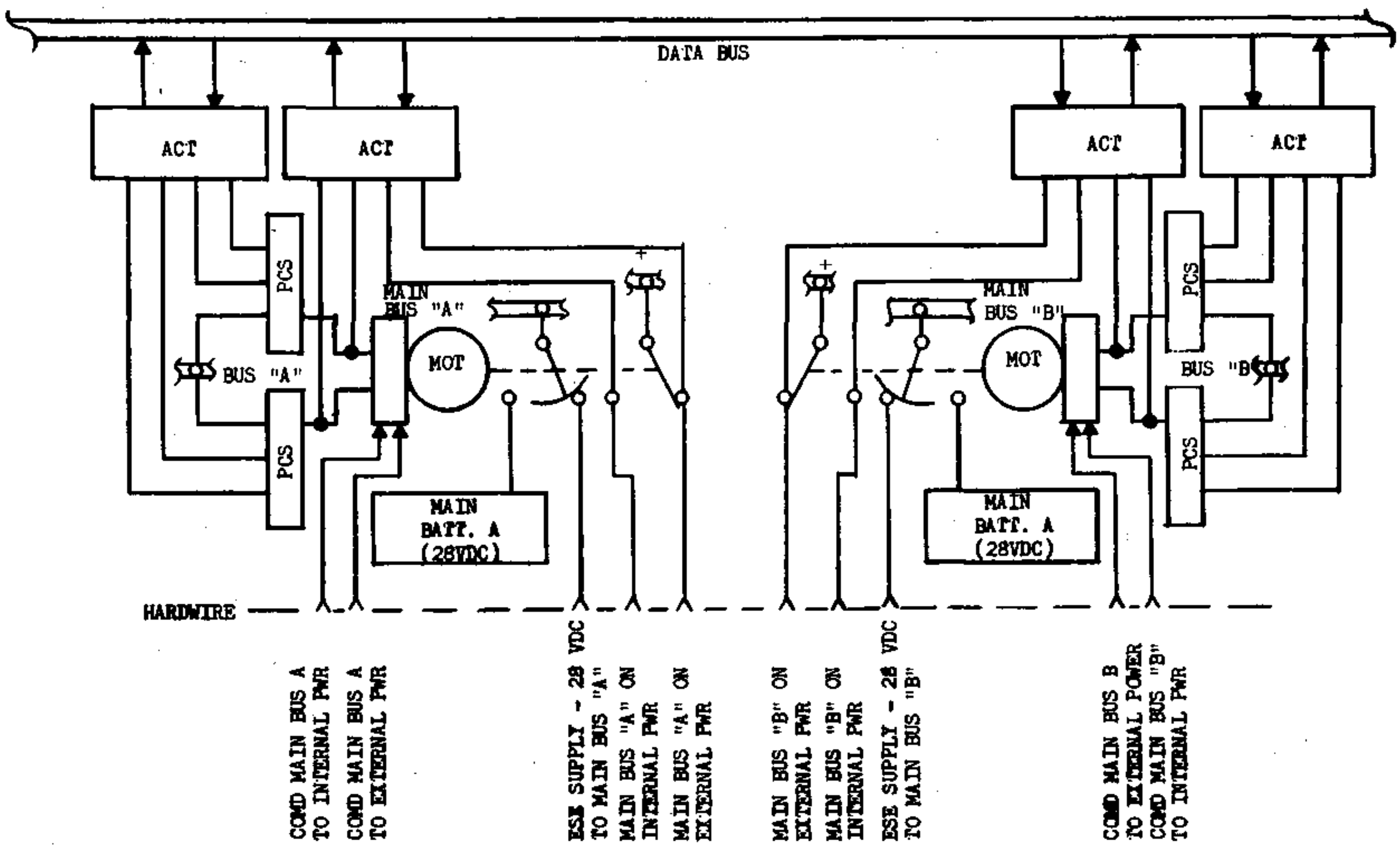


Figure 4-19. EPS Block Diagram

The power system supplies energy for the main, instrumentation, heater and recirculation/TVC distribution systems. Capacity by bus system is:

Bus	Ampere-Hour Capacity	Estimated Ampere-Hour Load
Main	4500	3210
Instrumentation	300	153
Heater	600	257
Recirculation/TVC	300	142

Control of the internal-external power source will be by 200-ampere transfer switches with hardwire and data bus control. Among the failure detection and isolation methods used will be monitoring devices to verify stage current levels.

Conversion capability for AC power needs will be supplied from the recirculation/TVC bus system utilizing inverters to provide the necessary voltage/current/Hertz requirements.

Batteries are to be designed with a 60-day minimum wet-stand life. They are to be installed after erection of the ESS just prior to launch.

Batteries are expendable and no provision will be made for their recovery from orbit.

Subsystem Test Requirements

Electrical power subsystem test requirements are delineated in Table 4-11.

Approach and Rationale

The approach and rationale for the electrical power subsystem development is shown by the electrical power subsystem test logic and constraint network, Figure 4-20. Subsystem design verification will be demonstrated during acceptance test and static firing of the first two vehicles. The in-process checkout operations will be to the extent necessary to verify correct installation and functional integrity of the subsystems components.

Support Requirements

Support requirements for the electrical power subsystem are summarized in Section 8.0 of this document.

Table 4-11. Electrical Power Subsystem Certification Requirements

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
1.	Verify that all subsystem components are accessible for maintenance							X
2.	Verify that replaceable components can be replaced in the horizontal and vertical positions, mated configurations							X
3.	Verify that all electrical connections are accessible, can be readily connected or disconnected, have positive means to prevent cross-connections.					X		X
4.	Verify the subsystem can be monitored and controlled from the ground using GSE						X	
5.	Verify the booster crew can monitor and control the subsystem						X	
6.	Verify the subsystem can be monitored by the centralized data bus system						X	
7.	Verify capability of subsystem to withstand mission environmental conditions (temp, press., vib, shock, accel, acoustics, vacuum, zero-g)	X		X				X
8.	Verify the functional interface between the power subsystem and other vehicle subsystems							X
9.	Verify capability for functional checkout of redundant elements							X
10.	Verify electrical power subsystem has sufficient capacity for mission duration, including prelaunch and deorbit activities	X					X	
11.	Verify cable assembly continuity and bus isolation resistance are within specified limits	X			X	X	X	
12.	Verify harness insulation resistances are within specified limits					X	X	
13.	Verify cable high potential integrity is within specified limits					X	X	
14.	Verify EMI levels are within specification limits						X	

Table 4-11. Electrical Power Subsystem Certification Requirements (Cont)

No.	Requirement	Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
15.	Verify functional checkout limits for battery installation closeout				X			
16.	Verify conversion equipment provides specified levels of voltage/current/Hertz	X					X	

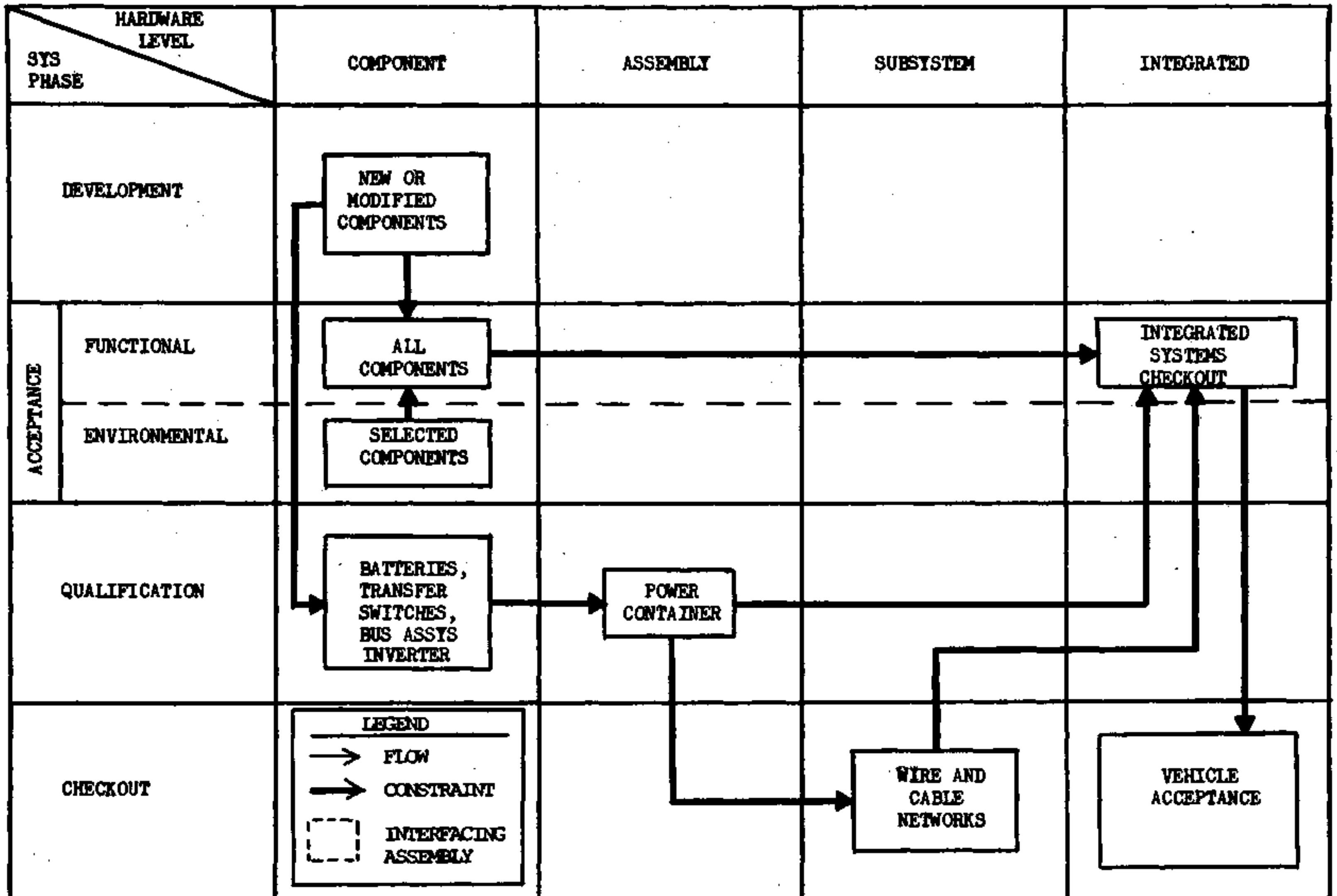


Figure 4-20. EPS Test Logic and Constraint Network

5.1.6 Data and Control Management Subsystem

Subsystem Description

The Data and Control Management Subsystem (DCM) is the central integrating agent for all ESS vehicle subsystems. The subsystem consists of the hardware and the software to implement the following:

Configuration control and sequencing

Guidance and navigation computation

Flight control

Data storage

Data acquisition and distribution

Checkout and fault isolation

Self-management

Major elements of the DCM hardware and software systems are shown in Figure 4-21. All elements function together to address storage, gather and store information, process arithmetic and logical data, execute sequential instructions, process interrupts, and initiate communications between storage and the input/output devices. Figure 4-22 is a general block diagram of the subsystem.

Subsystem Test Requirements

The DCM subsystem test requirements are listed in Table 4-12. General requirements of subsystems components are as follows:

1. Central Processing Unit. Verify ability of system to address storage, gather and store data, process equations, execute sequential instructions, and process interrupts.

2. Input/Output Units. Verify the ability to process transfer of data between the CPU's and all ACT/LRU's via the data bus and to devices controlled by dedicated hardwire system.

3. Data Bus. Verify the capability of the bus to interconnect all elements of the IAS, the IAS and other ESS subsystems, the ESS and the booster, and the ESS and the ESE.

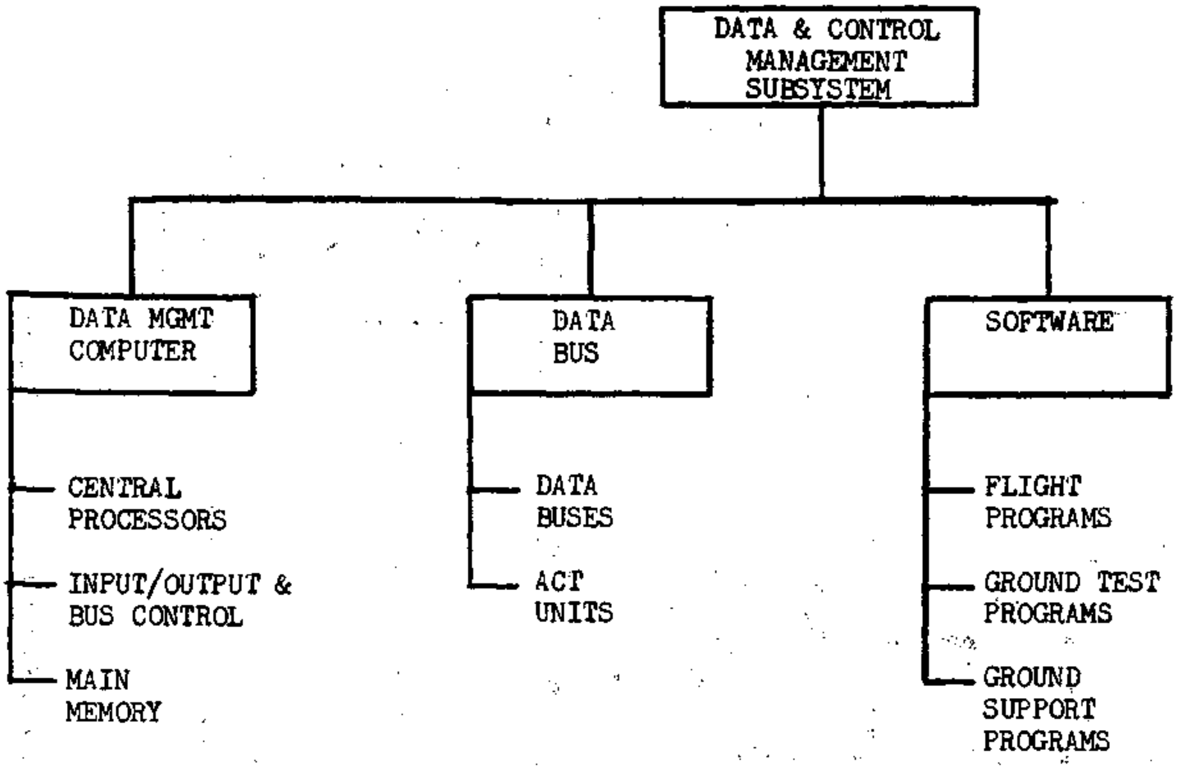


Figure 4-21. Data and Control Management Subsystem

4. Storage Units. Verify the ability to store and retrieve data located in the main memory section within specified time limits.

5. Software. Verify that the software modular units are compatible with the DCM system and are acceptable for ESS use. Verify that supplemental programs bridge the configuration gap between the shuttle and ESS requirements.

Approach and Rationale

The DCM subsystem requires considerable software to process command/response data and perform the other tasks necessary for vehicle operation. Adaptation of modular software developed for similar functions on the shuttle program and development of the specialized software for ESS demands will require a major share of the integration task. Steps to assure proper software integration are:

1. Integration of all elements of the DCM subsystem

2. Integration of the DCM with other avionics subsystems and with software

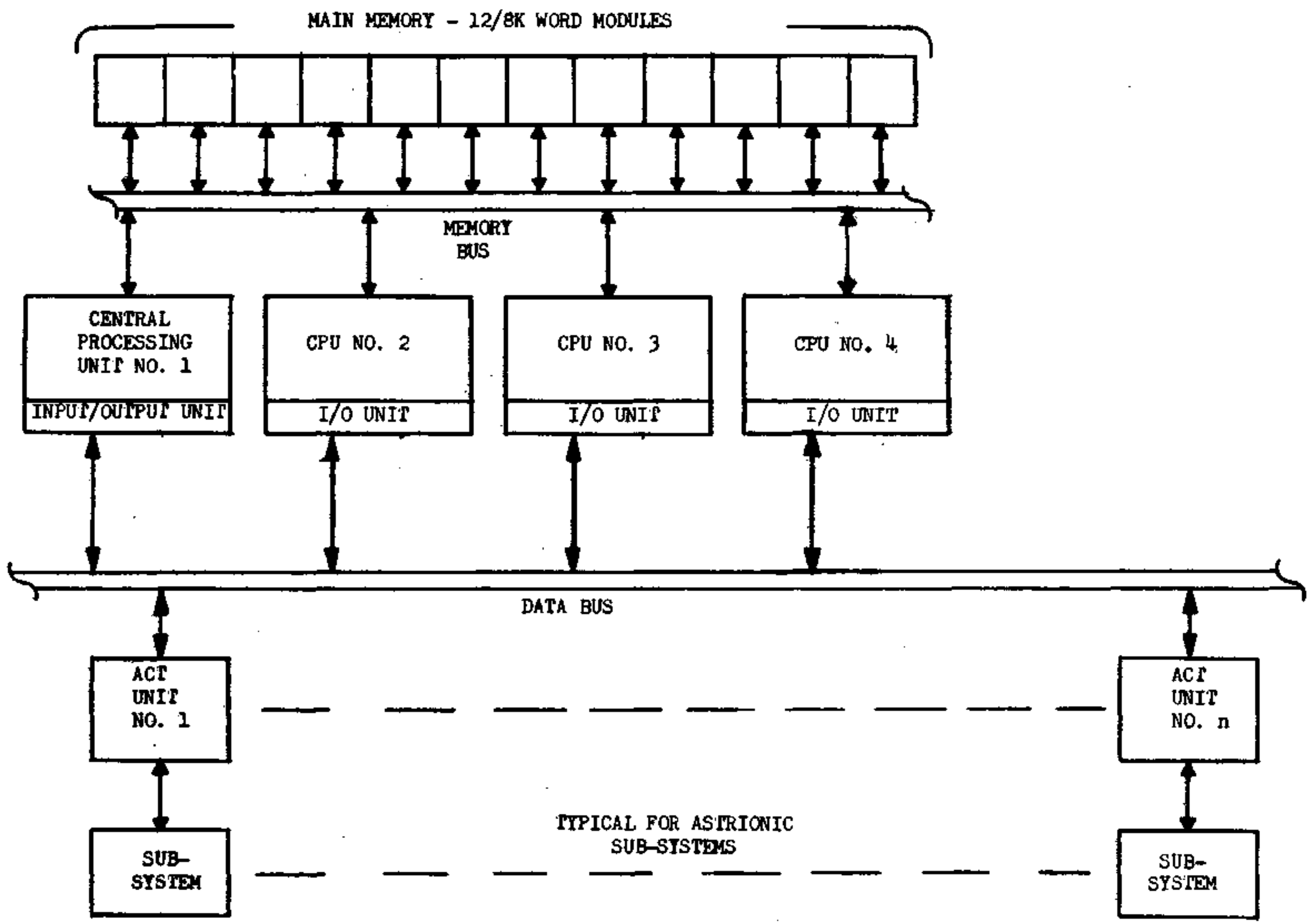


Figure 4-22. Data and Control Management Subsystem Block Diagram

Table 4-12. Data and Control Management Subsystem Certification Requirements

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
1.	Verify integration of all hardware elements of the DCM subsystem					X	X	
2.	Verify compatibility of DCM central processors, data bus, and memory					X		
3.	Verify DCM computer performance in input/output processing, register management techniques, instruction sets, execution timing, and instruction processing					X		
4.	Verify address and access procedures for computer main storage					X		
5.	Verify capability of DCM to manage internal redundancy					X		
6.	Verify executive software program					X	X	
7.	Integrate DCM with COMM, GN&C, electrical power and control subsystem						X	
8.	Verify that DCM and related software can perform management control, redundancy management, checkout and fault isolation						X	
9.	Verify functional interface between avionics subsystems and ACPS, OMS, main engines, EC, structure, and hydraulics subsystems (this includes integration of software)						X	
10.	Verify functional capability of DCM and related software to manage, control, monitor and record data for vehicle subsystems							X
11.	Verify functional interface between the DCM ground computers and related software							X
12.	Verify functional interface between ESS and the booster							X

3. Integration of the DCM, avionics subsystems and software with non-avionics subsystems

4. Integration of the DCM with ground support systems

Steps to achieve the hardware/software integration are shown in the test logic and constraint network, Figure 4-23. Use of the Avionics Systems Integration Laboratory (ASIL) reconfigured to support the ESS will enhance rapid verification of modular block utilization and verification of the ESS-dedicated software.

Support Requirements

The ASIL is required to develop and verify the compatibility of the software to ESS subsystem configurations.

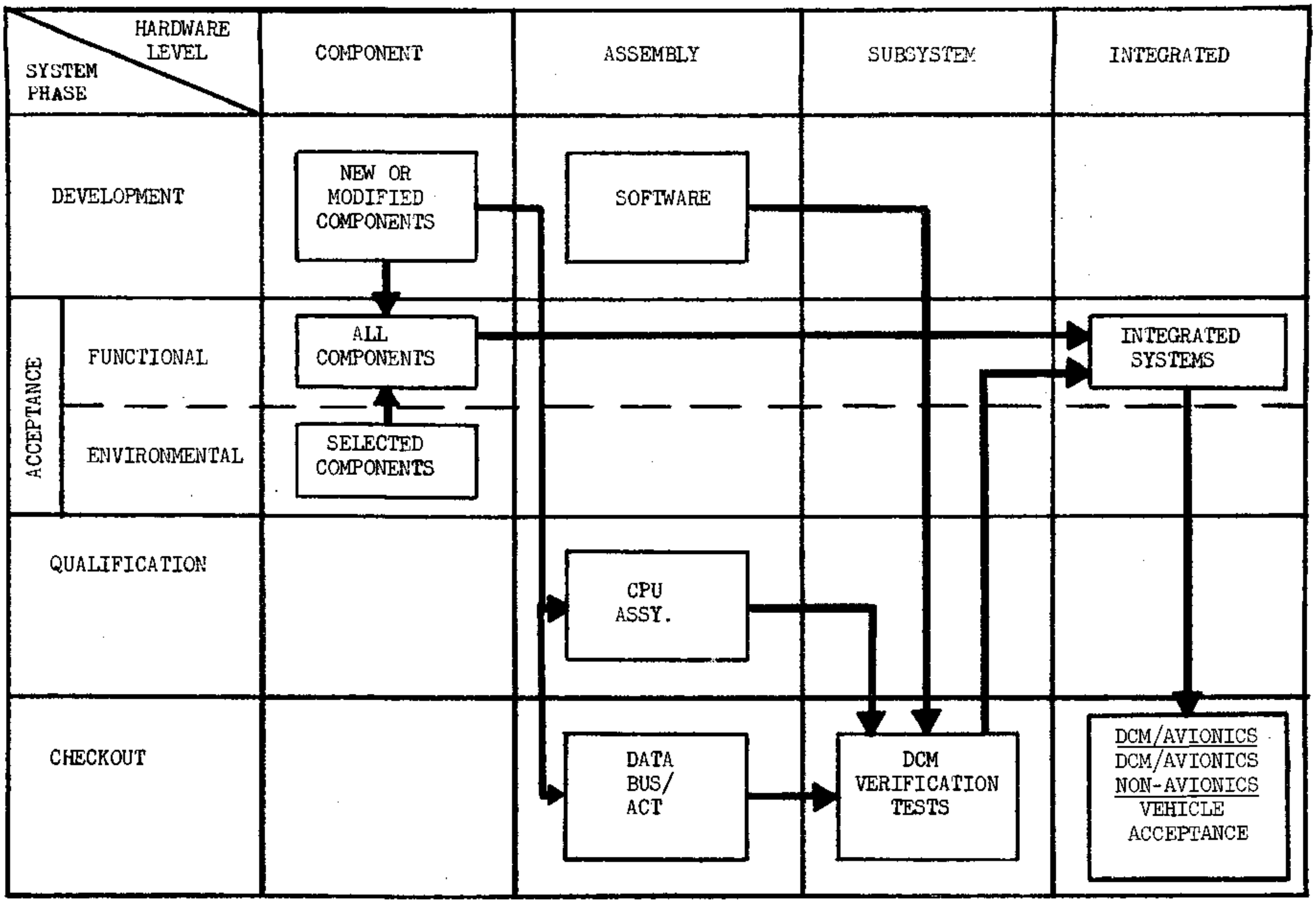


Figure 4-23. Data and Control Management Subsystem Test Logic and Constraint Network

5.1.7 Guidance, Navigation, and Control Subsystem (GN&C)

Subsystem Description

The function of the GN&C subsystem is to determine spatial or inertial position, velocity, attitude, and attitude rate of the vehicle, to compute desired changes to any or all of these vehicle states in accordance with internally-stored or alterable computer programs, and to provide control signals to the propulsion systems for commanding those changes. The basic GN&C equipment (without redundancy) consists of:

An inertial measuring unit (IMU)

A rate gyro set

Interfacing electronic control units

The main elements of the GN&C subsystem are diagrammed in Figure 4-24. The navigation equipment senses vehicle inertial changes and provides this information to the DCM computer. The guidance and navigation software operates on the received data and generates the control signals which command changes in the vehicle attitude and/or state vector in accordance with pre-planned mission objectives. Other inputs from non-GN&C hardware (tracking and communications) contribute to the solution of the navigation problem for determining partial vehicle state vector parameters. Figure 4-25 is a block diagram of the GN&C subsystem as it interfaces with other elements of the avionics subsystems group.

Subsystem Test Requirements

The GN&C subsystem test requirements are shown in Table 4-13. Primary functions of the separate GN&C assemblies to be verified are as follows:

Inertial Measuring Unit. Verify the system attitude measurement capability. Verify the system acceleration measurement capability.

Rate Gyros. Verify the capability to measure attitude rates of change.

Electronic Control Units. Verify the capability of the units to adequately perform in accordance with the design transfer function.

Approach and Rationale

The approach for the GN&C development is shown in Figure 4-26. The ASIL will be utilized for all development and testing certification at the subsystem and integrated avionics subsystem level.

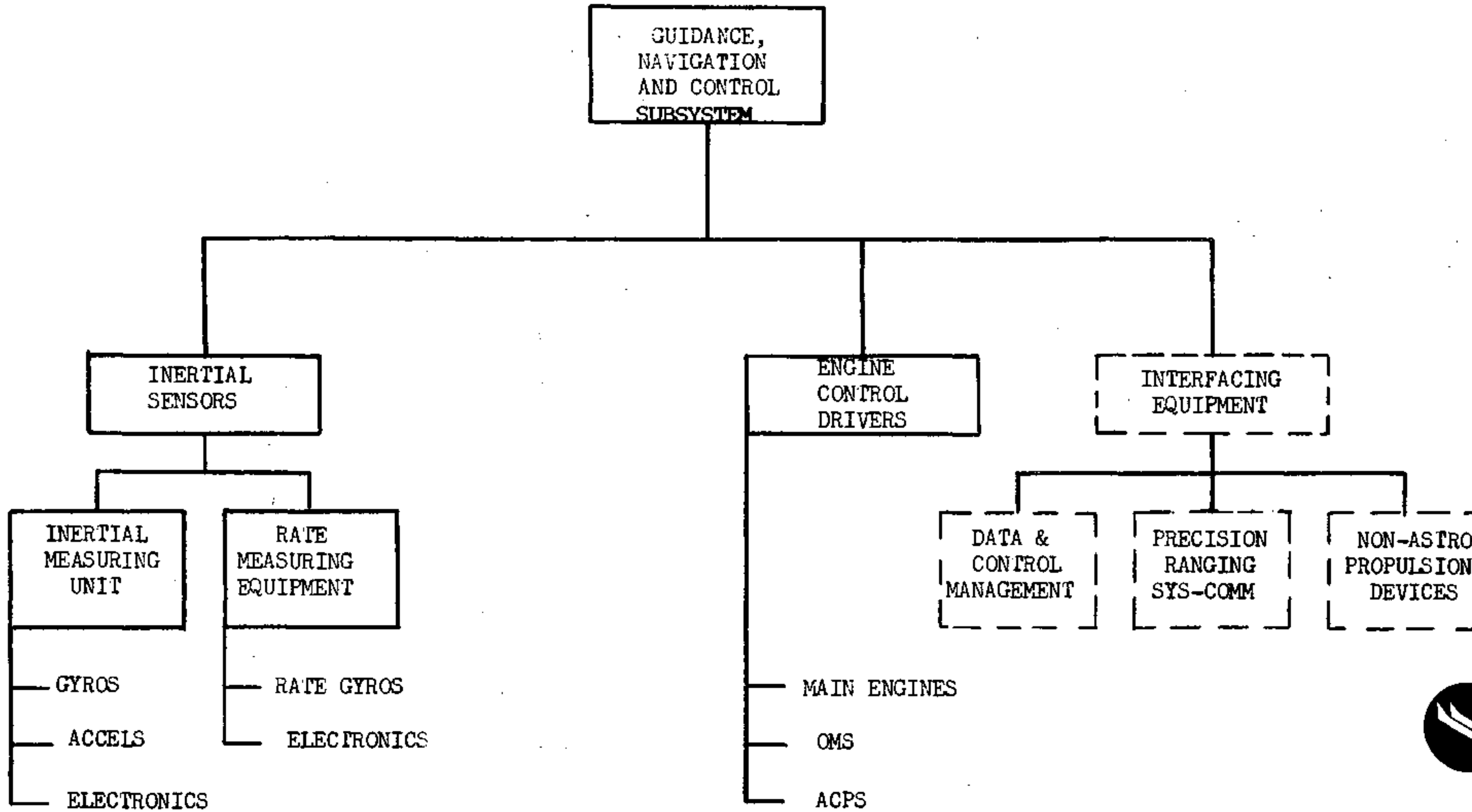


Figure 4-24. Guidance, Navigation and Control Subsystem Hardware Hierarchy

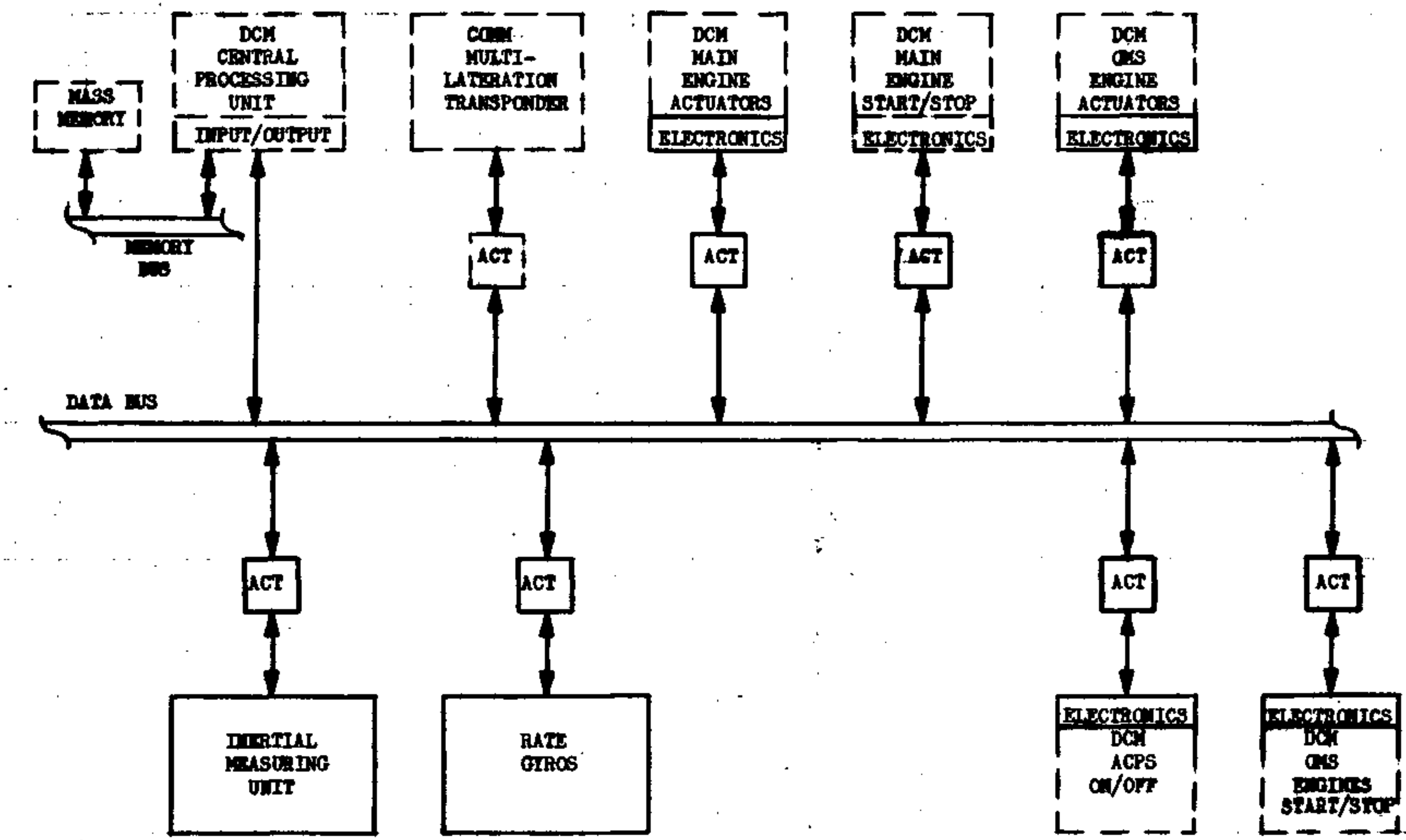


Figure 4-25. GN&C Subsystem Block Diagram

Table 4-13. GN&C Subsystem Certification Requirements

No.	Requirement	Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
		Certification Category						
1.	Verify assemblies meet functional and performance requirements:							
	New or modified SS				SS (P)			
	Existing SS				SS			
2.	Verify assemblies meet environmental requirements							
	New or modified SS				SS (P)			
	Existing SS				SS			
3.	Verify ESS-compatible performance with deletions and deltas from SS	X	X			X		
4.	Verify critical interface compatibility for differences from shuttle	X					X	
5.	Verify software-hardware compatibility						X	
6.	Verify mission-hardware compatibility	X	X				X	
7.	Verify GSE and checkout procedure compatibility	X					X	X
8.	Verify failure detection and isolation logic						X	X
9.	Verify assemblies ready for flight vehicle installation				X			
10.	Verify GN&C subsystem safe and ready for combined subsystems tests					X		X
11.	Verify IMU alignment				X			
12.	Verify IMU installation alignment						X	
13.	Verify GN&C installed subsystem is flight ready					X	X	

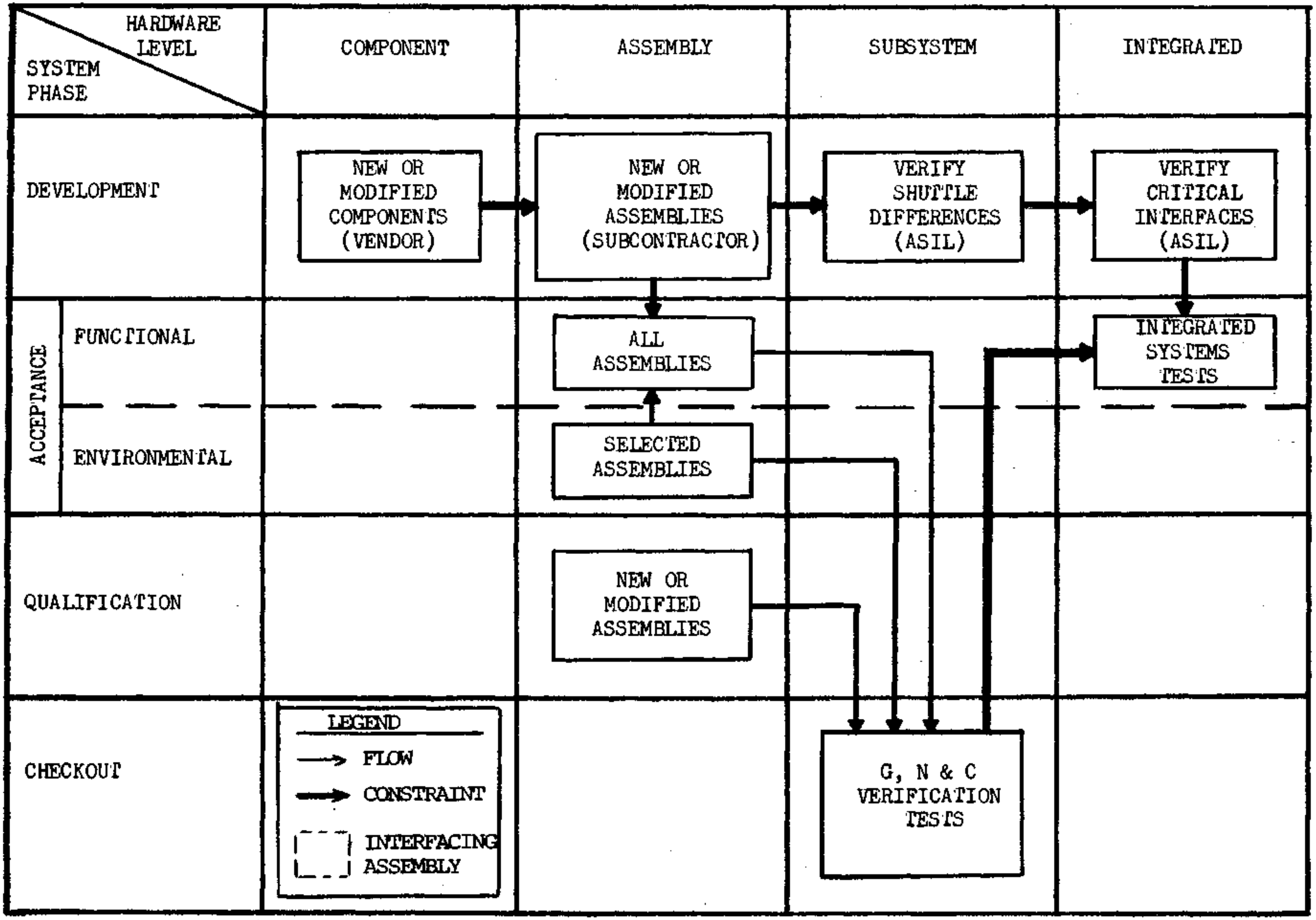


Figure 4-26. Guidance, Navigation, and Control Subsystem Test Logic and Constraint Network

Support Requirements

The ASIL will be required to support the type of testing suggested above. Aside from verifying that no physical problems exist among interfacing hardware, the compatibility of the software programs with all interdependent hardware will be assured.

5.1.8 Communications Subsystem

Subsystem Description

The communications subsystem has the capability of transmitting and receiving all RF information necessary to accomplish the basic ESS mission by transmitting telemetry data, turn-around ranging data, and receiving up-data and range safety commands. The subsystem provides the medium for the following five data links:

Data bus communications (DBC)

Telemetry communications

Updata communications

Range and range rate communications

Range safety communications

An integrated approach has been used in providing these functions resulting in the three major assemblies depicted in Figure 4-27. Figure 4-28 depicts the communications subsystem block diagram.

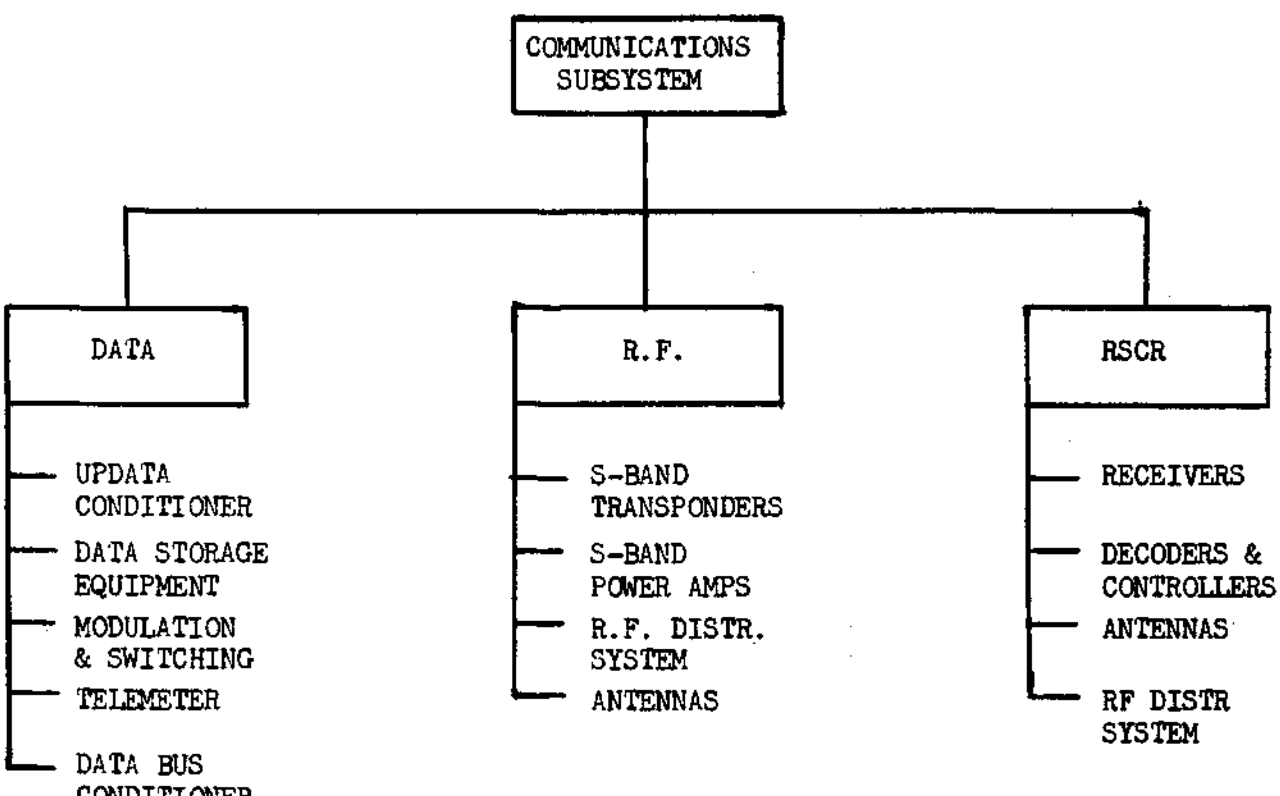


Figure 4-27. Communications Subsystem

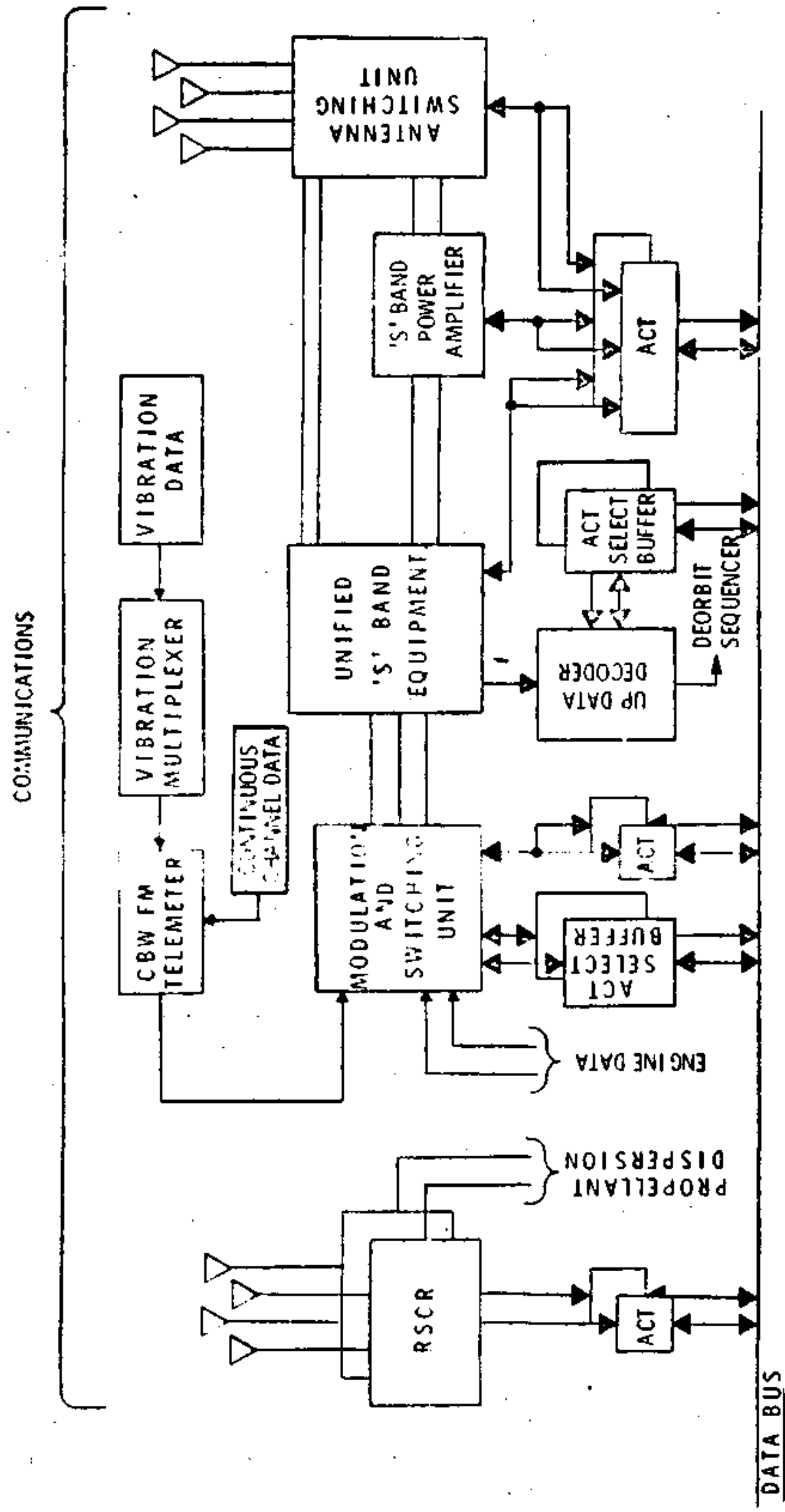


Figure 4-28. Communications Subsystem Block Diagram

Subsystem Test Requirements

The communications subsystem test requirements are listed in Table 4-14. General requirements of the subsystem assemblies are as follows:

Data Bus Transmission. Verify the ability of the S-band equipment and the data bus converter to transmit the data bus information and the ability of the transmitter to maintain the required power output, frequency stability, low distortion, and spurious mission suppression.

Telemetry Data Transmission. Verify the ability of the Universal S-Band Equipment (USBE) to transmit the interlaced data in proper and selected format, and to transmit stored data mixed with the ranging data on subcarriers.

Range and Range Rate Communications. Verify the ability of the USBE to receive, demodulate, delay and coherently retransmit range coded information.

Up-Data Communications. Verify the ability of the USBE to receive and demodulate up-data and the ability of the up-data equipment to decode, test, and read information onto the data bus upon command from the DBC.

Range Safety Command Receiver. Verify that the radio frequency, modulation sensitivities, and bandwidth of the system are in accordance with existing ETR range safety requirements.

Range Safety Command Antenna. Verify that the RF, insulation resistance, voltage standing-wave ratio, attenuation, isolation of directional components and phase match from antennas to transmitter are acceptable for ESS use and will provide an R-F link between MSFN and the ESS.

Range Safety Command Language. Verify systems ability to terminate the vehicle flight by a coded digital data command in the event of deviation from the pre-planned trajectory.

Approach and Rationale

The approach and rationale to be used in the communications subsystem test program were developed to preclude constraint of total systems by incompatible requirements. Those components and assemblies requiring development are subjected to analytical tests to insure compatibility with the vehicle requirements and systems. The items requiring tests of an analytical nature

Table 4-14. Communications Subsystem Certification Requirements

No.	Requirement	Certification Category: Analysis	Computer/Model	Component	Assembly	Subsystem	Comb. Subsystem	Flight Vehicle
		1	2	3	4	5	6	7
1.	Verify on an antenna range adequate antenna radiation coverage by antennas for all RF links in the mated and unmated configurations	X	X					
2.	Verify antenna compatibility with applicable transmitter or receiver	X					X	X
3.	Verify that RSCR's properly de-code and initiate proper subsystems response			X		X	X	X
4.	Perform insulation resistance on communication subsystem cables			X				
5.	Verify VSWR and attenuation on communications subsystem coaxial cables and antennas					X		
6.	Perform EMI testing on communication component assemblies to verify that they neither radiate to or absorb from other RF energy sources					X		
7.	Verify communications subsystem capability to receive range data and provide coherent turnaround data			X			X	
8.	Verify TLM system capability to interlace data from engines and data bus	X		X		X	X	
9.	Verify capability of data storage equipment to receive, store, and dump data as required by the mission profile	X		X			X	
10.	Verify USBE modulation, frequency, stability, and freedom from spurious emissions			X			X	
11.	Verify communications subsystem control and interlocking with the DBC						X	X
12.	Verify conversion and control of data bus information for transmission			X			X	
13.	Verify that the up-data can be transmitted to the data bus and error flags can be shown under error conditions			X			X	X

are the antenna systems, telemetry, and the data storage equipment. The antenna systems are model tests to verify proper location of the antennas to insure coverage in all directions with respect to the vehicle. The telemetry development program will require breadboard tests toassure interlacing of the engine data with the data bus data and priority channels using worst-case phase and capacity parameters. The data-storage equipment will require tests similar to the telemetry system to assure storage adequacy during periods of high exception data.

Component level tests are conducted on all items prior to use in the communications systems at a level sufficient to insure the design parameters are met. The test category as utilized in the Communications Systems Test Requirements, is selected to insure the test requirement is met at the lowest level of assembly that testing is practical and at the highest level the parameter can be adequately tested. The subsystem and combined subsystem tests will be conducted on a completed vehicle. The communications subsystem test logic and constraint network is presented in Figure 4-29.

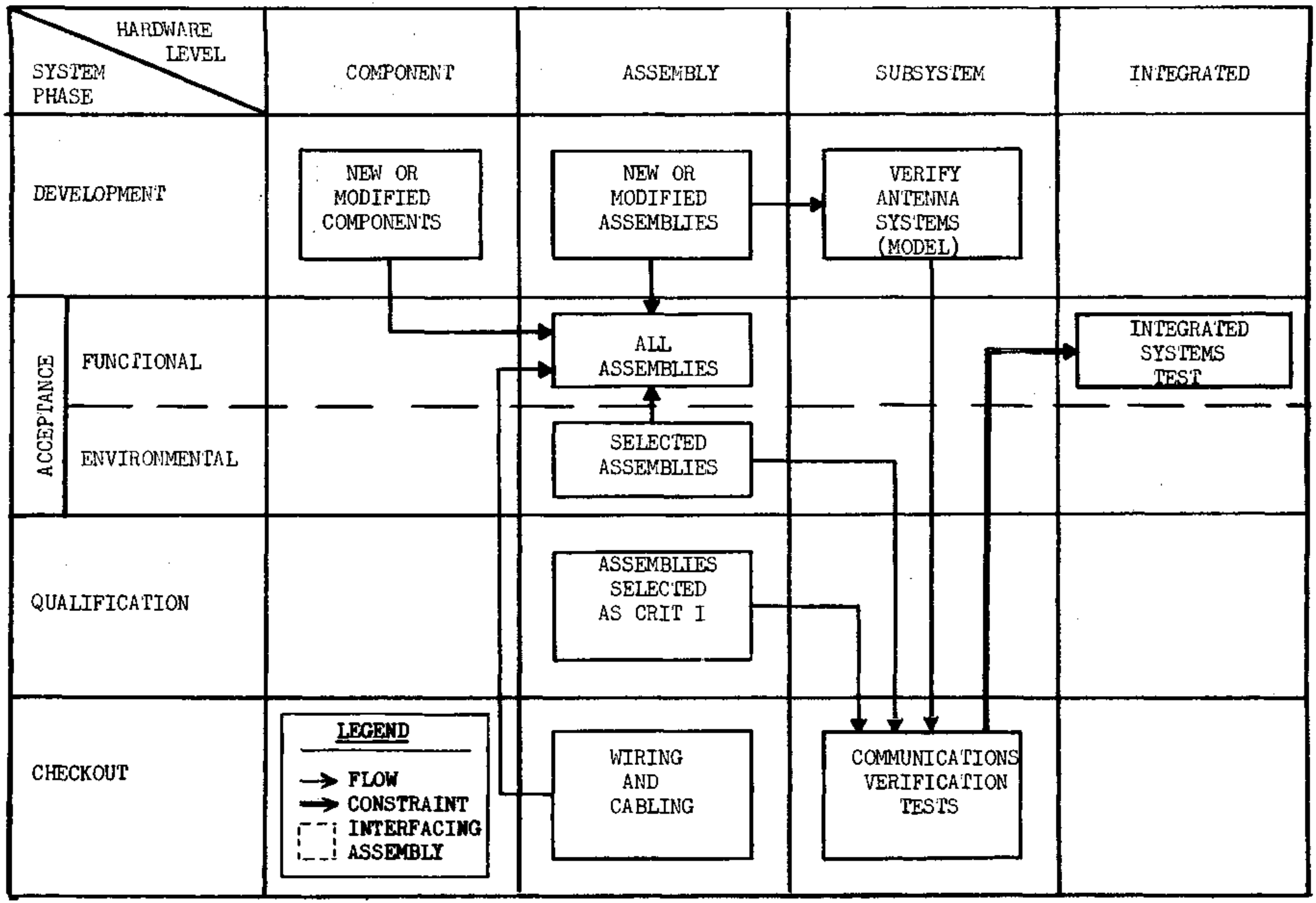


Figure 4-29. Communications Subsystem Test Logic and Constraint Network

5.1.9 Electrical Controls Subsystem

Subsystem Description

The Electrical Controls Subsystem (ECS) is the interfacing agent between avionic and non-avionic subsystems. From this area is derived the requirements for operation of the mechanical subsystems. The subsystems grouped as electrical controls are:

1. Main propulsion subsystem

   Main engines

   Thrust vector control

   Pressurization

   Propellant feed

   Safing

2. Auxiliary propulsion subsystem

   Orbital maneuvering system

   Attitude control propulsion system

3. Propellant management

4. Separation control

The functional requirements for sequencing, timing, response times, analog and discrete measurements, redundancy criteria, and software requirements are established within each of the subsystems noted. These requirements drive back into the DCM subsystem for software programming and equipment sizing. These requirements will also define checkout and fault isolation (COFI) techniques as well as tolerances for subsystem operations. Equipment elements are shown in Figure 4-30. Figure 4-31 is a block diagram of subsystems interfaces.

Subsystems Test Requirements

The ECS test requirements are shown in Table 4-15. The general requirement for testing is to verify that the subsystem can receive DCM commands through its ACT units, implement the commands through the non-avionic subsystem, receive responses from the non-avionic subsystem, and

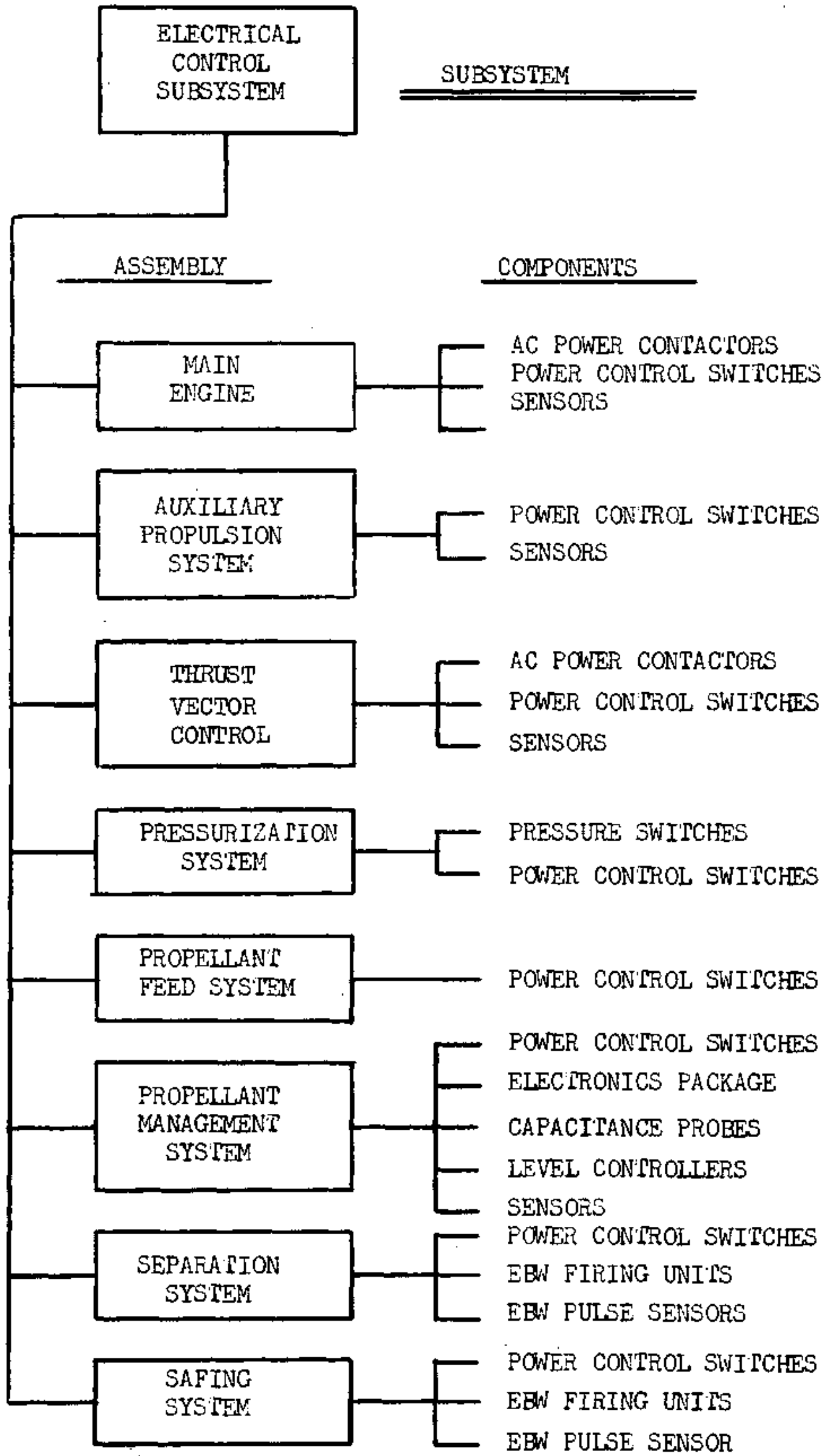


Figure 4-30. Electrical Control Subsystem Hardware Requirements

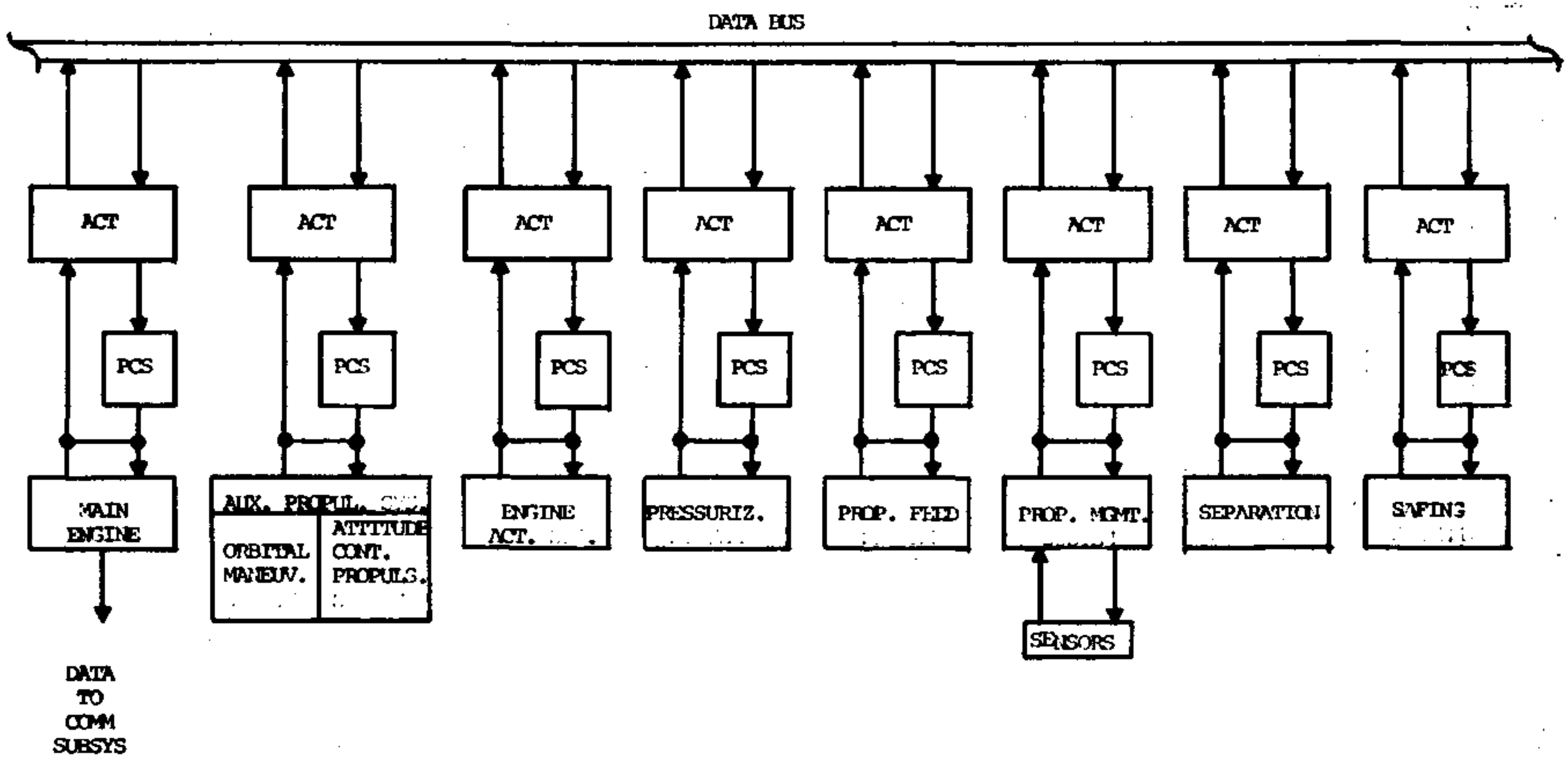


Figure 4-31. Electrical Control Subsystem Block Diagram

Table 4-15. Electrical Controls Subsystem Certification Requirements

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
	A. MAIN ENGINE							
1.	Verify capability of subsystem to respond to DCM commands and to provide responses indicating proper operation					X	X	
2.	Verify capability of subsystem to perform all operations, including start, stop, power level, and nozzle retraction and extension					X	X	X
	B. AUXILIARY PROPULSION SUBSYSTEM							
1.	Orbital maneuvering engines							
	Verify capability of subsystem to respond to DCM commands and to provide responses indicating proper operation				X	X		
	Verify capability of subsystem to perform multiple stop, start sequences						X	X
2.	Attitude control propulsion							
	Verify capability of subsystem to respond to DCM commands and to provide responses indicating proper operation					X	X	
	Verify capability of subsystem to react in proper combinations selected and for start/stop reaction capability					X	X	X
	C. PROPELLANT FEED							
1.	Verify capability of subsystem to respond to DCM commands and to provide responses indicating proper operation					X	X	
2.	Verify hardwire control and response for launch control					X	X	X
	D. PRESSURIZATION							
1.	Verify all functional paths by DCM command and response monitoring					X	X	X
2.	Verify capability of pressure switches and actuation points (calips switches)			X				

Table 4-15. Electrical Controls Subsystem Certification Requirements (Cont)

No.	Requirement	1 Analysis	2 Computer/Model	3 Component	4 Assembly	5 Subsystem	6 Comb. Subsystem	7 Flight Vehicle
3.	Verify hardwire paths to vent valves						X	
	E. PROPELLANT MANAGEMENT							
1.	Verify capability of subsystem to respond correctly to simulation commands of 1/3, 2/3, and full						X	
2.	Verify integrity of mass sensors by performing calibration			X				
3.	Verify commands and responses from the level and depletion cutoff sensor, controllers						X	
4.	Verify compatibility of mass sensor and level monitor measurements	X						X
	F. SEPARATION							
1.	Verify capability of subsystem to respond to DCM commands and to provide responses indicating proper operation					X		
2.	Verify proper voltage levels inputed to pulse sensors (for evaluation of firing unit output)						X	
	G. SAFING							
1.	Verify capability of subsystem to respond to DCM commands and to provide responses indicating proper operation					X		
2.	Verify proper voltage levels inputed to pulse sensors (for evaluation of firing unit output)						X	

introduce the response to the DCM subsystem for COFI evaluation. This testing would include verification of each alternate command and response path.

Approach and Rationale

The test logic and constraint network is shown on Figure 4-32. For the most part, component development is confined to mechanical equipment and the only ECS components are power control switches and the propellant management electronics.

Support Requirements

Initial systems support will be required of the ASIL to configure to the ESS and assure proper verification of each subsystem interface, command, response and COFI capability.

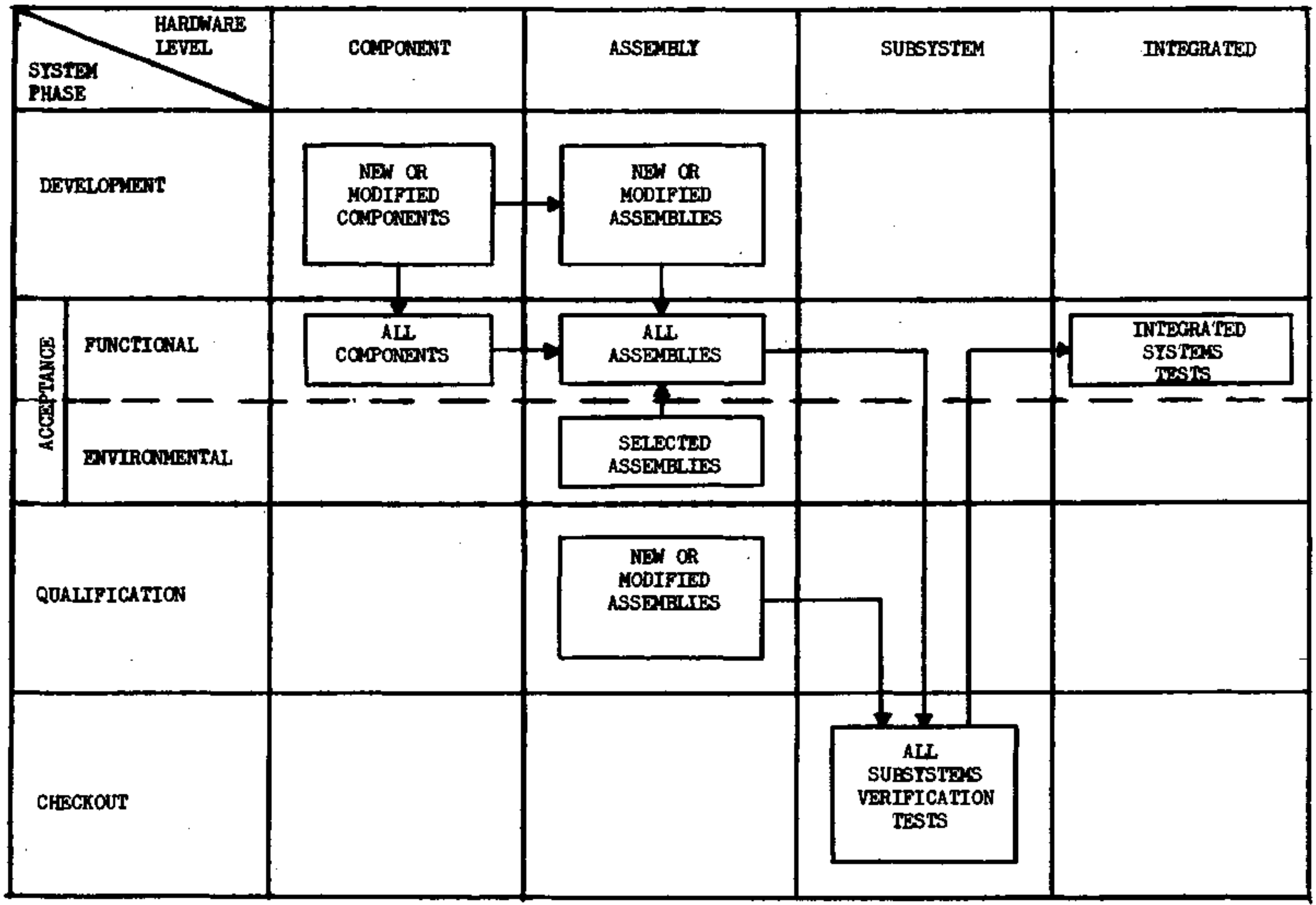


Figure 4-32. Electrical Control Subsystem Test Logic and Constraint Network

5.1.10 Instrumentation Subsystem

Subsystem Description

The instrumentation system provides a means of obtaining component or subsystem information required during subsystems, combined systems or mission operations. It consists of data sensors, signal conditioners and sensor signal conditioner calibration. The hardware elements are shown in Figure 4-33 and a typical circuit in Figure 4-34.

Subsystem Test Requirements

The instrumentation test requirements are shown in Table 4-16. General requirements of subsystem components are as follows:

1. Measurement Channelization. Verify end-to-end measurement channelization and, where applicable, reference electrical or frequency signals, utilizing the calibration system to establish measurement.

2. Instrumentation Component Integration. Verify the ability of instrumentation system components to operate within design specifications after integrated into the communications system.

3. Instrumentation Cables. Verify insulation resistance on instrumentation subsystem cables.

4. Signal Conditioning. Verify the ability of the signal-conditioning units to convert low-level analog transducer signals to digital, to amplify those signals, and to convert amplified digital signals to 0-5 volt analog signals.

Approach and Rationale

The approach and rationale to be used in the instrumentation system test program is an efficient, proved, and reliable method of checkout and calibration of the instrumentation system. An end-to-end calibration approach is used in which electrical or frequency signals are injected between the transducer and signal conditioning, in the signal conditioners, and upstream of the signal conditioning.

Components and subsystems requiring development are subjected to an analytical test to ensure compatibility with vehicle requirements and systems. The items requiring analytical tests are digital signal conditions and digital-to-analog converters integrated with various types of transducers.

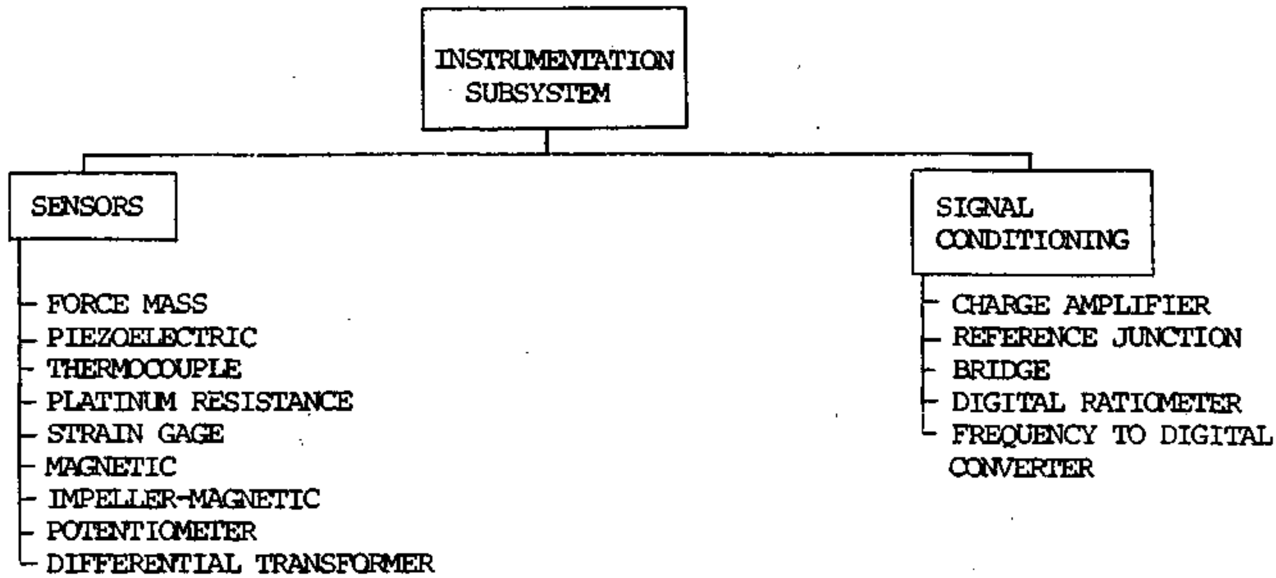


Figure 4-33. Instrumentation Subsystem

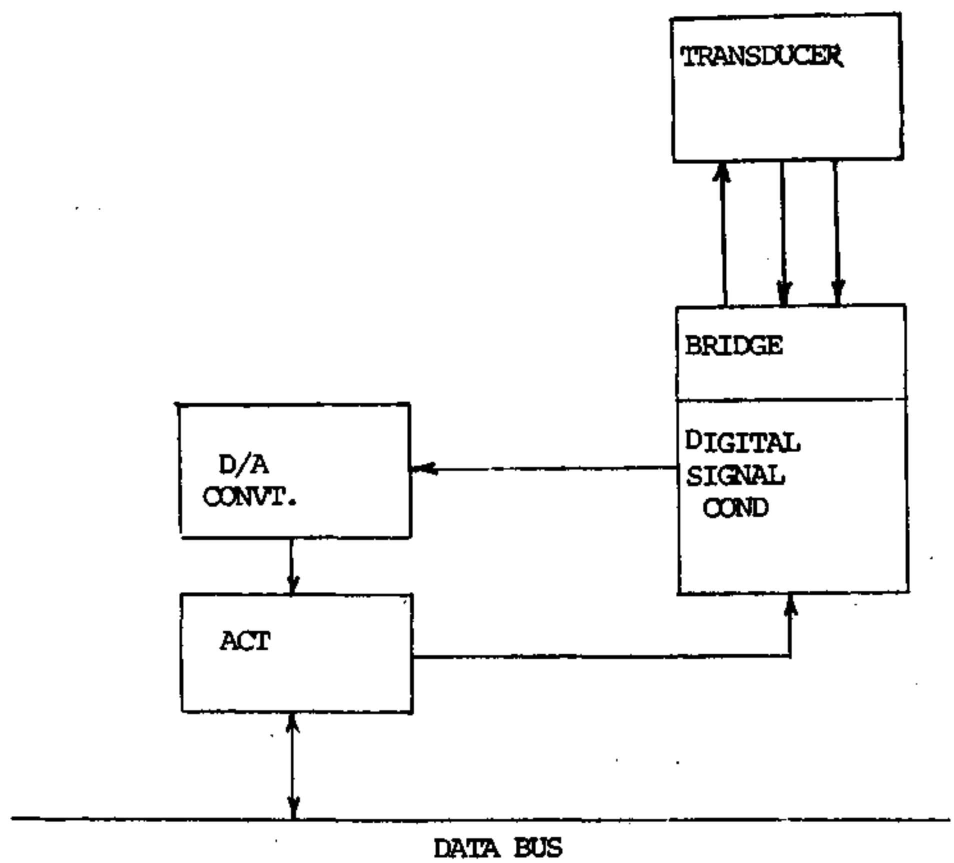


Figure 4-34. Typical Instrumentation Circuit

Table 4-16. Instrumentation Subsystem Certification Requirements

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
1.	Perform insulation resistance on instrumentation subsystem cables			X				
2.	Verify measurement channelization					X		
3.	Verify end instruments and associated signal conditioning are operating within measurement tolerance					X	X	X
4.	Verify system components are functionally correct and ready to support systems testing					X	X	
5.	Verify digital signal-conditioning equipment compatibility with applicable transducers	X		X				

Component-level tests are conducted on all items prior to use in the instrumentation systems to ensure that the design parameters are met. The test category, as used in the instrumentation systems test requirements, is selected to ensure that test requirements are met at the lowest level of assembly for which testing is practical and at the highest level the parameter can be adequately tested. The subsystem and combined subsystem tests will be conducted on a completed vehicle.

5.1.11 Phase C Wind Tunnel Test Program

Configuration

The wind tunnel test program will utilize various sized models of the ESS and space shuttle booster for mated testing to satisfy the investigative requirements. Since the size and configuration are dependent on the flight regime to be explored and the facility utilized, individual models will not be described.

There are no contract end item (CEI) specification requirements for wind tunnel testing. However, because wind tunnel test data can be extrapolated to full-scale conditions with satisfactory correlation, the requirements for subscale testing are indirectly the same specification requirements that define the aerodynamic, dynamic, and thermal dynamic performance of the flight vehicle.

Table 4-17 presents the general requirements for wind tunnel testing. Detailed simulation requirements that specify angle of attack, free-stream Mach number, and Reynolds number will be defined later for each test condition. These requirements will be based upon the design reference mission.

Approach and Rationale

Wind tunnel testing will be conducted to support design, development, verification, and refinement of the ESS and mated ESS/booster vehicles.

General objectives of the Phase C/D wind program are to obtain test data for (1) analysis and development of design criteria, (2) evaluation of configuration changes, and (3) substantiation of analytically predicted performance and design environment.

The main test categories are aerodynamics, heat transfer, structural dynamics, and special tests. Discrete test objectives have been assigned under each category as described in Table 4-18.

The Phase C/D wind tunnel test program has been planned as a continuation of the testing already accomplished or in process in Phase B. Phase B models will be utilized at Phase C go-ahead in test categories where early data are required — refined heating and aerodynamic stability and control— for both configurations. Phase C models will be employed as they are available.

Wind tunnel test planning for Phase C/D is subdivided according to technology areas (aerodynamics, heat transfer, and structural dynamics).

Table 4-17. Phase C/D Wind Tunnel Certification Requirements

No.	Requirement	Certification Category: Analysis 1	Computer/Model 2	Component 3	Assembly 4	Subsystem 5	Comb. Subsystem 6	Flight Vehicle 7
1.	Provide appropriate speed, angle of attack, and Reynolds number simulation of mated vehicle launch trajectories		X					
2.	Provide appropriate speed, angle of attack, and Reynolds number simulation of ESS normal and abort separation conditions		X					
3.	Provide appropriate temperature and angle of attack simulation of mated vehicle launch trajectories		X					
4.	Establish and verify ESS aerodynamic configuration		X					
5.	Establish and verify ESS structural and control loads		X					
6.	Establish and verify ESS pressure distribution		X					
7.	Establish and verify static and dynamic stability and control		X					
8.	Establish and verify separation characteristics		X					
9.	Establish and verify power effects		X					
10.	Establish and verify aeroelastic loads and flutter characteristics		X					
11.	Establish and verify ESS aerothermodynamic characteristics		X					
12.	Establish and verify mated aerothermodynamic characteristics		X					

Table 4-18. Wind Tunnel Test Categories

Aerodynamics
Stability and control forces and moments
Hinge moments
Pressure distribution for loads
Dynamic stability
Heat transfer
Heat transfer distribution; phase paint, T/C, calorimeter, film gauge
Base heating, plume heating
Structural dynamics
Flutter
Rigid and flexible ground wind model loads
Pressure distribution for aero noise

The principal area of aerodynamic wind tunnel test uncertainty is the transonic flight regime. Aerodynamic analyses and wind tunnel data are always suspect in this area. Scale effects, Reynolds number mismatch, aeroelasticity, flutter, buffet, aerodynamic damping, and aerodynamic cross coupling are all significant considerations in this region. In addition, aerodynamic forces, moments, and pressure distributions are undergoing rapid changes.

The following assumptions were made in designing this Phase C/D wind tunnel test program.

1. Limited wind tunnel testing would be continued during the interim period beyond the completion of Phase B and up to the start of Phase C.

2. The model configurations in the interim period would not match the Phase C contractual design requirements exactly but would be close enough to provide useful data for early design efforts in critical long lead time areas. These areas include continuing tests to update heating rates and maximum temperature profiles for configuration refinements beyond Phase B designs.

3. It was anticipated that the Phase C contract would specify design refinements such that a completely new set of wind tunnel models would be required to provide detail design data prior to preliminary design review (PDR).

4. Phase C design studies, coupled with the completion of booster and ESS PDR's, would introduce enough changes to require a new set of models that would then be used in development testing to support final design of the flight hardware.

5. Additional models would not be required for verification tests, which would continue beyond critical design review (CDR).

6. All wind tunnel testing will have been completed prior to the first orbital flight.

The Phase C/D wind tunnel test program rationale was to expand upon the work conducted prior to and throughout Phase B and to use the largest possible models and the maximum performance capabilities of existing wind tunnel facilities throughout Phase C/D. An attempt has been made to obtain the highest possible assurance of flight worthiness with the lowest possible expenditure of test hours and test dollars.

Aerodynamic Tests

Within the limitations of existing facilities, aerodynamic wind tunnel tests will be used to determine and to verify ESS/booster air vehicle performance, stability, and control, and air loads and pressure distribution. Various ranges of angles of attack and angles of yaw will be investigated. In addition, rotary derivatives and base pressure-base flow characteristics will be defined for the two configurations (ESS and the mated ESS/booster vehicle).

Additional tests required on the launch configuration include the determination of interference forces, moments, loads, and pressure distributions on each vehicle as a result of the presence of the other. Aerodynamic data must also be measured during simulated launch and separation phases for nominal and abort conditions.

Main propulsion systems impact aerodynamic performance of the ESS/booster vehicle.

Elements of engine system investigations are contained in both aerodynamic and heat transfer wind tunnel test studies.

Wind tunnel tests will determine the effects of the main propulsion system (MPS) exhaust on the ESS and launch vehicle base drags to provide basic data for both nominal operations and for subsequent abort studies. Heating and acoustic data will be obtained.

ESS and booster ACPS control and heating effects will be measured to establish local flow field and shock interaction phenomenon.

Heat Transfer Tests

Aerothermodynamic environments that determine the thermal structural design requirements are developed from extrapolation of theoretical prediction techniques and wind tunnel test results. Initial wind tunnel tests will employ paint models to determine constant temperature contours on the Phase C configurations. Streamlines and flow fields will be determined with pressure models. Finally, larger-scale thermocouple models will be used to verify earlier results and to obtain more detailed temperature data and heating rate information. Available wind tunnel facilities can accommodate the range of ascent conditions.

Structural Dynamics Tests

Wind tunnel testing will be accomplished on large-scale models of the aerodynamic surfaces for the ESS/booster vehicles and on smaller-scale complete vehicle models to determine structural dynamic responses. Wind tunnel tests will provide preliminary design, advanced design, and final verification of structural dynamic data as the air vehicles' designs progress. For flutter margin assurances, duplicate models will be constructed with scaled nominal stiffness and with reduced stiffness for the flight regime determined to be most critical. The ESS dynamic models and booster dynamic models used to investigate flutter and buffet will be mated for a study of launch vehicle structural dynamics in other than the liftoff flight region. Ground wind studies will then be made in which the scaled stiffness launch configuration models will be used.

Structural dynamic wind tunnel tests will provide air vehicle design data directly and by providing assurance for the analytical methods used to calculate dynamic responses and flutter margins.

Support Requirements

Table 4-19 is a summary chart that lists the wind tunnels considered in development of this test program. Other facilities may be added to or substituted for those listed because of scheduling problems or other considerations.

Table 4-19. Candidates for Phase C/D Wind Tunnel Facility Utilization

NASA FACILITIES		
Ames Research Center	ARC 6 ft x 6 ft	M = 0.6 → 2.0
	ARC 3.5 ft	M = 5.5, 7.4, 10.4
	ARC 12-ft press.	M = 0.0 → 0.96
	ARC unitary	M = 0.7 → 3.5
Langley Research Center	LRC LTPT	M = 0.0 → 0.4 *
	LRC 8 ft TPT	M = 0.2 → 1.3 *
	LRC unitary	M = 1.5 → 4.5
	LRC 16-ft TDT	M = 0.1 → 1.2
	LRC 18-in. var density	M = 8.0
Marshall Space Flight Center	MSFC 14 in.	M = 0.6 → 5.0
AIR FORCE FACILITIES		
Arnold Engineering Development Center	AEDC VKF 40-in. A	M = 1.5 → 6.0
	AEDC VKF 50-in. B	M = 6.0 → 8.0
	AEDC VKF 50-in. C	M = 10.0 → 12.0
	AEDC PWT 16-ft	M = 0.5 → 4.7
CONTRACTOR FACILITIES		
General Dynamics Convair	GD 4 ft x 4 ft	M = 0.6 → 5.0
North American Rockwell	NR TWT 7 ft x 7 ft	M = 0.2 → 3.5
	NR NAAL 7.75 ft x 11 ft	M = 0.0 → 0.26

*Alternate

5.2 VEHICLE LEVEL REQUIREMENTS

A compilation of the subsystem design verification requirements that will be satisfied with vehicle-level testing is presented here. Three primary modes of verification testing are indicated: post-manufacturing checkout (PMC), static firing (S/F), and flight. Flight requirements are those that will be satisfied either during mated prelaunch operations, mated ascent, or ESS ascent or on-orbit operations.

No.	Requirement	Primary Verification Mode		
		PMC	S/F	Flight
	MAIN PROPULSION SUBSYSTEM			
	A. Operational Requirements			
1.	Verify component accessibility	X		
2.	Verify ability of components and engine to withstand acoustic and vibration		X	
3.	Verify adequacy of base heating thermal protection of components and engine		X	
4.	Verify ability of MPS to withstand boost environment			X
5.	Verify ability to start engines in boost environment			X
6.	Verify ability to engage and disengage umbilicals			X
7.	Verify ability to leak-test	X		
8.	Verify ability to functional-test	X		
9.	Verify ability to purge and inert		X	
10.	Verify MPS/GSE compatibility	X		
11.	Verify capability to extend/retract engine nozzle under flight loads			X

No.	Requirement	Primary Verification Mode		
		PMC	S/F	Flight
12.	Verify engine/stage compatibility from 50 to 109 percent thrust		X	
13.	Verify engine/stage compatibility during 5.5 to 6.5 mixture ratio excursion		X	
	B. Propellant Feed Assembly Requirements			
1.	Verify ability to provide engine start NPSP requirements		X	
2.	Verify ability to monitor and maintain vacuum-jacket conditions	X		
3.	Verify pogo suppression		X	
4.	Verify tank isolation capability		X	
5.	Verify ability to fill main tanks within two-hour servicing time		X	
6.	Verify ability to drain tanks		X	
7.	Verify capability of depletion cutoff to protect engines		X	
8.	Verify heat leak rates		X	
	C. Pressurization Assembly Requirements			
1.	Verify ability to meet engine mainstage NPSP requirements		X	
2.	Verify capability of vent system to maintain tank pressure	X	X	
3.	Verify prepressurization capability		X	
4.	Verify vent system capability to vent tanks	X	X	

No.	Requirement	Primary Verification Mode PMC	S/F	Flight
	D. Engine Servicing Assembly Requirements			
1.	Verify ability to supply in-flight helium at ICD pressure and flow rate		X	
2.	Verify ability to vent fuel pumps without excessive back pressure		X	
3.	Verify GN_2 purge supply adequacy		X	
4.	Verify capability to fill/drain hydraulic fluid	X		
	E. Thrust Vector Control Assembly Requirements			
1.	Verify ability to dry gimbal with sufficient clearance	X		
2.	Verify engine alignment	X		
3.	Verify capability to gimbal engines over angular rate and response range	X		
	AUXILIARY PROPULSION SUBSYSTEM			
	A. Operational Requirements			
1.	Verify component accessibility	X		
2.	Verify ability of subsystem to operate in flight environment			X
3.	Verify capability to withstand vibration and acoustic effects from main propulsion operation		X	
4.	Verify capability to withstand base heating environment		X	
5.	Verify ability to withstand space environment			X
6.	Verify ability to leak- and functional-test	X		
7.	Verify capability to purge and inert		X	

No.	Requirement	Primary Verification Mode PMC	S/F	Flight
	B. Propellant Feed and Tank Assembly Requirements			
1.	Verify capability of propellant retention devices to maintain liquid at the tank outlets in zero g			X
2.	Verify ability to provide required conditions at pump inlets continuously			X
3.	Verify ability to fill propellant tanks within two-hour service time		X	
4.	Verify ability to drain propellant tanks		X	
5.	Verify capability to evacuate and monitor vacuum-jacketed lines	X		
6.	Verify capability of thermal vent to vent only gas under zero-g conditions			X
	C. Pressurization Assembly Requirements			
1.	Verify ability to meet pump NPSH requirements			X
2.	Verify capability of vent system to maintain pressure	X		
3.	Verify capability of pre-pressurization		X	
4.	Verify ability to vent tanks	X		
	D. Thrust Vector Control Assembly			
1.	Verify ability to dry gimbal with sufficient clearance	X		
2.	Verify engine alignment	X		
3.	Verify capability to gimbal engines over rate and response range	X		

No.	Requirement	Primary Verification Mode PMC	S/F	Flight
	INTEGRATED AVIONICS SUBSYSTEM			
	A. Electrical Power			
1.	Verify that all subsystem components are accessible for maintenance	X		
2.	Verify that replaceable components can be replaced in the vertical mated configuration	X		
3.	Verify that all electrical connections are accessible, can be readily mated or de-mated, and have positive means to prevent cross-connections	X		
4.	Verify capability of subsystem to withstand mission environmental conditions (temp, press., vibration, shock, acceleration, acoustics, vacuum, zero-g)			X
5.	Verify the functional interface between the power subsystem and other vehicle subsystems	X		
6.	Verify capability for functional checkout of redundant elements	X		
	B. Data and Control Management			
1.	Verify functional capability of DCM and related software to manage, control, monitor, and record data for vehicle subsystems	X		
2.	Verify functional interface between the DCM ground computers and related software	X		
3.	Verify functional interface between the ESS and the shuttle booster			X

No.	Requirement	Primary Verification Mode		
		PMC	S/F	Flight
	C. Guidance, Navigation, and Control			
1.	Verify GSE and checkout procedure compatibility	X		
2.	Verify failure detection and isolation logic	X		
3.	Verify design compatibility with removal and recovery in space	X		
4.	Verify GN&C safe and ready for combined subsystems tests	X		
5.	Verify IMU installation alignment	X		
6.	Verify GN&C installed subsystem is flight ready			X
	D. Communications			
1.	Verify antenna compatibility with applicable transmitter and/or receiver	X		
2.	Verify that RSCR's properly decode and initiate proper subsystems response	X		
3.	Verify communications subsystem control and interlocks with the DBC	X		
4.	Verify ability of the updata to be transmitted onto the data bus and error flags shown under error conditions	X		
	E. Electrical Controls			
1.	Main engine - Verify capability of subsystem to perform all operations, including start, stop, power level, nozzle retraction, and extension	X		
2.	OMS - Verify capability of subsystem to perform multiple start-stop sequences	X		

No.	Requirement	Primary Verification Mode PMC	S/F	Flight
3.	ACPS - Verify capability of subsystem to react in proper combinations selected and start-stop reaction capability	X		
4.	Propellant feed - Verify hardwire control and response for launch control	X		
5.	Pressurization - Verify all functional paths by DCM command and response monitoring	X		
6.	Propellant management - Verify compatibility of mass sensor and level measurements	X		
	F. Instrumentation			
1.	Verify end instruments and associated signal conditioning are operating within measurement tolerance	X		

Preceding page blank

6.0 APPROACH AND RATIONALE

The scope of the test program is determined primarily by test requirements, whereas the approach and rationale are shaped by test philosophy and criteria. This section describes, in general terms, the approach and rationale for the overall test program. In more detail, it describes the mated ESS/booster test activities. The approach and rationale for testing each subsystem is found in paragraph 5.0.

6.1 OVERALL TEST PROGRAM

The test program meets the major milestones identified on the ESS Phase C/D Master Program Schedule and reflects the program requirement for cost-effectiveness. The test program schedule is shown in Figure 4-35.

When compared with previous space programs, the ESS test program has (1) combined tasks to eliminate the need for numerous major test articles; (2) been designed to minimize the requirements for development testing; (3) approached qualification on the basis of functional criticality of hardware; and (4) minimized duplication of support equipment.

Dual use of vehicles to satisfy development test program requirements and later operational requirements has eliminated the need for dedicated test vehicles in static firing, facility fit check, and integration of the installed subsystems.

The two static-firing vehicles are operational vehicles with nonstatic firing subsystems installed to satisfy certification testing requirements. In addition to the primary purpose of main propulsion subsystem integration and interfacing of the main propulsion with support structure, power, control, and instrumentation subsystem, the test vehicle interfaces and functional compatibility with the operational ground support equipment and facilities will be demonstrated where applicable.

Facility fit checks will be performed with the first operational vehicle. These checks will be supplemented by a launch facility fit check of the fully configured ESS and booster in the mated configuration.

Installed subsystem integration tests will also be performed with a flight vehicle. ESS 1 will provide the means for the first end-to-end checks on a total vehicle. Previous combined subsystem tests of the avionics and propulsion subsystems, in conjunction with subsystem level tests of hydraulics,

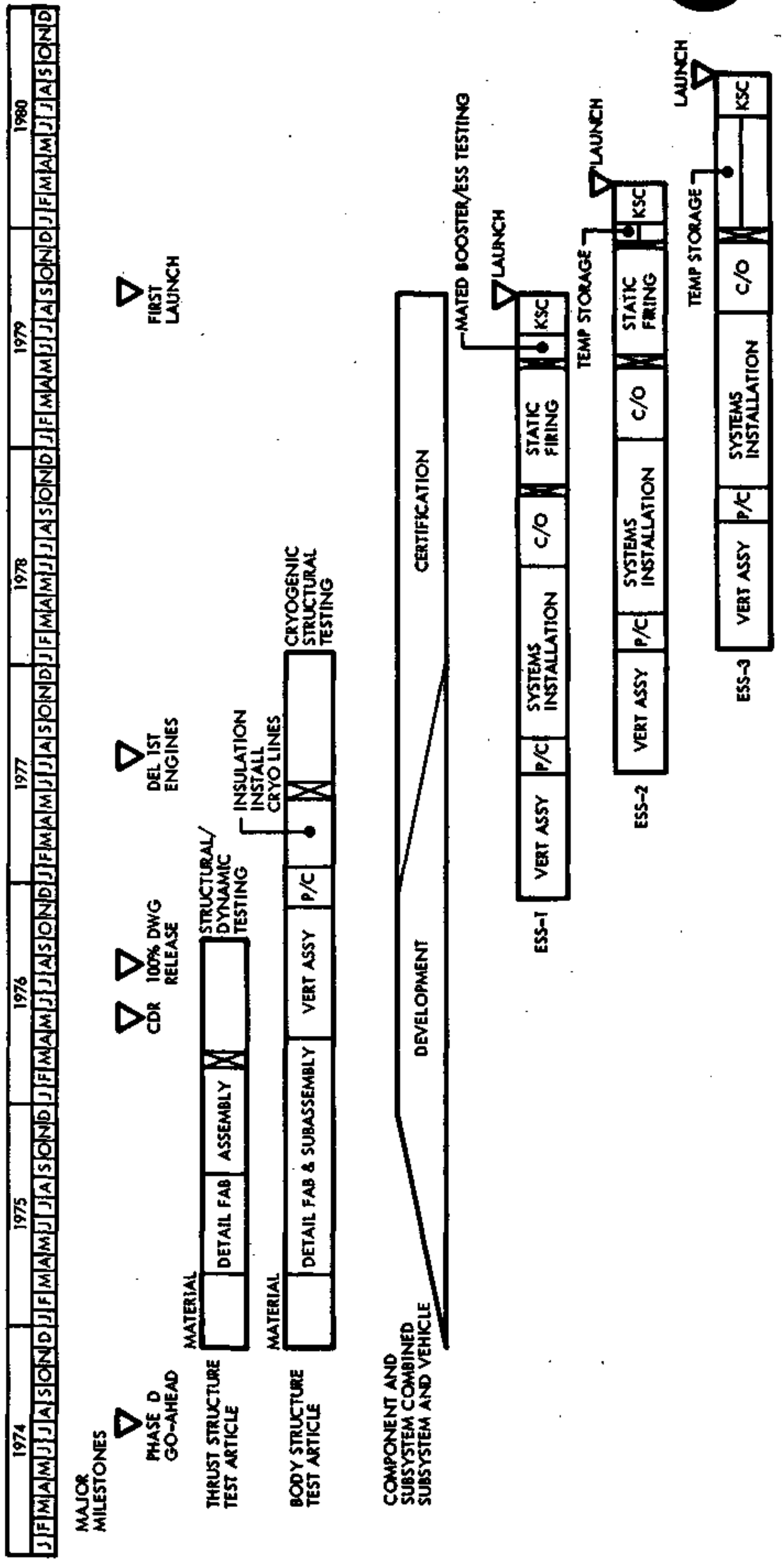


Figure 4-35. Test Program Schedule

will provide the assurance that major discrepancies will not be uncovered for the first time on the flight vehicle during these integrated subsystem tests.

Of the major ground-test vehicles and articles delineated on the MPS schedule, only the structural test articles used for static and fatigue tests will not be reusable as operational vehicles.

In addition to use being made of major test vehicles, the design approach of selecting previously developed hardware and employing proved concepts will further enhance the cost-effectiveness of the test program by minimizing development testing. This is particularly applicable to hydraulics, communications, and other avionics subsystems. Selection of common components for use on the ESS, orbiter, and booster or common support equipment will further reduce the development test requirements.

Qualification testing is required on all Functional Criticality I items (items on which the functional capability could be lost as a result of a single stress or environment and upon which the safety of the crew or vehicle depends). Functional Criticality II items will be certified through the accumulation of test data from development tests, acceptance, and other areas of checkout. Functional Criticality II includes items whose loss could cause the launch to be delayed, the mission to be safely terminated, or primary or secondary objectives to be lost. Limiting qualification testing to Functional Criticality I and only selected items of Functional Criticality II with management approval will minimize the qualification program without introducing hazards to the crew or vehicle.

The test program documentation will consist of plans, procedures, and reports. Certification, flight verification, and acceptance requirements are delineated in the ESS system and end item specifications. These requirements, combined with functional criticality level of hardware items, are the primary factors in establishing the test logic and constraint networks (Figure 4-36). The certification and flight verification plan will incorporate these networks, the justification for analysis for test, and the rationale for the hardware level selected for those tests. Test plans will define the approach and rationale for implementing the tests. Support requirements will be identified for each test or test series in their respective plans. In addition, lists of facility, support equipment, and software requirements will be compiled into separate documents. These will identify need dates, total requirements, and shared or common usage items.

Any additional development testing will be based upon development test requirements. All development, qualification, and acceptance test and checkout will be performed to standardized test and checkout procedures prepared in consonance with quality assurance and safety ground rules. Quick-look and engineering-analysis reports will be prepared on all

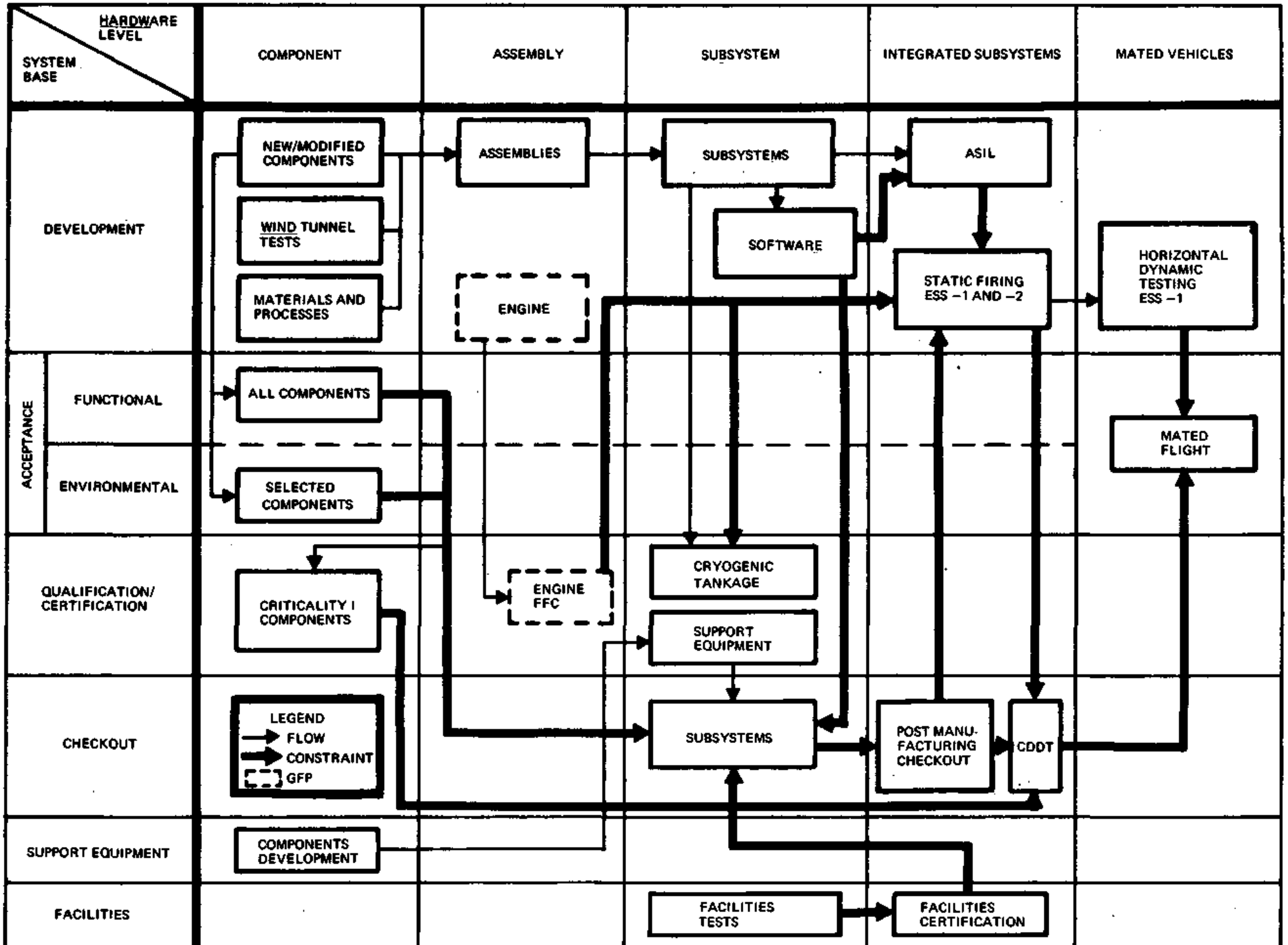


Figure 4-36. ESS Test Logic and Constraint Network

development tests and those qualification tests where anomalies occur. Final reports will be prepared on development and qualification testing of subsystems, major combined subsystems, and for vehicle acceptance tests.

A data base will be compiled for ready retrieval of test data. The base will include test-article configuration, test results, mean time between failure, and any anomalies during test.

Components and subassemblies are accepted by process and procurement specifications. The vehicle, support equipment, and software will be accepted according to checkout procedures. Such approvals will become a part of the customer acceptance data package. Services and support agreements or program requirement documents will be prepared delineating all base and range support for launch operations. Before checkout stations are used at the test sites, the facilities, with support equipment installed, will be verified by site certification checkout procedures.

Manufacturing checkout comprises in-process and final acceptance checkout functions starting with acceptance of a component at a subcontractor facility and ending with integrated vehicle checkout and delivery to the operational site. In-process checkout is performed as a function of the vehicle major assembly build cycle. It includes structural integrity and cleanliness verification of the tube systems. It also includes wire harness and limited subsystem functional checks to verify correct installation of the subsystem elements peculiar to that major assembly under test. The major assemblies are delivered for final assembly and integrated acceptance checkout. Acceptance checkout will be accomplished on the vehicle to demonstrate that the product complies with specifications, is capable of performing in conformance with contractual requirements, and is free from manufacturing defects.

6.2 MATED ESS/BOOSTER

The mated ESS/booster test activities are defined as those tests performed in the mated configuration and ESS and booster tests performed in preparation for a mated launch. The ground tests include low-frequency dynamic tests of the mated ESS/booster; interface checks of the ESS, booster, and the mated configuration with the operational site facilities and support equipment; and prelaunch checkout of the ESS and booster.

The ground vibration test is planned to obtain bending and torsion modes and damping characteristics. It is similar to the tests conducted independently on the ESS and booster. The mated vehicle will be in the horizontal position supported by a low-frequency suspension system and will be stimulated by low-force-level inputs. These measured responses will provide a basis for analytically extrapolating ESS and booster measurements to the mated boost configuration.

Interface checks with the support equipment and facility at each applicable launch site checkout area will be required for both the ESS and booster. These areas include maintenance and repair, mated vehicle launch complex, and post-mission safing areas. At each checkout area, the support equipment/facility interfaces will be checked, and the support equipment/facility will be functionally verified with an integrated acceptance checkout before connecting with the vehicle for interface checks. Interface checks will be repeated as each new ESS and booster is cycled through the checkout areas.

Prelaunch checkout of the first ESS and booster at the launch site includes subsystem tests in the maintenance and repair (M&R) checkout stations. An integrated subsystems test, including a mission simulation, will precede the move to the mating area where the ESS and booster will be erected, mated, and readied for transport to the launch complex. Support equipment hookup, interface checks, and an integrated vehicle checkout will be conducted prior to tanking tests, which will then be accomplished for the first time with the vehicles in the mated configuration. Vehicle subsystems will be verified ready for launch, including interface with range tracking and communication systems. After it has been verified that all ESS/booster system elements are ready for launch, the countdown will be initiated.

The first launch of the mated configuration will demonstrate booster main propulsion subsystem performance and ESS/booster controllability, and will provide measurements to verify static and dynamic load predictions in the areas of ignition shock, acoustics, and separation. Aerodynamic interference and boost heating parameters will be measured to verify analytical estimates and wind tunnel measurements. Separation performance will be evaluated based on sequence of events, ESS thrust buildup and booster thrust decay, and separation linkage loads for nominal conditions. There is currently no requirement for demonstrating separation at other than nominal conditions.

7.0 COMMONALITY/COST EFFECTIVENESS

In accord with the overall program objective of cost-effectiveness, the test program has been developed with commonality and cost-effectiveness as salient features. Although specific subsystem components will not be selected until Phase C of the program, the subsystems selected during Phase B all have significant commonality with either the S-II or the space shuttle orbiter.

However, cost-effectiveness' only role is not with the hardware involved in a test program. It has a major role when personnel and techniques are considered. A cadre of the highly successful S-II and Apollo post-manufacturing checkout and S-II static firing personnel is available to implement the test programs on the ESS. This cadre also has at its disposal detailed records and histories that will enable cost-effective operations to be initiated at the onset of the test program.

Cost-effectiveness has been the byword of this test plan, with emphasis in the realms of development and qualification testing. Use of S-II and space shuttle orbiter subsystems will, in effect, dictate the use of S-II- and orbiter-developed components, thereby minimizing the ESS DDT&E costs. Adoption of the Criticality I qualification standard significantly reduces qualification costs.

The following breakdown by system and subsystem defines the major hardware cost-effectiveness features of the ESS test program.

Vehicle

- No dedicated full-scale all systems test article, mated dynamic testing will be conducted on the first flight vehicle.
- The first two flight vehicles only will be static-fired.

Main propulsion

- Development and certification of the space shuttle orbiter engines by the engine contractor and preliminary subsystem development by the orbiter program
- Propellant feed, vent, and fill and drain assemblies developed by the S-II

Auxiliary propulsion	• Developed and certified by the orbiter program • Subsystem testing only by the engine contractor
Structures	• Fabrication techniques developed by S-II
Insulation	• Spray-on-foam insulation and installation techniques developed by S-II
Integrated avionics	• Use of orbiter-developed and certified subsystems • Use of proposed tracking and data relay satellite and/or existing MSFN data network
Wind tunnel test	• Use of space shuttle booster wind tunnel models • Maximum use of space shuttle wind tunnel test data

8.0 SUPPORT REQUIREMENTS

The cost-effectiveness goal of the ESS program dictates heavy use of S-II- and space-shuttle-developed hardware during Phase C component selection. This will minimize the support requirements for component- and assembly-level testing. As components are selected during Phase C, design verification requirements will be established. From these requirements the support requirements will be established. It is anticipated that existing and space shuttle facilities will satisfy these requirements. The following paragraphs describe the support requirements for the combined subsystems level requirements of paragraph 5.2.

8.1 AVIONICS SUBSYSTEMS INTEGRATION LABORATORY (ASIL)

ESS avionics will be integrated in a laboratory known as the Avionics Subsystem Integration Laboratory (ASIL). The ASIL will consist of (1) the data and controls management subsystem (DCM) with applicable flight software and special purpose software; (2) the guidance, navigation, and control subsystem (GN&C) with the inertial measurement unit mounted on a (TBD) degree of freedom table and the capability to interface with the hydraulics/controls laboratory for end-to-end flight controls testing; (3) the communications subsystem (COMM) with artificial stimuli of the navigation and rendezvous aids; (4) the electrical power subsystem with simulations of all actual power sources and selected non-avionics loads; and (5) the electrical controls subsystem. To facilitate DCM, software, and COFI evaluations, computer and/or other simulations of selected portions of non-avionics subsystems and payload interfaces will be available

8.2 POST-MANUFACTURING CHECKOUT

Post-manufacturing checkout (PMC) will be accomplished in a facility in which leak and functional checks can be performed on all vehicle subsystems and automatic functional checkout of the integrated subsystems can be conducted. The facility must be able to supply the vehicle with regulated pressurants and electrical power. It must include a hydraulic servicing unit for the thrust vector control systems. It will be required to have both manual and automatic data acquisition systems via both hardwire and telemetry links. It must have the capability to interface with the vehicle integrated

C-4

avionics subsystems to verify the operation of the vehicle on-board checkout (OBCO) routine. Software developed for the ASIL will also be used during PMC.

8.3 STATIC FIRING

The static firing conducted on the first two ESS flight vehicles will be performed at the operational site. The concept used for the space shuttle orbiter static firing program will also apply to the ESS program; that is, a temporary support structure will simulate the booster attach fittings and will suspend the ESS at the proper elevation for swing-arm interfacing. The ESS will be suspended directly above the flame deflector, and main propulsion aspirators will be provided to direct the rocket engine exhaust into the flame deflector. Extensions will be necessary to provide electrical, pneumatic, and fluid servicing from the swing arms to the vehicle umbilical panels. The static firings will be conducted by launch operations personnel from the launch control center with launch support equipment.

9.0 REUSABLE SHUTTLE BOOSTER AND SEPARATION STRUCTURE

9.1 GENERAL DESCRIPTION

The ESS consists of a modified Saturn S-II stage plus one of three payloads: (1) a nuclear stage, (2) a McDonnell Douglas space station, or (3) a space tug. The ESS/B-9U separation subsystem operates similarly to the 161C orbiter/B-9U separation subsystem. However, since the booster is designed to react all drag loads from the second stage orbiter at the forward separation links only, and the Saturn S-II is designed to take concentrated drag loads at its aft end only, an adapter is required to transfer the drag load from the ESS aft end forward to the forward separation mechanism. This adapter will be a fixed platform (Dwg 76Z1223) pinned to the booster at the same points as the baseline forward separation links. It incorporates aft separation links between the aft end of the ESS and the aft end of the platform. The forward separation links tie the forward end of the platform to the ESS. During boost, the ESS drag load is carried by the aft separation links in compression and the platform in tension. During separation, the platform will experience transient compression and bending loads as the ESS moves away from the booster. This subsystem uses seven separation bolts: four to disconnect the vertical support links and deploy the separation (swing) links and three to disconnect the separation links from the ESS.

The forward and aft separation (swing) links, as well as their retract actuators, will be modified to account for higher loads. There will be two additional retract actuators for stowing of the aft separation links. The stage separation controller and communications link will be modified to ESS/B-9U requirements.

9.2 REQUIREMENTS

The ESS separation subsystem certification requirements are identical to orbiter/booster stage separation system requirements.

9.3 TEST APPROACH AND RATIONALE

The following tests will be used to develop and qualify the ESS separation subsystem. These are in addition to the baseline test program outlined for the orbiter/booster stage separation subsystem (Sections 5.18 and 6.4 of Preliminary Test Plan, SD 71-105-3).

9.3.1 Structural Tests

Structural development testing will include static and fatigue tests of full-scale lugs, pins, and rod ends plus any unique fittings. A single full-length side beam out of the platform will be tested in tension, compression, and bending. Truss member attachment to the beam will be simulated with supports of correct stiffnesses.

Structural qualification of the complete ESS/booster separation subsystem will be accomplished in a combined subsystem test on the aft body structural qualification articles.

Some additional static test conditions will be required in the stiffness determination tests on the booster aft body static test article for ESS/booster dynamic data.

The full-scale vibration test of the complete booster (in the horizontal position) will be expanded to include tests of the booster-ESS mated configuration. These will determine total system mode shapes and frequencies for verification of the dynamics mathematical model.

9.3.2 Booster Subsystems Tests

The separation system controller will be tested for the additional programming required for ESS separation, plus additional fault-tolerance as required, using probabilistic failure conditions. The breadboard electrical system will be modified to include the added network and will be tested with the separation system controller to verify sequencing and timing requirements.

Electrical/hydraulic components consisting primarily of the separation bolts and retract actuators will be qualified per subcontract design specifications. All electrical/electronic LRU's will be common with the baseline system types. No additional individual LRU qualification would be anticipated.

9.3.3 Performance Analysis

Additional wind tunnel tests will be conducted with mated booster/ESS models to describe the interference aerodynamics of the two vehicles. Main engine plume effects will be included. Approximately 10 Mach points will be investigated. These data will be used in the separation system simulation computer program.

In the final validation of the complete ESS separation subsystem a computer simulation program will be used similar to that used for the baseline configuration. The simulation will include off-nominal, abort, and failure conditions. Final operating characteristics, including tail clearances, will be defined. These tests will qualify the subsystem for flight.

9.3.4 Flight Tests

Nominal separation performance will be verified in a flight of the mated configuration and subsequent postflight analysis. No experimental attempts will be made to verify abort separation.

9.4 TEST CONFIGURATION

This program will use the same major vehicle assemblies planned for the baseline program; namely, the static and fatigue structural test assemblies comprising two structurally complete LH_2 tanks, intertank adapters, thrust structures, and sets of separation linkage/mechanisms. Two platforms, modified swing links, etc. will be added.

Static testing to design ultimate loads will be conducted on one complete ESS separation structure installed on the static test structural aft body mounted in the vertical position. These will also serve as local load conditions for the aft body, thus qualifying both the mechanism and affected body structure for ESS separation loads.

Functional testing will be performed at the combined subsystem level on a second set of separation mechanisms installed on the fatigue test structural aft body in the vertical position. This will provide simulation of actual loads, operation, and sequencing, including bolt separation, except that tests will not be conducted in true time.

Since the total number of ESS flights planned is relatively small, full-scale fatigue testing of the ESS separation system is not planned.

9.5 TEST HARDWARE REQUIREMENTS, SEPARATION STRUCTURE

No.	Item	Quantity
	Subsystem-Level Tests	
1.	Full-scale lugs and pins	1 Set
2.	Support link rod ends	1 Set
3.	Separation link rod ends	1 Set
4.	Full-scale beam of platform	1
5.	Stowing actuators	1 Set
	Combined-Subsystem-Level Tests	
1.	Full set of ESS support and separation structures and mechanisms	2
2.	Stowing actuators	2 Sets
3.	Aft body static test article (not added hardware)	0
4.	Aft body fatigue test article (not added hardware)	0

10.0 GLOSSARY

The following definitions are applicable to the test plan. They are subject to change with the completion of other acquisition plans.

Acceptance	The act by which the customer approves specific services rendered or acknowledges that certain specific articles or end items are in conformity with the contract and/or with applicable Class I documents.
Acceptance tests	Tests to verify that the end-item hardware conforms to the applicable specification for performance as a basis for acceptance. Also, where applicable, tests to confirm that the end-item performance and configuration is equivalent to a previously certified end item.
ACPS	Attitude control propulsion subsystem.
Aerodynamics	The branch of dynamics that treats (1) the motion of air and other gaseous fluid and (2) the forces acting on solids in motion relative to such fluids.
ASIL	Avionics Subsystems Integration Laboratory.
APS	Auxiliary propulsion subsystem (composed of the ACPS and OMS).
Attitude	The position of a vehicle as determined by the inclination of its axes to the relative wind.
Breadboard	A subsystem or functional portion of a subsystem assembled schematically correct but not packaged in the final configuration and not necessarily using qualified components. Used during development testing to ascertain the feasibility of a design approach.
Checkout	A sequence of functional, operational, visual inspections or calibration tests to determine the condition and status of system equipment or element thereof.

COFI	Checkout fault isolation.
Combined subsystems tests	Any test that involves the operation and interdependence of two or more subsystems through a common interface (or interfaces).
Common data base	Diverse data collected and stored in a compatible format with a minimum of redundancy and structured in a manner that permits timely data correlation and retrieval.
Common use	Use of an item in, or in conjunction with, multiple program support applications.
Commonality	Any item of hardware, materials, software, or any services common to or having equal usage with two or more system prime elements (i. e., ESS, orbiter, booster, payload module, or associated ground systems) that can be developed, procured, or performed in a common manner.
Component	Any self-contained part or unit that performs a distinctive function necessary to the operation of a system.
Constraint network	A portrayal of the verification requirements of an end item showing the sequence of verification operations and the appropriate rationale for each component/subsystem. The network also depicts the prerequisites and the constraints that require a prescribed level of verification by one component/subsystem before being operated with another item. The constraint network will ensure that all test requirements are satisfied with a minimum of redundant testing.
Contract end item (CEI)	A contract end item is defined in the contract and normally is an item that has a functional entity capable of being controlled through a separate part number and serial number.
Controllability	The quality of a vehicle that determines the ease of operating its thrust vector controls and the effectiveness of thrust vector control displacement in producing change in flight attitude.

Criticality I	A measure of the critical nature of a function that, if a failure were to preclude satisfactory performance of that function, would make loss of crew members' lives or vehicle imminent.
Criticality II	A measure of the critical nature of a function that, if a failure were to preclude satisfactory performance of that function, would cause one or more of the following conditions to occur, depending on the particular time in the mission of the failure: (1) immediate (safe) mission-flight termination, (2) unscheduled termination of the next planned earth impact area, (3) loss of primary and/or secondary mission objectives, and (4) launch scrub or delay.
DCM	Data and control management subsystem.
Development	The process of advancing from one state or condition to an improved condition and/or the achievement of improved capability as an outgrowth or derivative of a previous capability.
Development tests	Tests employed as a part of the development process to verify design predictions, to determine the feasibility of the design approach, to develop test and checkout procedures, to ascertain the responses to stimuli or combination of stimuli that are difficult to predict accurately, and to provide confidence in the ability of the hardware to pass qualification tests.
End item	A complete functional item of equipment, a separate entity normally capable of being controlled through a separate part number and serial number.
Facility	A permanent or semipermanent functional capability that is built, installed, or established to perform a particular function or to serve a particular purpose.
Failure mode and effect analysis (FMEA)	A systematic evaluation of a system or subsystem design, analyzed to the component level, to find the possible modes of failure and determine their effect on the system.

Ground tests	Any tests performed on the ground as opposed to flight tests performed in a flying vehicle. Includes wind tunnel tests, subsystem development and qualification tests, simulation tests, etc.
GN&C	Guidance, navigation, and control
Integrated systems test	A test of the prime item involving multiple subsystem operation to verify the overall capability of the flight subsystems to meet the mission performance requirements as a total or integrated system and to verify that the subsystems are physically, functionally, and operationally compatible with each other and with mating ground support functions.
Launch complex	A collection of all of the support equipment, servicing equipment computers, communication equipment, and all related services required at the launch site to perform the countdown and launch of the shuttle vehicle.
Qualification	The determination, performed with appropriate rigor, that an item of hardware meets it specified design and performance requirements throughout the predicted environments or combination of environments with designated margin. Qualification can be accomplished by analysis of data, by similarity, by demonstration, by test, or by some combination of these methods.
Qualification test	A test performed with appropriate rigor on selected hardware of production configuration and manufactured by production processes to verify that the item meets the design and performance requirements while being subjected to the worst-case predicted environment or combination of environments with specified margins as defined in applicable specifications. The tests are conducted as a formal demonstration of design and performance adequacy.

Reynolds number	A nondimensional coefficient used as a measure of the dynamic scale of a flow. Its usual form is the fraction $\rho Vl/\mu$ in which ρ is the density of the fluid, l is a linear dimension of a body in the fluid, μ is the coefficient of viscosity of the fluid, and V is the velocity relative to the fluid.
Mating area	A specific area at the launch facility set aside and properly equipped for the assembly operation of mating the ESS and booster prior to launch.
Mission-critical	A function or hardware item whose successful operation is essential to the satisfactory execution of the intended mission.
MPS	Main propulsion subsystem.
OMS	Orbit maneuvering subsystem.
Operational facility	A facility devoted to performing all or part of the functions associated with the operational aspects of the ESS/booster vehicle.
Operations plan	Document that describes the requirements and sequence of tasks for operation and maintenance of the ESS/booster system to ensure capability to perform a variety of orbital missions.
Pogo	An interaction among fuel-pressure pulsations, chamber-pressure fluctuations, engine-thrust variations, vehicle structural deflections, and line/tank volume change producing a divergent longitudinal oscillatory coupling that can reach levels hazardous to the vehicle structure and thereby impair flight crew safety.
Safing area	An area of, or adjacent to, the prime landing site specifically dedicated to and equipped for rendering the booster safe (1) for personnel ingress and egress and (2) with respect to the functional integrity of the vehicle after returning from a mission.
Scale effect	The change in any force coefficient, such as the drag coefficient, due to a change in the value of the Reynolds number.

Shuttle system	A collection of reusable prime system elements (orbiter, booster, payload module, and ground systems) and related supporting hardware, software, personnel, and consumables that provide a capability for the delivery and/or retrieval of personnel and/or cargo into a variety of low earth orbits at minimum cost.
Software	Punched cards, punched or magnetic tapes, etc. used to control the operation of semiautomatic or automatic devices.
Stability	That property of a body that causes it, when disturbed from a condition of equilibrium or steady motion, to develop forces or moments that tend to restore the body to its original condition.
Stability, directional	Stability with reference to disturbances about the normal axis of an aircraft; i. e., an airplane possesses directional stability in its simplest form if a restoring moment comes into action when it is given a small angle of yaw.
Stability, dynamic	That property of an aircraft that causes it, when its state of steady flight is disturbed, to damp the oscillations set up by the restoring forces and moments and gradually return to its orignal state.
Stability, inherent	Stability of an aircraft due solely to the disposition and arrangement of its fixed parts; i. e., that property which causes it, when disturbed, to return to its normal attitude of flight without the use of the controls or the interposition of any mechanical device.
Stability, lateral	Stability with reference to disturbances about the longitudinal axis; i. e., disturbances involving rolling or sideslipping. The term lateral stability is sometimes used to involve both directional and lateral stability since these cannot be entirely separated in flight.
Stability, longitudinal	Stability with reference to disturbances in the plane of symmetry; i. e., disturbances causing airplane pitching and variation of the longitudinal and normal velocities.

Stability, static	That property of an aircraft that causes it, when its state of steady flight is disturbed, to develop forces and moments tending to restore its original condition.
Subsystem	A major functional part of a system essential to the operational completeness of the system.
Support equipment	All equipment required to support the operation and maintenance of the vehicle and all its airborne equipment.
System	A composite of equipment, skills, and techniques (including all related facilities, equipment, material, services, and personnel) that is capable of performing a clearly defined function in the achievement of an objective.
Test flows	A diagram showing the sequence of tests to be performed on an item of hardware.
Test logic	The rationale for performing a series of tests in a particular sequence.
Test logic and constraint network	See constraint network.
Vendor testing	Testing by a vendor or subcontractor on his product prior to delivery to the prime contractor or customer.
Wind tunnel	An apparatus producing an artificial wind or air stream in which objects are placed for investigating the air flow about them and the aerodynamic forces exerted on them.

SECTION V

LOGISTICS AND MAINTENANCE PLAN

Preceding page blank

CONTENTS

Section		Page
1.0	INTRODUCTION	5-1
	1.1 OBJECTIVES	5-1
	1.2 SCOPE AND CONTENT	5-1
	1.3 REFERENCE DOCUMENTS	5-2
	1.4 GROUND RULES	5-2
2.0	MAINTENANCE CONCEPT	5-3
	2.1 PURPOSE	5-3
	2.2 CONCEPT	5-3
	2.3 MAINTENANCE LEVELS	5-4
	2.4 MAINTENANCE QUALITY REQUIREMENTS	5-5
	2.5 MAINTENANCE SUPPORT REQUIREMENTS ANALYSIS	5-5
	2.6 SUPPORT ANALYSIS AND PLANNING	5-6
	2.7 MAINTAINABILITY	5-6
	2.7.1 Definition	5-6
	2.7.2 Purpose	5-6
	2.7.3 Scope	5-7
	2.7.4 Maintainability Analysis	5-9
	2.7.5 Quantitative and Qualitative Requirements	5-10
	2.7.6 Maintainability Verification	5-10
	2.7.7 Vendor Control and Prime Associate Contractor Liaison	5-10
3.0	SUPPORT EQUIPMENT	5-11
	3.1 PURPOSE	5-11
	3.2 SCOPE	5-11
	3.3 REQUIREMENTS	5-11
	3.4 REQUIREMENTS DEFINITION	5-12
	3.5 ACQUISITION OF SUPPORT EQUIPMENT	5-12
	3.6 CONTROL OF SUPPORT EQUIPMENT	5-13
4.0	FIELD SUPPORT SERVICE	5-15
	4.1 PURPOSE	5-15
	4.2 SCOPE	5-15
	4.3 SITE SUPPORT	5-15
	4.4 SUPPORT SERVICES	5-15

Section		Page
	4.5 MATERIAL ACCOUNTABILITY AND INVENTORY	5-16
	4.6 FACILITY MAINTENANCE	5-17
	4.7 SITE ACTIVATION	5-17
5.0	TRANSPORTATION	5-19
	5.1 TRANSPORTATION SYSTEM REQUIREMENTS	5-19
	5.2 DOCUMENTATION REQUIREMENTS	5-19
6.0	PROPELLANTS, PRESSURANTS AND COOLANTS	5-21
7.0	SUPPLY SUPPORT	5-23
	7.1 PURPOSE	5-23
	7.2 SCOPE	5-23
	7.3 PROVISIONING	5-23
	7.3.1 Spares Configuration Control	5-24
	7.3.2 Acquisition of Spares	5-24
	7.3.3 Reuse of Retrieved Hardware	5-24
	7.3.4 Inventory Management	5-24
	7.3.5 Expedite System	5-26
	7.3.6 Reparables and Recovered Hardware Refurbishment Controls	5-26
8.0	TRAINING	5-27
9.0	TECHNICAL SUPPORT DOCUMENTATION	5-29
	9.1 DOCUMENTATION DEVELOPMENT	5-29
	9.2 DOCUMENTATION TYPES	5-30
	9.2.1 General Manual	5-30
	9.2.2 Subsystems Maintenance Manuals	5-30
	9.2.3 Support Systems Maintenance Manuals	5-30
	9.2.4 Illustrated Parts Breakdown (IPB) Manual	5-30
	9.2.5 ESS Operations Manual	5-30
	9.2.6 Modification Instructions	5-31
	9.2.7 Document Preparation, Revision, and Validation	5-31
10.0	PACKAGING AND HANDLING	5-33
	10.1 PURPOSE	5-33
	10.2 SCOPE	5-33

Section		Page
	10.3 PACKAGING FOR FLIGHT VEHICLE AND MAJOR ASSEMBLIES	5-34
	10.4 SPARE PARTS AND REPARABLES . . .	5-35
	10.5 SUPPORT EQUIPMENT.	5-35
11.0	DEFINITIONS	5-37
12.0	BOOSTER AND SEPARATION STRUCTURE	5-43

SECTION V. LOGISTICS AND MAINTENANCE PLAN

1.0 INTRODUCTION

1.1 OBJECTIVE

The objective of this section is to define and establish the ESS Program requirements for maintenance and logistics activity that will provide effective and economical support of the ESS Program test and operations effort within schedule constraints.

1.2 SCOPE AND CONTENT

The Logistics and Maintenance Plan provides a description of maintenance activities required to support the test and operations effort on the ESS vehicle and support equipment at the static firing and launch site. The plan also identifies the supporting elements required to conduct the maintenance activities and details the requirements on which the support systems will be developed. The plan also considers the ESS earth orbital hardware removal from a maintenance design standpoint and the reuse of this hardware.

Hardware removal, retrieval, and return to earth operations are covered under the Operations Plan (Section I of this volume). The plan is divided into sections which delineate the requirements and the approach to satisfying these requirements for each of the major logistical support elements. Initially, the ground rules are identified that provide the constraints within which the plan is formulated. The maintenance concept section defines the maintenance levels, the concepts to be developed, and the support requirements analysis utilized as the central integrating function for all support planning effort. Maintainability is presented as a requirement to be incorporated in early design to minimize the expenditure of time, personnel skills, and logistics resources under the planned maintenance environment. The support equipment section depicts the related maintenance, storage, control, and support needs. Field support service activities are depicted that include the requirements for establishing site support and activation. The requirements for transporting the stage and support equipment items between the manufacturing, static firing/launch site are depicted. Supply support requirements include the management and control systems for the processing, acquisition, and refurbishment of stage support equipment spares, and modification kits and materials to support site operations. Customer and contractor training considerations are identified for the operations and maintenance personnel. Finally, packaging requirements are depicted which include the protection of vehicle and support equipment, assemblies, components, and spares during handling transportation and storage phases.

1.3 REFERENCE DOCUMENTS

SID 62-286	S-II Logistics Implementation Plan
SID 62-1222	S-II Maintenance Concept for Saturn
SD 71-106	Space Shuttle Logistics and Maintenance Plan for Phase C/D

1.4 GROUND RULES

The ESS Logistics and Maintenance Plan is predicated on the following ground rules:

1. Launch rate - two per year

2. Duration of launches - ten years

3. Stages 1 and 2 will undergo KSC static firing

4. Six ESS shuttle engines (two per ESS) will be utilized for initial installation, recovery, refurbish, and recycle.

   Five sets of recoverable avionics packages will be utilized for initial installation, recovery, and recycle.

   Two engines and four engine actuators plus avionics packages constitute one set of recovered, and reinstalled hardware.

   New design concepts, as identified by Engineering, will be analyzed and evaluated for feasibility of support with existing S-II hardware and documentation.

5. Stages 1 through 3 will undergo initial engine installation and checkout at Seal Beach. Stage 4 and subsequent stages will undergo engine installation and checkout at the launch site.

6. Stages 1 through 5 will undergo initial avionics (recoverable) package installation and checkout at Seal Beach. Stage 6 and subsequent stages will undergo recovered and refurbished avionics package installation and checkout at the launch site.

2.0 MAINTENANCE CONCEPT

2.1 PURPOSE

This section establishes requirements for the Phase C/D Maintenance Plan, which will provide a cost-optimized ESS system maintenance program responsive to total program objectives. Space shuttle-oriented vehicles require different maintenance approaches than those currently used in the manned spacecraft program, because of the reuse of the systems and the rapid turnaround requirements. The questions of "why, where, how, and when" to implement and accomplish maintenance will be developed to support the ESS program requirements.

2.2 CONCEPT

The ESS maintenance concept must satisfy maintenance requirements identified for the ESS, the associated support equipment, and the ESS-peculiar facilities. The ESS maintenance concept is substantially similar to the S-II program concept, but tuned to the space shuttle requirements in terms of minimum time impact to the booster. Maintenance at each support site will generally be limited to removal of the deficient item, installation of a certified like item, verification of the "fix," and calibration or adjustment for matching or mating of the replacement item to other assemblies of the system in which it functions. Selected support equipment end items, and facilities systems as defined, will be subjected to corrective and preventative maintenance. The requirements will be detailed to the lowest replaceable component and to the most practical level of replacement commensurate with fault isolation and repair time, verification capability, and level of support required to maintain an overall cost-effective program.

The on-board checkout equipment will provide identification of discrepant vehicle equipment to the replaceable level. In many cases, the on-board checkout capability will delete the requirement for additional checkout support equipment to verify corrective maintenance tasks.

Maintenance concepts will be developed to support the quantitative and qualitative requirements. The concepts will identify an integrated approach, using engineering, logistics, reliability, operations, and maintenance skills to determine maintainability design performance requirements and to assure that maintainability is operationally developed and verified. Typical concepts, such as the following, shall be evaluated, developed, and implemented for ESS application in subsequent phases:

1. All flight elements will be maintainable unless system reliability would be degraded to an unacceptable level by the maintainability features.

2. Maintenance methodology will be validated on functional hardware, or dimensional simulators, in a controlled manner during the hardware development phase.

3. Subsystem design and installation will consider methods to eliminate, reduce, and simplify maintenance tasks and special tools.

4. Maintenance methodology and design solutions will consider mission support costs, with the goal to achieve minimum life cycle costs.

5. Tradeoffs between reliability and maintainability will be performed to establish the best design solution for optimum program balance.

2.3 MAINTENANCE LEVELS

Maintenance effort is required at the following three levels:

Level 1. Ground Checkout: This level will be limited to fault isolation, module replacement, subsystem servicing and adjustment, and maintenance action verification.

Level 2. Bench Maintenance: This level will be direct support to ESS Level 1 maintenance for ground operations. The functions may be performed at Seal Beach or at the launch site maintenance shops. It is anticipated the shuttle maintenance shops can perform all of the effort with minimal impact.

Level 3. Depot Maintenance: This level of maintenance is coupled with complete module and subsystem overhaul, refurbishment, and modification capability. The locale of this effort will be the contractor facility or customer repair sites where the detailed repair parts or modification kits requisitioned from spares inventory and special complete overhaul capability exists. Maximum effective use will be made of shuttle facilities.

2.4 MAINTENANCE QUALITY ASSURANCE REQUIREMENTS

Performance of effective maintenance and support will require implementation of a quality assurance operation consistent with each maintenance level being performed. Maintenance accomplished will conform to the applicable quality assurance guidelines and procedures. Inspection will be performed periodically and on a selective basis to critical sequences to ensure that maintenance actions accomplished are of acceptable quality.

2.5 MAINTENANCE SUPPORT REQUIREMENTS ANALYSIS

Maintenance support requirements analysis is defined as the composite analytical studies, decisions, and related documentation made in conjunction with the design of an item to determine or influence the maintainability/supportability characteristics of the item and to determine the total support requirements resulting from the design. The support analysis will be based on review of design, test, operations, and missions analysis data. It is the central integrating function for all support planning effort. The analysis is a continuing effort to the component level and will identify, classify, and describe the following:

1. The required maintenance tasks, their sequences, level, and location

2. Potential maintenance problems for solution such as inadequate design consideration of maintenance and other support requirements

3. Source maintenance recoverability (SMR) code identifying spares and their support, consumables, and other equipment and materials to perform the identified task

4. The quantity, skills, and training of personnel required to perform these tasks

5. The required support documentation by type and projected use

6. The preoperational and operational support systems, transportation and handling, and packaging required in terms of quantities and allocations

7. The commonality of support requirements to decrease the resource expenditures.

2.6 SUPPORT ANALYSIS AND PLANNING

The logistics support required for Seal Beach ESS checkout and KSC prelaunch and launch operations will include maintenance facilities, support equipment, personnel and skills, support documentation, and supply support functions involving on-time supply of spares, material, and hardware. A maintenance/support analysis effort will be established as an integral part of the overall requirements analysis system, which is performed concurrent with the design process. The analysis will serve to identify the total support resources requirements resulting from the design, based on drawings, test, operations, and mission analysis review feedback. Requirements and impact on support cost will be coordinated with design to achieve the most overall cost-effective ESS design logistics and support optimization.

Support maintenance planning will be performed concurrent with the analysis. It will define the optimum support and repair level and will consider alternate design approaches, safety, operating environment, repair and discard decisions, and skills and support equipment (SE) requirements. The planning activities will include both ground systems and flight hardware. The planning activities utilize the design, operational plans, safety and reliability considerations as the source from which the support resources will be derived. Included are the relationships with subcontractors supplying GFE and their maintenance planning inputs. A contractor ESS maintenance/support data collection system will be established to verify the maintenance analysis.

2.7 MAINTAINABILITY

2.7.1 Definition

Maintainability is defined as the design characteristic that makes possible the preservation or restoration of a functional element to its operational state with a minimum expenditure of time, personnel skills, and logistics resources under a planned maintenance environment. Maintainability characteristics must be included among the first design considerations for developing a hardware system, so that maintainability can be achieved in a cost-effective manner. These characteristics include, but are not limited to, accessibility, serviceability, repairability, commonality, standardization, interchangeability, component mounting, lifting and attach points, and related operational flexibility.

2.7.2 Purpose

The maintainability program established for the vehicle and support equipment will (1) provide a systematic method and continuous process to promote the feasibility of SE recycle and related maintenance activities as allocated by program operational requirements, (2) minimize maintenance manhours and subsequent training requirements, and (3) increase vehicle and support equipment availability with resultant reduction in quantitative hardware requirements. The system will provide the criteria, methods, controls, and verification for maintainability incorporated into early design. ESS maintainability studies will be coordinated with like studies on the space shuttle to ensure maximum commonality of approach and resources.

2.7.3 Scope

The maintainability program will provide for design evaluation and the incorporation of maintainability features that will reduce maintenance activities and allow the following:

1. Recoverable hardware access, disconnection, shuttle manipulator arm attachment, and removal and load into the shuttle cargo module during earth orbit.

2. Hardware remove and replace considerations during ground operations.

3. Refurbishment of recoverable hardware, recycling, and reinstalling.

The maintainability program will provide the criteria, analysis, and verification that maintainability is incorporated into the early design. The impact of design changes on maintainability predictions and operational activities will be assessed for compatibility with maintainability goals.

Close liaison between maintainability and design engineering personnel will be an integral part of the system engineering approach to achieve the maintainability objective. A closed-loop process (Figure 5-1) will be implemented to ensure that maintainability problems are documented and resolved prior to final design approval.

The maintainability (M) program will support the systems, subsystems, support equipment, and component level to provide standards and characteristics that effectively support the maintenance environment during the pre-operational and operational phases. The M program will include the following elements:

1. M design requirements

2. M design review

3. M quantitative apportionment and evaluation

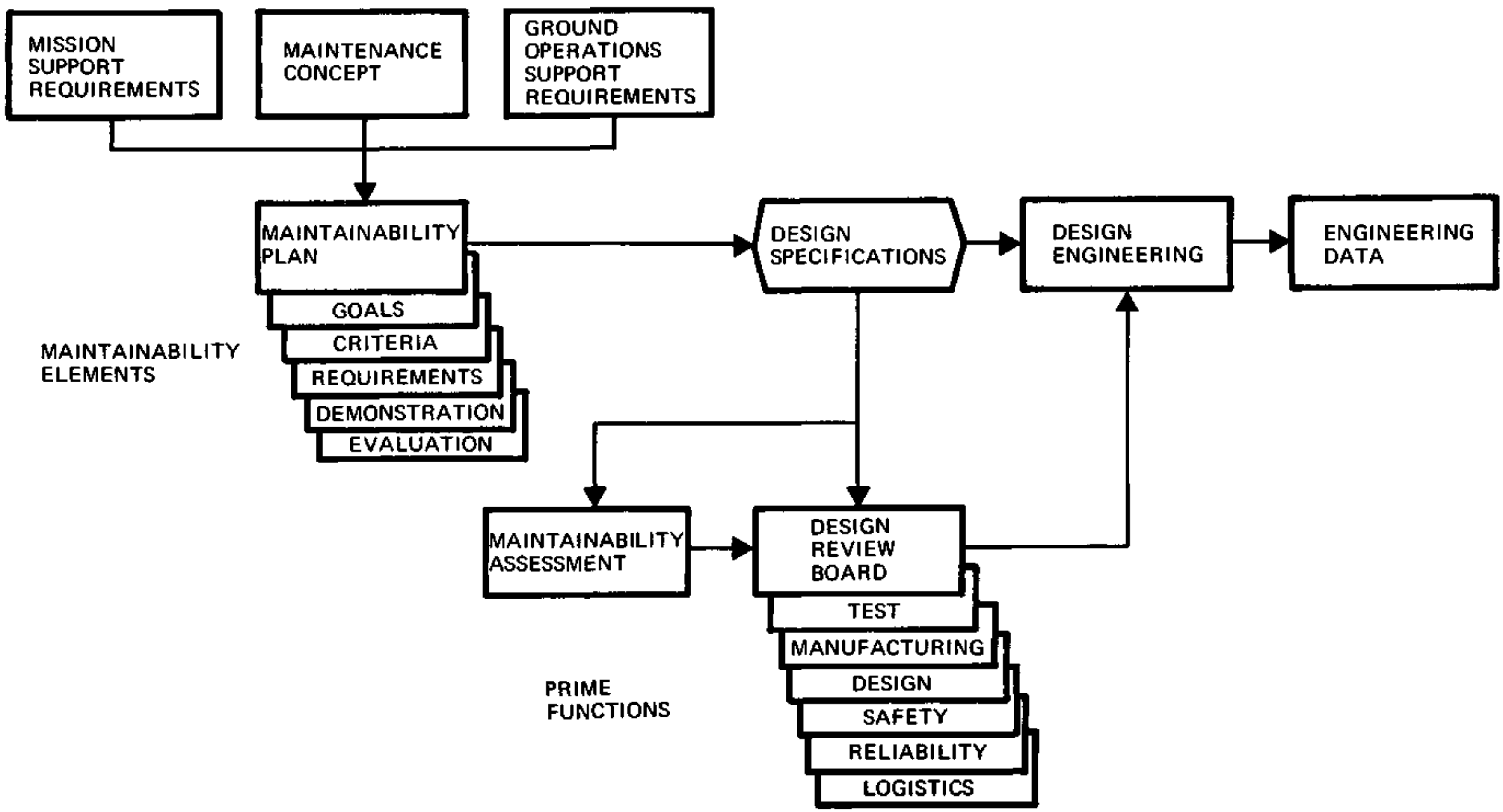


Figure 5-1. Maintainability Process

4. Tradeoff studies

5. Problem resolution

6. Subcontractor/vendor control

7. Prime and associate contractors' coordination

8. M verification.

The requirements of the maintainability program are as follows:

1. Develop maintainability criteria and requirements for system and subsystem performance consistent with maintenance concepts and plans

2. Conduct an analysis of design to develop maintainability qualitative and quantitative apportionment and to assess actual achievement of defined maintainability requirements.

3. Establish a program to conduct and evaluate trade studies and problem resolution

4. Invoke maintainability requirements on supporting suppliers and vendors.

2.7.4 Maintainability Analysis

To ensure incorporation of maintainability features in the vehicle and support equipment system/subsystem design, maintainability analyses will be conducted at initial design by defining program maintainability criteria. Maintainability analyses throughout the design phase on the basis of the established baseline concepts and requirements will be conducted with subsequent modification commensurate with the developing design and operational needs. The analyses will define specific maintainability requirements, allocation of task times, and verification of maintainability design features, maintenance tasks, and maintainability support requirements. The process will also identify and resolve alternate approaches by tradeoffs, will provide specific maintenance requirements; will establish the level and degree of maintenance, and will define the scope of the maintainability features to be incorporated in the design. This analysis will be coordinated with space shuttle to provide maximum cost saving through commonality.

2.7.5 Quantitative and Qualitative Requirements

Both quantitative and qualitative requirements will be developed during the maintainability analysis to establish design requirements and constraints for ease of maintenance. Quantitative requirements are those time estimates allotted for maintenance to meet total time and manhour limitations to support ESS mission criteria. Qualitative requirements consist of the incorporation of specific design characteristics and philosophy into specifications and the physical review of design, installation, and testing procedures to meet maintainability criteria.

2.7.6 Maintainability Verification

Maintainability verification requirements are identified as part of the M analysis process. Redundant operations will be avoided by phasing the verification requirements into the development test, manufacturing, checkout, and test operations activity. Demonstration of the maintenance concept and criteria and verification of the ability to perform maintenance will be accomplished with hardware as applicable events occur during the manufacturing test operations of the ESS. Only key maintainability requirements, which cannot reasonably be proven by analysis, will be given demonstration. Included will be such items as engine and avionics package removal which must be performed in space, where, if an analysis error were made, the hardware would not be recoverable. S-II experience should be used to determine the demonstration requirement for ground maintenance operation. Apollo and Skylab experience should be utilized for space operations. Procedures, hardware to be used, and measurements to be taken will be identified as part of the verification process.

2.7.7 Supplier Control and Prime Associate Contractor Liaison

Supplier/subcontractor procurement specifications will incorporate maintainability requirements and establish procedures for surveillance. Existing supplier in-house maintainability processes will be used where proven to be effective, with special ESS requirements added where required only. Procedures will be established for effecting coordination and information exchange with the prime contractor and associate or major subcontractors. Provisions will be made for the interchange of maintainability information and data to support maintenance of government-furnished equipment (GFE) and contractor-furnished equipment (CFE).

3.0 SUPPORT EQUIPMENT

3.1 PURPOSE

This section establishes the requirements for the identification, definition, acquisition, and control of support equipment in the most cost-effective manner.

3.2 SCOPE

The support equipment to be identified will provide equipment and facilities for the tests and operations phase for launch, recovery, maintenance, storage, and support needs. Included are the Seal Beach checkout operations. This considers the use of existing, shuttle, and new or modified support equipment. Space shuttle support equipment will be considered prior to design of any specific ESS support equipment.

3.3 REQUIREMENTS

Support equipment includes nonflight equipment and associated software that service and checkout the ESS for flight or perform support for maintenance activities. Support equipment will be identified for the program manufacturing, test, or operations function or requirement. The requirements will be developed by an analysis of the program functional flow diagrams, the system level CEI specification, the physical and functional test article configuration, the basic facility characteristics, and the support functions to be performed. Each analysis resulting in a support equipment requirement will be documented and indexed to a facility where the function will be required. When the support equipment system is being synthesized, the index and associated requirements will be correlated to assure completeness of the support equipment design and compliance and traceability to CEI specifications.

The analysis is part of the planning activity discussed under Section 2.0.

3.4 REQUIREMENTS DEFINITION - REQUIREMENTS SUMMARY

1. Establish functions and design requirements for each item of support equipment.

2. Screen space shuttle support equipment for applicability.

3. Prepare specifications for customer review prior to design and acquisition.

4. Change and update specifications when item function changes.

When the need has been identified for an item of support equipment, the function to be performed by the item will be established and the design requirements prepared. These design requirements will consist of the characteristics required of the support equipment to satisfy the needs of the function, the environments to be encountered, and the quality assurance and safety features required to provide safe repeatable operations. The information will be prepared in a support system specification and end item specification for customer review before an end item is released for final design and acquisition. The support system specification will be a contractual document, and all changes to it will be controlled by contract action.

3.5 ACQUISITION OF SUPPORT EQUIPMENT - REQUIREMENTS SUMMARY

1. Forward the support equipment requirements documentation to the customer.

2. Screen the support equipment requirements for the government-furnished equipment (GFE) that is available.

3. Contractor prepare a GFE request or fabricate or procure the item.

The support equipment requirements and utilization will be integrated into a support equipment requirements document. The utilization will be cross-indexed to each facility and will show phasing of equipment from one facility to another as the needs of each facility change with program phasing. Existing and modified S-II support equipment and space shuttle support equipment will be utilized where applicable. The engines are common to the shuttle and ESS; therefore, common usage of the related support equipment is a prime consideration. The ESS, shuttle, and S-II propellants and propellant transfer requirements are similar. Similarity of shuttle and ESS avionics subsystems should also result in common avionics checkout equipment hardware requirements. It is postulated that the S-II support equipment could be modified to support shuttle propellant transfer requirements. This modified support equipment could be utilized with the ESS, since the shuttle propellant transfer requirements exceed ESS requirements.

The contractor will forward the initial requirements documentation to the customer. Concurrently, the contractor and the customer will screen the government-furnished equipment inventory to determine the availability of existing hardware that can satisfy the requirement. If the screening is successful in identifying an item from the inventory, the contractor will prepare and submit a GFP request. Once the request is approved, use of the GFP item will be reflected in the support system specification. In the event existing equipment is not available, the contractor will use established procedures in acquiring the necessary equipment.

3.6 CONTROL OF SUPPORT EQUIPMENT - REQUIREMENTS SUMMARY

1. Establish a system to control the allocation and movement of support equipment.
2. Maintain support equipment configuration data and check against program hardware to assure configuration knowledge.
3. Establish a maintenance program on the support equipment.

The contractor will be responsible to manage the support equipment assets to satisfy the program needs. The support equipment requirements and utilization document identified in paragraph 3. 5 will be used as the prime document to control the allocation and movement of all support equipment to the program's operating facliities. The document will be maintained in a current condition and will reflect location and use of each identifiable item of equipment. The document will also reflect the equipment configuration identification. The contractor will relate this document to the program hardware configuration management system to assure continuous knowledge of support equipment configuration.

In addition to the support equipment management system, the contractor will also establish a maintenance program for the support equipment to obtain maximum serviceability and utilization of the equipment. On-condition corrective maintenance will be required to correct out-of-tolerance conditions and to recover from malfunctions; but the major emphasis, particularly on mechanical equipment, will be planned preventive maintenance program based on expected usage, design life, and established periodic service and parts replacement. In addition to design data, the history of malfunctions and repairs will be compiled during early program use for updating the planned maintenance program.

4.0 FIELD SUPPORT SERVICE

4.1 PURPOSE

This section provides the requirements for the establishment of a field support service during Phase C/D, which defines the support services and materials for test, static firing, and operational sites.

4.2 SCOPE

The site support functions will be established for the test and operational program phases for both the ESS and the ground systems. The support services requirements for test functions and operational levels of maintenance will be standardized, integrated, and centrally managed where possible.

4.3 SITE SUPPORT - REQUIREMENTS SUMMARY, PHASE C/D

1. Define and implement a site support program that considers the commonality of the Space Shuttle Program.
2. Define required support services by site.
3. Standardize support where possible.
4. Define articles to be supported, maintenance levels, and personnel requirements.
5. Define a system to accommodate design changes to site support equipment.
6. Define a system for development of usage data.
7. Define support manual requirements.
8. Define tenancy facilities.

4.4 SUPPORT SERVICES

The requirements for support services and resources at specific periods during the site activation and subsequent operational phases shall be identified during the Phase C/D activities. The allocation of these resources provides the facilities, hardware, personnel training, and data necessary to assure adequate schedule and performance attendant to site activities. This will include defining the GFE that should be made available to support the program, space, and warehousing requirements for storage and deployment of spares consumables, support material, and test equipment. Field support services will start with activation of the site elements required to support the first stage. Following detailed planning during Phase C/D, site modification and construction requirements will be established in preparation for equipment installations. Facility activation responsibilities are under the cognizance of NASA. Support equipment and related facility interfacing is the responsibility of the contractor. Supply support activities pertaining to sparing requirements and provisioning are discussed under Section 7.0. The activation of the first on-site construction/modification will be the start of site support. Site support will continue from this point through completion of the ESS program.

Site-peculiar requirements for test and operations program support include the following:

1. A system to accommodate design changes to contractor- and government-provided equipment, spares, and repair parts for vehicle and support equipment at each site.

2. Collection and utilization of equipment usage data.

3. A system and capability to accomplish maintenance, repair, and overhaul of vehicles, spares, and support equipment at each site.

4. Technical support manuals for each site.

5. The space and tenancy facilities required at each site for personnel and equipment.

6. Data processing capability to be used for collecting, storing, and providing data, including reliability, maintainability, maintenance, quality, and safety information.

7. A training program based on site support needs.

4.5 MATERIAL ACCOUNTABILITY AND INVENTORY - REQUIREMENTS SUMMARY

The contractor will establish a logistics support center at the launch site. The center will be responsible for the receipt, documentation, storage, and issue of support equipment, vehicle and support equipment spares, modification kits, and for the processing of unserviceable reparables and inventories of usage hardware. In the case of refurbishment, the center will provide for the packing and routing of recovered hardware to the Seal Beach or supplier refurbishing facility. The center and methods will be common with space shuttle.

4.6 FACILITY MAINTENANCE - REQUIREMENTS SUMMARY

1. Establish maintenance requirements and frequencies for ESS facilities installations in conjunction with the requirements of the space shuttle.

2. Refurbish launch facilities and perform preventive maintenance.

The contractor will establish the maintenance requirements and frequencies for maintenance on facility installations which he fabricates or modifies, or which he procures and installs. The contractor will refurbish the launch facility after launch and perform preventive maintenance on facilities, equipment and systems utilized for maintenance and launch preparation of the ESS vehicle.

4.7 SITE ACTIVATION

The contractor will identify the site activation requirements for the ESS static firing launch operations site. The scope of the site activation activities described entails the planning and implementation requirements for support equipment installation activation and validation so as to assure compatibility of facility, support equipment, and ESS subsystems and integration with the shuttle booster interfaces. The activity includes the general activation planning, scheduling, and staffing; the receipt, assembly, installation, test, and integration of site equipment; and validation to demonstrate that the installed equipment is capable of performing its intended purpose. Facilities construction requirements and installation sequences will be established and schedules developed. The requirements for interface activities with associate contractors and the customer will be defined for coordination and monitoring to provide status and schedule data and will include contractor and customer management visibility processes for information and control action.

Requirements for Phase C/D (Coordinated with Space Shuttle)

1. Establish a site activation and deployment master and detailed schedule system capable of programming and controlling ESS site activation and deployment events and functions. The schedule system will graphically depict milestones, accomplishments, and status to permit program visibility and control.

2. Define and establish site activation plan and detail requirements for the ESS sites, including hardware, test equipment, manning, operating systems, and interface responsibilities.

3. Develop a site activation (S/A) analysis and planning phase stating the requirements of an S/A master plan, an interface control document system, a construction drawing review system, and site activation change control and requirements analysis.

4. Define an S/A and deployment total support system. The support system will cover the site activation development, activation, and site turnover phases. The support system will determine the contractor's requirements for spares support, repair, and modifications; also inventory management and software requirements. In addition, site GFP support, transportation, and base support requirements and functions for the ESS sites will be defined as part of the support system.

5. Establish requirements and responsibility at the site for interface, commonality, schedules, and daily coordination. Cover functions for the integrator contractor, associates, and customer.

6. Implement a procedure to receive, store, control, and issue all site activation materials and software. Describe the operations procedure and inventory management requirements and controls.

7. Initiate assembly, installation, and checkout of support equipment at the activated ESS site. Commence installation and checkout of physical interface, support equipment, fluid and electric system, tooling, stands, etc.

8. During the activation checkout, and after completion of the activation phase at the specific ESS sites, verification and certification are required. Verification and certification will include document review, physical inspection, surveillance, and demonstrations. Orderly turnover to the ESS operations phase will complete site activation.

5.0 TRANSPORTATION

The contractor will provide the plans, transportation, and handling protection requirements for the ESS, support equipment, and spares during handling, transportation, and storage phases. The requirements will reflect an efficient and cost-effective transport capability of all items to and from the static firing launch and hardware recovery sites. The transportation system will primarily utilize a capability similar to the S-II. The shuttle launching or ferry sites will be utilized for transporting recovered hardware directly to the contractor or supplier for refurbishment as applicable.

5.1 TRANSPORTATION SYSTEM REQUIREMENTS

The transportation system requirements will be identified for each transportable item. The S-II Program transportation capability will be assessed for applicability to the ESS Program. Typically, the S-II stage transporter will be utilized for transporting the ESS between the manufacturing and launch sites. Modification to the S-II stage transporter pallet will be required because of the shorter length of the ESS. ESS-peculiar items will be identified and the following characteristics evaluated and identified.

1. Complexity and fragility of item
2. Quantity and delivery schedule
3. Availability of transport conveyance
4. Protection of item afforded by transport vehicle.

5.2 DOCUMENTATION REQUIREMENTS

An ESS transportation requirements specification will be prepared. The specification will be essentially in accord with the following NASA publication:

NHB6000.1 (1A) Requirements for Packaging, Handling and Transportation for Aeronautical and Space Systems Equipment and Associated components.

A transport data sheet will be prepared and maintained for the transportable items. The data sheet will contain the following types of information:

Weight and size

Special protection requirements and handling methods

In-transit monitoring requirements

Packaging and handling considerations are identified under Section 10.0.

6.0 PROPELLANTS, PRESSURANTS, AND COOLANTS

This section recognizes the requirements for propellants, pressurants, and coolants in support of the ESS at the test and operational sites. Quality and quantity requirements must be forecasted. Since ESS and shuttle quality requirements are similar, the ESS quantity requirements can be forecasted along with the shuttle requirements. The ESS quantity requirements are substantially less than those anticipated for the shuttle. The use of protected shuttle storage, as planned capability, is an objective.

7.0 SUPPLY SUPPORT

7.1 PURPOSE

This section describes the requirements for establishing a supply support inventory management capability to assure availability of support resources defined in paragraph 4.0 for maintenance and other operational activities. These support resources include spares, supplies, and warehousing. The primary objective of the supply support inventory management function is to define the resources, requirements, schedules, and management techniques needed to provide maintenance and other operational support capabilities at minimum cost consistent with ESS schedule requirements. This includes the requirements for recovered hardware refurbishment and recycling and the resupply of support resources.

7.2 SCOPE

Supply support covers the test and operations activities and entails the following requirements consistent with the maintenance concept.

Provisioning

Acquisition

Refurbishment

Inventory management.

7.3 PROVISIONING

This section describes the activities involving concurrence and approval of the various categories of spares provisioning. Spares selected under the supply support activity are from the candidates that are identified in the Maintenance Analysis. Concurrence meetings for provisioning of spares are convened; those attending are representatives of the various disciplines, i.e., Engineering, Material, etc., and may include the customer representative. High-dollar-value spare candidates will be reviewed by, and approved by, the customer at a spares provisioning meeting. Long lead items that are required to meet an operational date will be procured through an interim release system. Low-cost, high-usage bulk hardware will be provisioned in economical quantities consistent with program application and will not require concurrence meeting review. Affected hardware, prior to release for acquisition, will be screened for availability from the S-II and Shuttle Program, current and government inventory. A Priced Spare Parts List (PSPL) will be submitted to the customer at 90-day intervals.

7.3.1 Spares Configuration Control

Continual review of baseline documentation is required to monitor configuration changes. When changes affect spares, the spare will be removed from inventory for modification or termination.

7.3.2 Acquisition of Spares

Acquisition will be initiated through documentation authorizing fabrication or procurement of hardware for delivery to a specified requirement schedule. Delivery schedules will provide hardware concurrent with activation of the equipment to be supported. Specific items identified for phased procurement due to cost, lead time,and usage frequency considerations will be subject to accelerated production lay-in.

All spare parts will be inspected and accepted to ESS specifications. Spares will be cleaned, preserved, packaged, and marked in accordance with governing directives. They will be delivered and documented by a DD250 form. The contractor will retain custody and control of spares.

7.3.3 Reuse of Retrieved Hardware

The hardware retrieved from the ESS during earth orbit are the main propulsion engines and recoverable avionics packages. The recovered hardware, after visual and physical inspection and refurbishment, as necessary, will be reinstalled and checked out. The hardware reuse utilization schedule is depicted in Table 5-1. Reuse of main propulsion engines will be in ESS Vehicles 4 through 20. ESS Stages 6 through 20 will utilize refurbished avionics packages. Finally, ESS 6 and subsystem stages utilize totally retrieved and reused avionics packages and engines. Refurbishment of the recovered ESS hardware will be performed consistent to the space shuttle refurbishment of similar hardware.

7.3.4 Inventory Management

A centralized inventory management and control system will be established over all sites inventory utilization. Information on available parts (quantities and locations) and parts transactions will be maintained. A mechanized system provides visibility of spare inventory on a real-time basis and for a resupply notification when a minimum spare part balance has occurred. The system also includes records of modification kits. Included

Table 5-1. Utilization of Retrieved and Reused Hardware

ESS Vehicle No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Avionics package																				
Initial installation and checkout	1	2	3	4	5															
Reuse						1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Engine set																				
Initial installation and checkout	1	2	3																	
Reuse				1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2

Notes: Five avionics (recoverable) packages for initial installation, checkout and reuse.
Three sets of engines (2 per stage) for initial installation checkout and reuse.

is the statusing of repair and refurbishing activities. A system of inventory periodic review will be established with test and operations requirements and plans. The system provides a complete status of each spare line item from release through program completion. Spares data will identify spare part number release and shipping dates, quantities, sites, repairability, and costs. The controls also provide for current configuration status consistent with current engineering configurations. A priority system will be utilized to provide launch site critical hardware on an expedite basis. Finally, cost for hardware consumption/utilization will be established.

7.3.5 Expedite System

An expedite system will be employed as part of the support hardware inventory management system to provide the methods of requesting, approving, and supporting priority requirements for parts, material, failure analysis, technical operating supplies, or modification and repair efforts critical to the support of the ESS Program. This will include the capability of expediting the delivery of parts and materials required to meet test, launch, or resupply schedules.

7.3.6 Reparables and Recovered Hardware Refurbishment Controls

The system will provide for the control of parts being repaired from the inception of that activity until its completion and return to serviceable inventory. The system will be capable of tracking a given part through each step in the repair cycle and providing a general status of current condition. Minimum data provided by periodic listings will be as follows:

1. Part number
2. Serial or document control number
3. Coded status of repair
4. Forecast completion data
5. Current location.

8.0 TRAINING

A customer and contractor training program will be established for ESS specific items only, and will use the space shuttle training program for the common elements. The program will provide for training of customer general and contractor personnel. The contractor training entails the test operations and maintenance personnel. Training program requirements will be defined and established by utilizing exiting S-II date and space shuttle systems when applicable. As stated in the Operations Plan, the operations personnel for the ESS will not be dedicated to the ESS due to the very low flight rate. A few personnel (specifically trained for ESS operations and to act as the ESS operations team nucleus) will be added to the space shuttle operations personnel to offset the use of some fifty-five personnel to aid in the infrequent ESS operations.

The training requirements include documentation and skill requirements. The requirements also recognize the site-peculiar aspects. The training program interfaces with, and supports, the concepts of the Facilities, Manufacturing, Test Operations, and Logistics and Maintenance Plans and the Safety Program.

The training program will provide the following information:

1. Personnel and skill requirements by site
2. Milestone and schedule charts for training and training equipment need dates
3. Identification of training equipment, devices, and aids.
4. Training manual needs
5. Training and trainer facilities
6. Training and trainer facilities and support identification by site
7. Training program management policy and objectives.

Preceding page blank

9.0 TECHNICAL SUPPORT DOCUMENTATION

The contractor will develop the ESS specific technical support documentation necessary to furnish descriptive and procedural data pertaining to ground support and mission flight hardware maintenance and operations. The data will be used for crew training, mission procedure development, ground equipment maintenance, vehicle maintenance, and operations; but will not duplicate the space shuttle documentation. The technical support documentation effort will include the following general tasks:

1. Study program activity requirements with relation to technical support documentation requirements.
2. Define support documents to be produced and the organization functional responsibilities and schedules for each.
3. Initiate specifications governing the preparation of contractor and supplier support documentation.
4. Establish and maintain procedures and requirements for effective preparation and approval/verification of support documentation.
5. Prepare, coordinate, and update the support documents.
6. Prepare and validate modification instructions, as required.

9.1 DOCUMENTATION DEVELOPMENT

The documentation will be developed for use primarily during the final acceptance test and operational phase of the program. It will be written to the level of understanding of skilled technicians to provide descriptive data, theories of unique design, and step-by-step procedures to assure effective operation and maintenance of equipment. The support documents will be designed to afford maximum utilization by both contractor and customer personnel and be commensurate with the task complexity to maintain the operational status of the ESS vehicle and its mission support equipment.

The technical support documents will be prepared in the style specified for such documentation and in accordance with governing ESS specifications. These specifications will control consistency of coverage to minimize preparation costs and ensure the adequacy of the data depicted. Engineering

PRECEDING PAGE BLANK NOT FILMED

data will be obtained from a master data bank wherever possible to further reduce costs and assure technical accuracy.

9.2 DOCUMENTATION TYPES

The ESS documentation that will be prepared as part of this effort is categorically listed in the following paragraphs. The content and style of the manuals will be as indicated.

9.2.1 General Manual

This manual will briefly describe the planned operational phases including the pre-mission phase through mission support phase. It will also provide descriptive data and brief discussions of the operations and interfaces with logistics support missions. Illustrations and simplified schematics will be used to support the text.

9.2.2 Subsystems Maintenance Manuals

The subsystems maintenance manuals will provide instructions for periodic maintenance and instructions for the operation, servicing, checkout, trouble analysis, and removal and replacement of components.

9.2.3 Support Systems Maintenance Manuals

Manuals will be prepared for all major ground and flight support system deliverable end items. These manuals will provide descriptive data, operation, maintenance, servicing, inspection, and repair procedures for the pre-mission and mission support phase. In the case of purchased equipment, the purchase agreement will specify that manuals are to be prepared by the supplier in accordance with a format suitable for direct use by the prime contractor.

9.2.4 Illustrated Parts Breakdown (IPB) Manual

The IPB manual will provide an illustrated listing of replaceable parts by subsystem and GSE end item. The IPB will show physical configurations and relationships of parts and components of system, subsystems, and GSE end items.

9.2.5 ESS Operations Manual

This manual will provide descriptions, operational procedures, and operational modes relative to the ESS systems/subsystems. This manual will be specifically designed to support crew training and operational procedure development. The manual will consist of tabular step-by-step procedures for normal, backup, and alternate operating procedures.

9.2.6 Modification Instructions

Modification instructions will be prepared to provide detailed step-by-step directions to incorporate and verify all field modifications to delivered end items. This instruction will be an integral part of each field modification kit and part of the acceptance data package.

9.2.7 Document Preparation, Revision, and Validation

The contractor will establish a procedure for review, validation, and approval of the documents and develop change revision processes to account for fast reaction and schedule changes. In addition, a procedure for validation of procedural data against simulated and flight hardware will be developed.

Preceding page blank

10.0 PACKAGING AND HANDLING

10.1 PURPOSE

This section outlines the requirements for the protection of assemblies, components, spares, support equipment during handling, transportation, and storage phases. The primary objective is to assure no degradation of reliability or functional capability of the hardware during these phases, while minimizing costs for protective packaging. Requirements for packaging, handling, and transportation of hardware will be substantially in accordance with applicable requirements and guidelines of NASA Publication NHB 6000.1 (1A), Requirements for Packaging, Handling and Transportation for Aeronautical and Space Systems, Equipment and Associated Components. The S-II and shuttle packaging and related documentation will be utilized on the ESS program when hardware commonality exists.

10.2 SCOPE

The hardware protection requirements will apply to the test and operational program phases and will include the following requirements:

1. In-plant protection during fabrication, handling, and storage.
2. Precision clean packaging. Assures that critically cleaned gaseous or liquid components are packaged to maintain required cleanliness levels.
3. Package design qualification. Establish a program for analysis and test to verify the packaging and transportation system.
4. Packaging, handling, and transportation documentation. Defines documentation to be prepared and the distribution and approval requirements.
5. Control of supplier and subcontractor packaging procedures and transportation and delivery.

PRECEDING PAGE BLANK NOT FILMED

Packaging will be required for the shipment and storage of the following items:

1. Stages and/or major assemblies thereof

2. Spare parts and reparables

3. Support equipment.

10.3 PACKAGING FOR FLIGHT VEHICLE AND MAJOR ASSEMBLIES

Packaging, handling, and transportation methods will be designed to protect the hardware from natural and induced environmental extremes encountered during shipment or storage, which are in excess of the hardware allowable limits. Environments to be considered include shock, vibration, temperature, altitude (pressure), humidity, sand and dust, precipitation (rain, snow, etc.), and field forces (electrostatic, electromagnetic, magnetic, radioactive).

Packaging, handling, and transportation methods will be in consonance with the planned transportation mode and carrier vehicle. Design of packaging, handling, and transportation methods will consider all pertinent characteristics of the hardware, including size, weight, shape; materials, construction, and surface finishes and treatment; susceptibility to damage or deterioration from shock, vibration, corrosion, contamination, and potential modes of failure; practicality of disassembly, considering economy of packaging and ease of reassembly; delivery destination, including possible alternate destination; duration of planned storage, storage methods, and associated environments; and hazardous characteristics (explosives). Packaging will be designed for reuse where economic benefits are attainable and will interface appropriately with handling equipment at the shipping and receiving sites.

Designs of equipment for packaging and transporting flight equipment and support equipment will be released by engineering drawings. Preparation for delivery, packaging procedures, carrier loading, and in-transit operations will be released by engineering specifications. A packaging, handling, and transportation record (PHTR), similar to NASA Form 1426, will be prepared for each critical, high-cost item. The PHTR will provide specific instructions for preservation and packaging, for special controls during handling and transport (such as type and speed of carrier, shock and temperature monitoring, etc.), and for special container markings.

10.4 SPARE PARTS AND REPARABLES

Packaging, handling, and transportation methods will be designed to provide protection against corrosion, contamination, and physical damage for each spare part, including reparables shipped for failure analysis and repair. Requirements for packaging design will be substantially as outlined for flight vehicles and major assemblies, except as follows:

1. Preservation and packaging/packing levels, as further defined in NHB6000. 1 (1A), will be:

   Level A - storage for indefinitely long time

   Level B - storage not exceeding one year

   Level C - immediate use by first receiver

2. Packing: Level B (with Leval A rough handling design criteria)

3. Reusable containers: Packaging will be designed to be reusable, where economically practical.

10.5 SUPPORT EQUIPMENT

Packaging, handling, and transportation methods will be designed to provide protection against corrosion, contamination, and physical damage for each deliverable item of support equipment, modification kits, and other support hardware required for site support. Requirements for packaging design will be substantially as outlined for flight vehicles and major assemblies, except as follows:

1. Preservation and packaging/packing levels as defined in NHB6000. 1 (1A) will be as follows:

   Level A - storage for indefinitely long time

   Level B - storage not exceeding one year

   Level C - immediate use by first receiver

2. Packing: Level B (with Level A rough handling design criteria)

3. Reusable containers: Packaging will be designed to be reusable where economically practical or where equipment requires repeated packaging to provide protection during periods of inactivity.

Preceding page blank

11.0 DEFINITIONS

Terms used in the Logistics and Maintenance Plan are defined in this section.

Term	Definition
Access	Means of approach or admission; for example, and opening provided on equipment for inspection or for performance of maintenance tasks
Accessibility	Pertains to design features which affect ease of admission to an area for the performance of visual and manipulative maintenance or service (including component removal and installation)
Alignment	The act of bringing two or more components, or variable elements of an item, into a prespecified relationship with other
Analysis, Maintenance	The process of identifying required maintenance functions through analysis of a fixed or assumed design and determining the most effective means of accomplishing these functions
Assembly	A number of parts, subassemblies, or any combination thereof joined together
Bulk Items	Certain raw materials and semifabricated items used in the manufacture of an item, including standard, commercial, and military hardware (e. g. , clips, clamps, fasteners, bolts, nuts, washers, hoses, and lubricants)
Checkout	A sequence of functional, operational, visual inspections or calibration tests to determine the condition and status of a system or element thereof
Common Use Hardware	Items stocked in a common inventory having multiple support applications

PRECEDING PAGE BLANK NOT FILMED

Term	Definition
Component	Any self-contained part, combination of parts, subassemblies or units, which perform a distinctive function necessary to the operation of a system
Configuration	The physical nature of an item, the physical arrangement of components and/or parts which comprise an item, including unique identification and documentation
Consumable Material	A type of item that is expended through use
Equipment, Support	All equipment required to support the operation and maintenance of a vehicle
Failure Mode Effect and Cause Analysis (FMECA)	See Analysis, Failure Mode and Effect
Fault Isolation	Actions involved in identifying and determining malfunctions in equipment by means of systematic checking and analysis
Government-Furnished Property (GFP)	All property in the possession of, or acquired directly by, the government and subsequently delivered or otherwise made available to the contractor
Hardware	The physical object, as distinguished from its capability or function (engines, cases, pumps, the guidance system, or other components of the vehicle or SE); the term also is used in regard to a stage of development, e. g., the passage of a device or component from the design or planning stage into the hardware stage as the finished product
Inspection	The examination, normally by visual or nondestructive means, of vehicles and equipment to determine conformance to physical/structural requirements and to established standards.
Item	Any level of hardware assembly, i. e., system, subsystem, component, or part
Line Replaceable Unit	An item so constructed and installed as to make it readily replaceable at the vehicle/equipment maintenance level

Term	Definition
Logistics Support	Support required to operate, maintain, and repair equipment within the prescribed maintenance concept. Logistics support encompasses the selection, procurement, scheduling, stocking, and distribution of spares, repair parts, ground support equipment, technical publications, and maintenance training necessary to keep the equipment in a functional status
Maintainability	Combined characteristics of design, installation, and support that make it possible to maintain and service equipment to specified conditions within a minimum expenditure of maintenance resources; i. e., manpower, test equipment, technical support data, logicstics support and facilities
	A comprehensive statement of required maintenance characteristics, expressed in either qualitative or quantitative terms or both, to be satisfied by the design of an item
Maintainability Verification	A monitoring process intended to verify the vehicle and support equipment's maintainability and support resource goals and requirements were achieved
Maintenance	Actions required for restoring or maintaining an item in serviceable condition, including servicing, repair, modifications, upgrading, overhaul, inspection, and determination of condition
Maintenance, Phased	Maintenance (e. g., time-compliance items) planned and scheduled progressively by frequencies determined by specific numbered turnarounds, flight hours, or calendar-time designations
Maintenance Predictive	Maintenance performed to preclude an out-of-tolerance condition, enabled by trend analysis of equipment performance ouptut values as related to usage rate
Preventative Maintenance	Maintenance performed to retain an item in a serviceable condition by systematic inspection, detection, prevention of incipient failures, replacement of worn out items, adjustment, calibration, and cleaning

Term	Definition
Corrective Maintenance	Maintenance performed to restore an item to a satisfactory condition by correcting a known or suspected malfunction or failure which has caused degradation of the item
Modification	Alteration to the physical design of the vehicle or of the item affected in order to correct a design deficiency, facilitate production, or improve operational effectiveness
Overhaul	The disassembly, inspection, and check of a unit as required with attendant replacement, repair, adjustment, or refinishing of such parts to restore it in a specified condition to operate for another overhaul interval
Packaging	Cleaning, preserving, and packing in unit quantities; interior cushioning and bracing; design and utilization of interior and exterior containers; identification of contents of inner and outer containers, and loading
Part	The smallest subdivision of an equipment which would not normally be subjected to further subdivision or disassembly
Redundancy	The existence of more than one means for accomplishing a given function
Reliability	The probability that an item will perform a required function, under specified conditions, without failure for a specified period of time
Repair	The restoration of a device to a serviceable condition after malfunction, damage, or deterioration
Safing	Phasing, tasks, or functions necessary to render a vehicle, subsystem, or component safe with respect to personnel and/or the functional integrity of the item
Servicing	The replenishment of consumables needed to keep an item in operating condition

Term	Definition
Spare Part	Any part, subassembly, or component kept in reserve for the maintenance and repair of major items of equipment
Subassembly	Two or more parts which form a portion of an assembly or a unit replaceable as a whole, but having a part or parts which are individually replaceable
Subsystem	A major functional part of a system essential to operational completeness of the system (e. g. , structures, subsystem, main propulsion subsystem).
System	A composite of equipment, skills and techniques (including all related facilities, equipment, material, services, and personnel) capable of performing a clearly defined function in the accomplishment of an objective. The ESS is a system of the NASA-projected Space Transportation Program.
Test	Examination of an item to ascertain that the item meets specified requirements
Test Site	A facility established at a selected geographic location for conducting a specific test operation
Traceability	A term which indicates the degree of yield from search for an item's history, application use, and location
Tradeoff	The procedure of trading a degree of an attribute to gain a degree of another attribute; e. g. , sacrificing a degree of performance to obtain a greater degree of reliability under certain conditions, or vice versa.

Preceding page blank

12.0 BOOSTER AND SEPARATION STRUCTURE

Booster configuration changes for ESS operations consist only of software changes and a new separation linkage system. There is no other impact on shuttle booster configuration. Spares support of the ESS separation system and the associated maintenance operations are considered to have negligible impact in the logistics and maintenance areas. The baseline Logistics and Maintenance Plan (SD 71-106) is a requirements document and is not configuration oriented. Spares and maintenance requirements established by this plan will support either the shuttle or ESS.

The inclusion of the ESS concept into the booster space shuttle system will provide a minor impact on training requirements and implementation. The impact will be primarily in the areas of separation system, launch pad interface, and mating procedures. Further analysis of flight crew additional functions have been accomplished and establish that a requirement exists for an additional simulator training plan.

Ground and other support subsystems training and training equipment requirements are established as follows:

<u>Training</u>

1. Installation, rigging, and checkout of the ESS/booster separation system
2. ESS/booster pad interface hookup and checkout
3. ESS/booster mating procedures and handling
4. Flight crew payload monitor capability
5. Possible ESS abort contingencies.

<u>Equipment</u>

1. An additional separation system training aid will be required to provide real-time rigging and checkout techniques.
2. Additional mission simulator training plan to provide the added pilot functions.

PRECEDING PAGE BLANK NOT FILMED

SECTION VI

PROGRAM MANAGEMENT PLAN

Preceding page blank

CONTENTS

Section		Page
1.0	INTRODUCTION	6-1
2.0	ESS PROGRAM MANAGEMENT PLAN	6-3
	2.1 Summary	6-3
	2.2 Program Organization	6-3
	2.3 Performance Management	6-5
3.0	BOOSTER AND SEPARATION STRUCTURE MANAGEMENT	6-9

ILLUSTRATIONS

Figure		Page
6-1	Preliminary ESS Master Program Schedule	6-7
6-2	ESS Development Impact on Space Shuttle Booster - 360-Day Development Program	6-11

PRECEDING PAGE BLANK NOT FILMED

SECTION VI. PROGRAM MANAGEMENT PLAN

1.0 INTRODUCTION

The Program Management Plan for the Space Shuttle System is defined in SD 71-101 and the shuttle booster development program is reflected in the Phase C/D baseline schedule of SD 71-124-2. This report delineates the additional management requirements necessary for integration of the expendable second stage (ESS) into the overall shuttle program.

Preceding page blank

2.0 ESS PROGRAM MANAGEMENT PLAN

The purpose of this plan is to describe the organization structure and the program planning and control systems selected to assure the production of ESS vehicles with the highest standards of quality and reliability at minimum cost.

2.1 SUMMARY

The management plan for the ESS program has been developed from an analysis of program requirements, compared with the management plans of other current Space Division programs, plus a review of the start-up phases of the Apollo CSM and Saturn launch vehicles (SLV) programs.

The ESS program organization will be structured essentially as the SLV program organization is structured. Full responsibility for performance will be vested in the Program Manager, and he will receive support from functional organizations established to assure accomplishment of program objectives and requirements. The organization will be manned predominately with personnel with extensive experience in Saturn S-II production.

The systems for planning, directing, and controlling program operations will be those that have been developed and successfully employed on the SLV program. Major emphasis will be placed upon cost, scheduling, and performance controls as integrated in the work package management system.

Emphasis also will be placed on continuation of the management team relationship that exists between NASA and the Space Division of North American Rockwell (NR/SD) on the SLV program.

2.2 PROGRAM ORGANIZATION

The program organization must provide the means for the Program Manager to plan and control the program to fulfill contract requirements.

Analysis indicated that the ESS program presented no discrete organizational requirements which would dictate development of an organizational structure different from those employed on current Space Division programs. The analysis indicated instead, that the adoption of an established

PRECEDING PAGE BLANK NOT FILMED

structure would offer several important advantages. Foremost among the advantages are the retention of established program and functional interfaces, particularly with respect to the shuttle program, and the compatibility with existing management systems and controls provided by a relatively unchanged organization.

The ESS program accordingly will use the basic organization structure currently employed on the SLV program. This structure provides for a Program Manager with full authority and accountability for the implementation and performance of the program. He is supported by a management team consisting of the leaders of the program major organizational elements.

The major elements supporting the SLV program and proposed for support of the ESS program are Engineering, Production Operations, Test and Logistics, Quality Assurance, Program Administration, and Financial Management. Engineering is headed by a Chief Program Engineer, and each of the other functions by a director or manager at a level sufficiently high to assure effective execution of the authority delegated by the Program Manager. Sub-tier elements of the major functions include Configuration Management, Data Management, Contracts Administration, Facilities, Material, and Program Planning and Control. The Program Manager further augments his staff, and assures the support required by the program, through the addition of organizational elements such as systems safety, and program offices established at appropriate offsite locations.

The responsibility and authority of each of the functional leaders is clearly defined and documented in published position descriptions, and each is accountable to the Program Manager for the effective discharge of his assigned tasks in support of program requirements.

The use of an established organization structure for the ESS program offers several advantages in addition to the retention of established functional interfaces and the implementation of existing management systems and controls previously mentioned. The proposed organization structure was developed for a program essentially similar to the ESS program in both operation and end product. The organizational concept, in addition to having been proved effective, retains the structure, the management team, and many of the personnel responsible for its effectiveness. An additional advantage is the retention of established lines of communication both within the company and with the customer.

The combination of experienced personnel working in a familiar environment on a basically similar product provides a sound basis for the cost-effective design, production, and test of ESS vehicles.

2.3 PERFORMANCE MANAGEMENT

The performance management system comprises the documented procedures used by the Program Manager to plan the program, authorize the work, and determine program status in relation to established plans and objectives. The system to be employed for the ESS program is the basic system in use on various Space Division programs, including the SLV program. The system has proven effective in fulfilling company and contractual requirements.

Detailed planning of work developed by successively lower levels of management is fundamental to effective control of the program. The work breakdown structure (WBS) is used as a common framework for program planning and for managing program costs, schedules, and technical performance. The WBS is a division of the program into manageable segments of work which are product-oriented and extended to at least the subsystem level. The WBS clearly defines the end products to be produced as well as the work to be accomplished to achieve program objectives. All work required by the contract is covered, and changes to the WBS are controlled formally.

A work package (WP) is a functionally oriented set of tasks to be performed in support of a WBS element. Since program products result from the activities of various functions within the program organization, it is necessary to measure the performance of functions as well as the performance related to products. The WP is correlated to significant milestones, and serves as a meaningful unit for cost, schedule, and technical requirements identification. Work package task descriptions are sufficiently detailed to permit assignment of overall responsibility to a single individual designated as the work package manager (WPM).

The WP represents a unit of work at a level where work is physically performed, and must be assignable to a single cost account and organizational element. The WP contains budgets and schedules that constitute the plan against which the WPM assesses and controls the working level tasks. The sum of the budgets assigned to work packages within a cost account cannot exceed the total cost account budget established by the program financial plan.

Schedule planning is time orientation of the work represented on the WBS to the significant milestones established for the program. Schedules are used to establish the proper sequence and timing of tasks and serve as the basis for measuring schedule performance. A master program schedule (MPS) is the basic document used to identify and document contract milestones and significant program summary milestones. The MPS must be consistent with the WBS. The MPS for the ESS defined in this study is shown in Figure 6-1. A schedule control system, established in support of the MPS, assures immediate incorporation of program changes into the MPS. The MPS serves as the baseline for development of functional schedules, which in turn provide the basis for measuring performance against time allowed for the accomplishment of functional tasks.

Technical performance measurement (TPM) is the system by which management assesses technical performance and identifies problems or variances and their potential impact on program schedules or costs. The TPM system is an integral part of the engineering process and is based upon applicable contract end item specifications. TPM plans are developed for selected performance parameters, and identify specific events that permit measurement of progress against the parameters. The parameters are related to the WBS, and are measured and reported upon at planned frequencies.

Status analysis provides the basis for management visibility and action in relation to program cost, schedule, and technical performance. Actual costs, schedules, and technical performance are measured against the criteria established for each to verify performance or determine variances. Differences are analyzed to isolate the factors contributing to the variance. The results are conveyed to management through weekly status reports, the Program Manager's weekly reviews, and special briefing and reports if the nature of the problem or potential problems indicates need for immediate action. In addition, a management information center (MIC) is maintained to provide a permanent up-to-date display of the status of program activities. The MIC is intended for use by both the contractor and NASA management. Status information is further conveyed to NASA through contractually required reports and reviews, and through meetings at least once each week in which the Program Manager and the NASA Resident Manager discuss program status and activities.

A corrective action system will be maintained to assure appropriate management action concerning problems identified through the performance management system. The proposed system, currently in use, consists of two phases - the Program Bogie report and the Critical Problem report. Potential critical problems are designated as bogies and are listed on the Program Bogie report in the MIC and reviewed at the weekly program reviews. Bogies that persist or become critical are redesignated as critical problems and tracked through the Critical Problem report. During this phase, the action assignee prepares a weekly report, indicating actions taken to eliminate the problems, results of tests and studies, alternative solutions, final management selection of the optimum corrective action, and implementation of the action which closes the loop.

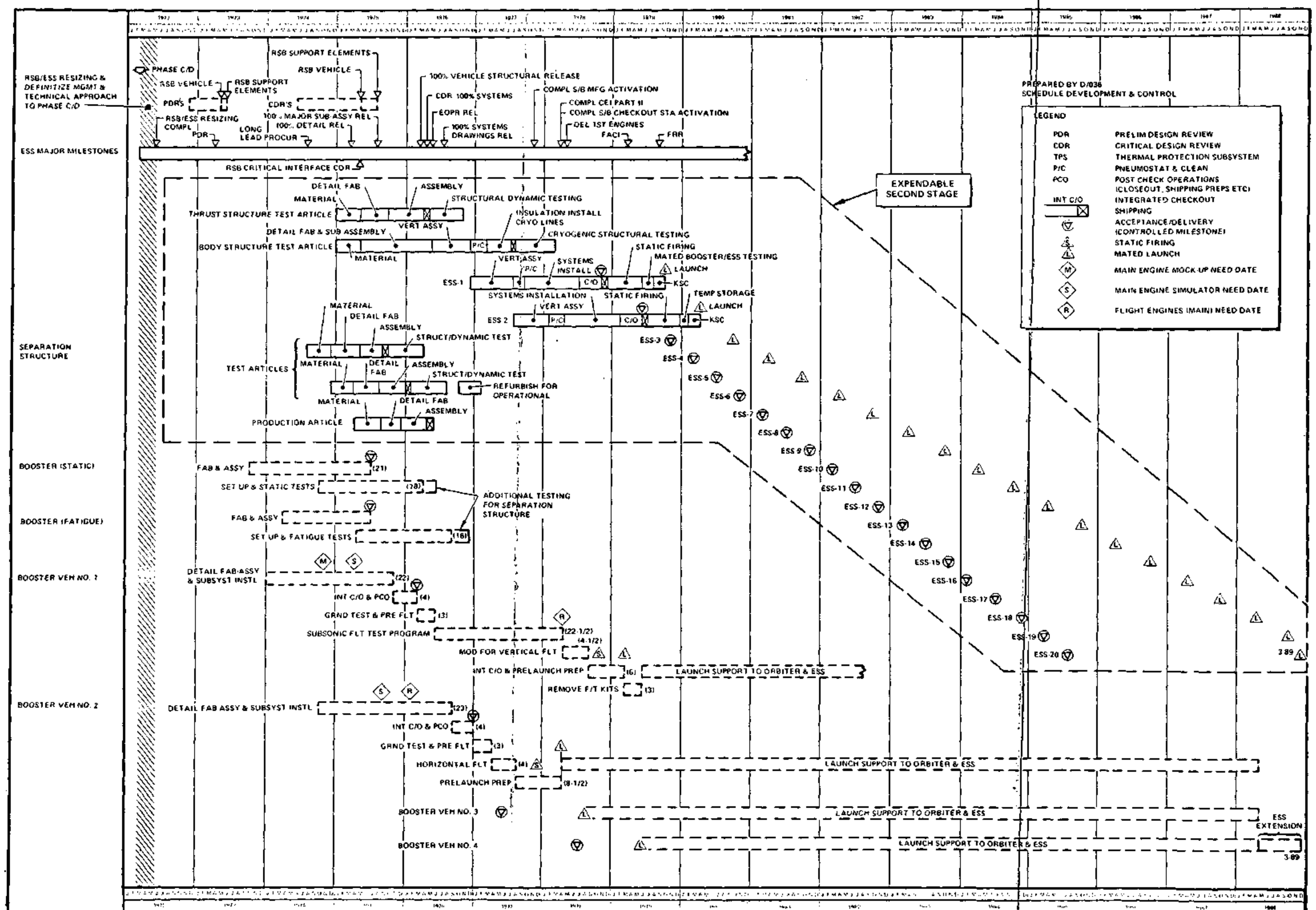


Figure 6-1. Preliminary ESS Master Program Schedule

6-7

FOLDOUT FRAME 1

FOLDOUT FRAME 2

3.0 BOOSTER AND SEPARATION STRUCTURE MANAGEMENT

This section defines the additional assumptions and booster program extensions necessary to assure that the Shuttle Booster system will also accommodate the ESS missions. Since the design of certain primary structural elements is driven by the ESS mission requirements, they must be recognized and accounted for early in the baseline system development prior to the formal ESS program go-ahead. There would be no significant program impact if the critical design requirements, as driven by the ESS mission requirements, are considered in the baseline pre-CDR design activities. The orbiter support bulkheads in the hydrogen tank are a critical example of ESS design, as it constrains the first test article tank assembly. If this assumption and those following are allowed, there would be little impact on the total booster development program as reflected in the schedule of Figure 6-2. There would be some slight extensions to specific design and testing activities; however, these would not alter the basic program milestones. On the other hand, if these assumptions were not allowed, the initial flight dates would be slipped by as much as 8 to 12 months. In either case, the basic management concepts and procedures as defined for the baseline booster program would still apply to the additional efforts to incorporate the ESS mission capability. Additions to the booster management plan to accommodate ESS missions include:

1. Design Engineering — The ESS design requirements would have to be considered in the baseline vehicle predesign efforts prior to ESS ATP (these would include selected W/T tests) to establish the proper vehicle sizing and configuration freeze. Preliminary design of the structure and structural layout drawings also should include the booster LH_2 tank bulkheads and aft tank skin gages associated with the ESS mission. Other booster structural elements, software development, and the detail design of the bulkheads can wait for the ESS ATP at mid-1973. The structural bulkhead detail design release would be the initial ESS release (~3 months) and would support assembly of the initial hydrogen tank for the static test article. The thrust structure hold-downs, separation system, and associated software are not considered critical constraints to this schedule, although significant design tasks.

2. Procurement — Long-lead raw material for the ESS designed tank skins and LH_2 tank bulkheads would have to be ordered prior to the ESS ATP to assure that the originally scheduled flight dates could be met.

3. Tooling and Manufacturing — Special bulkhead tooling considerations also would have to precede ESS ATP. The early design release on the bulkhead would permit sufficient time for fabrication of all parts prior to its need for tank assembly for both the structural qualification test article and the horizontal flight test article. Fabrication of the ESS designed parts could be accommodated within the planned manufacturing activities without any extensions of time necessary.

4. Additional Testing — The basic wind tunnel tests required for the additional ESS mission capability could be sandwiched into the baseline program with the significant portion being accomplished prior to the ESS ATP. Design support testing would have to be extended to accommodate testing for the ESS-required separation system. There also would be some material development testing and structural development testing on selected components which could be accommodated in the existing span times. The extensions to the booster static and fatigue test programs also are required to accommodate the ESS separation system which will be subsequent to the baseline separation system testing on these articles. A full scale vibration test on a complete horizontal booster for ESS conditions is planned and could be a 2 to 3-week extension to the equivalent tests for the baseline system on FTV-1 or it could be sandwiched into the ground operations on FTV-2 without significant program impact. Software integration for ESS separation controller for sequence and timing could be accommodated during the currently planned ASIL and support testing. Normal separation would be verified on the initial vertical flight as there are no experimental flight tests planned for this operation.

5. Facilities — Fabrication of the ESS-designed hardware and their subsequent assembly operations would not require any additional facilities over those defined in the baseline plan. The additional test requirements outlined above could also be handled in the same facilities specified in the baseline program. Likewise there would be essentially no schedule impact from flight facility requirements, as modification to the baseline plan using KSC's Complex 39 is virtually nil.

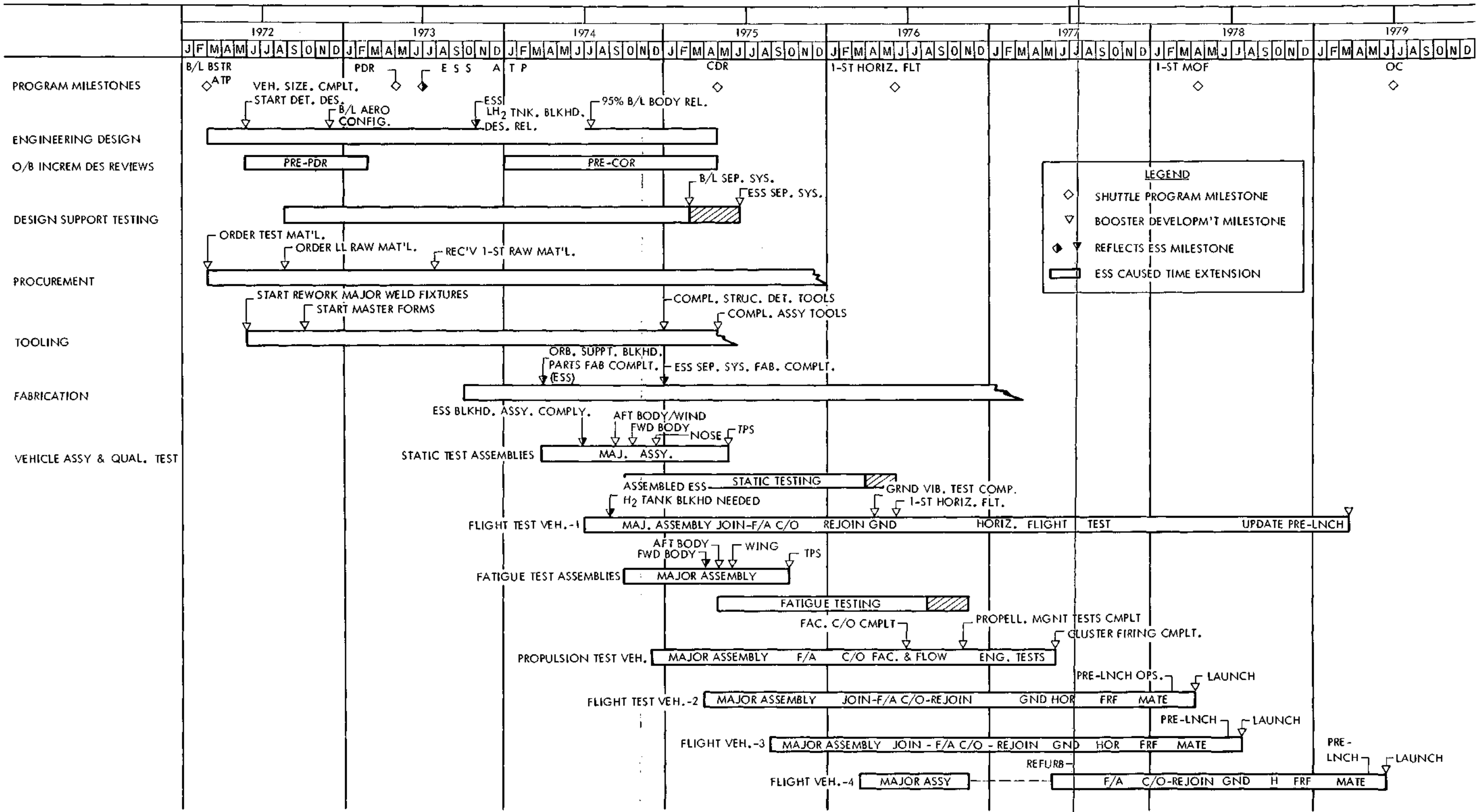


Figure 6-2. ESS Development Impact on Space Shuttle Booster - 360-Day Development Program