FIGURE 4-2 ORBITER TPS INTERFACES

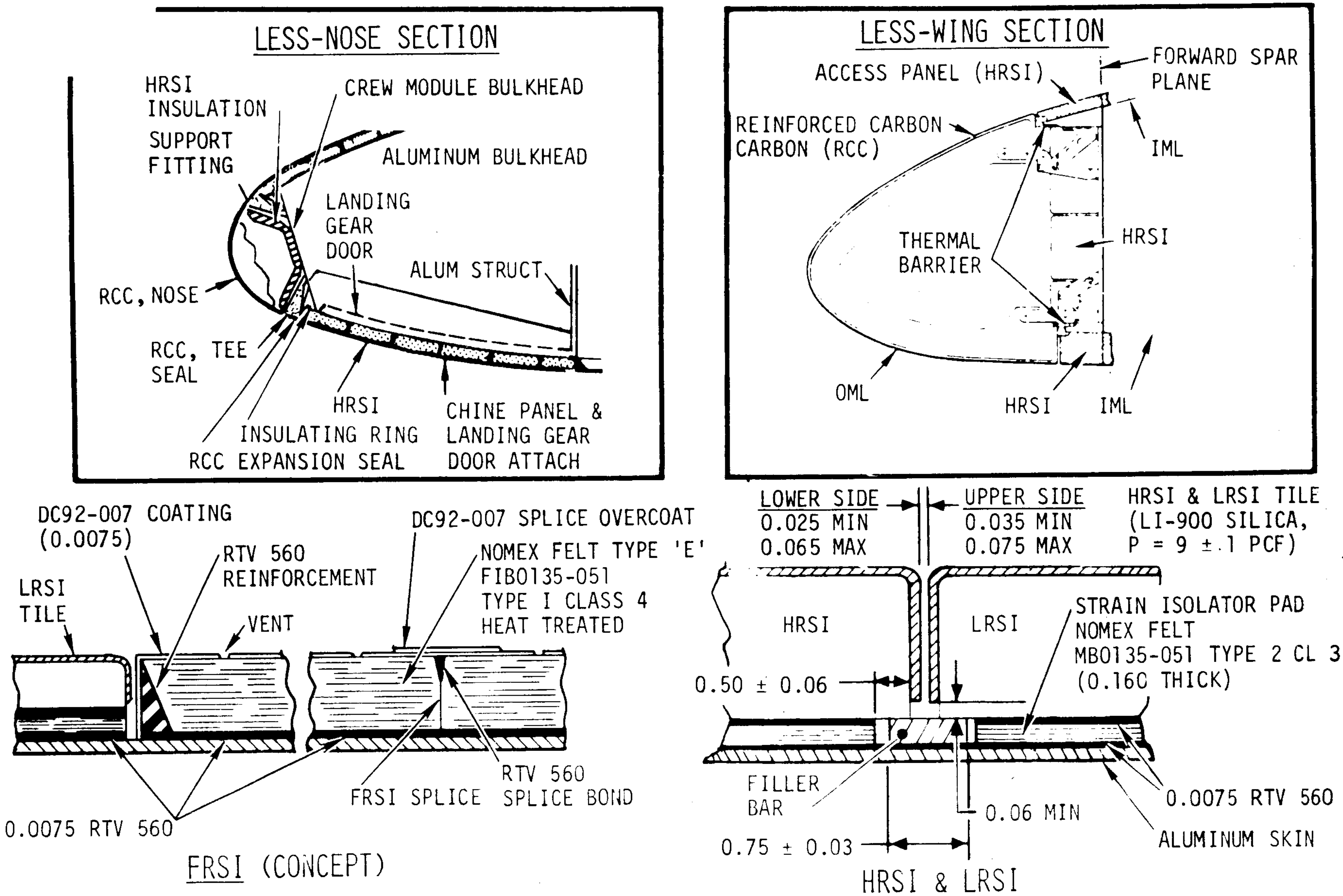
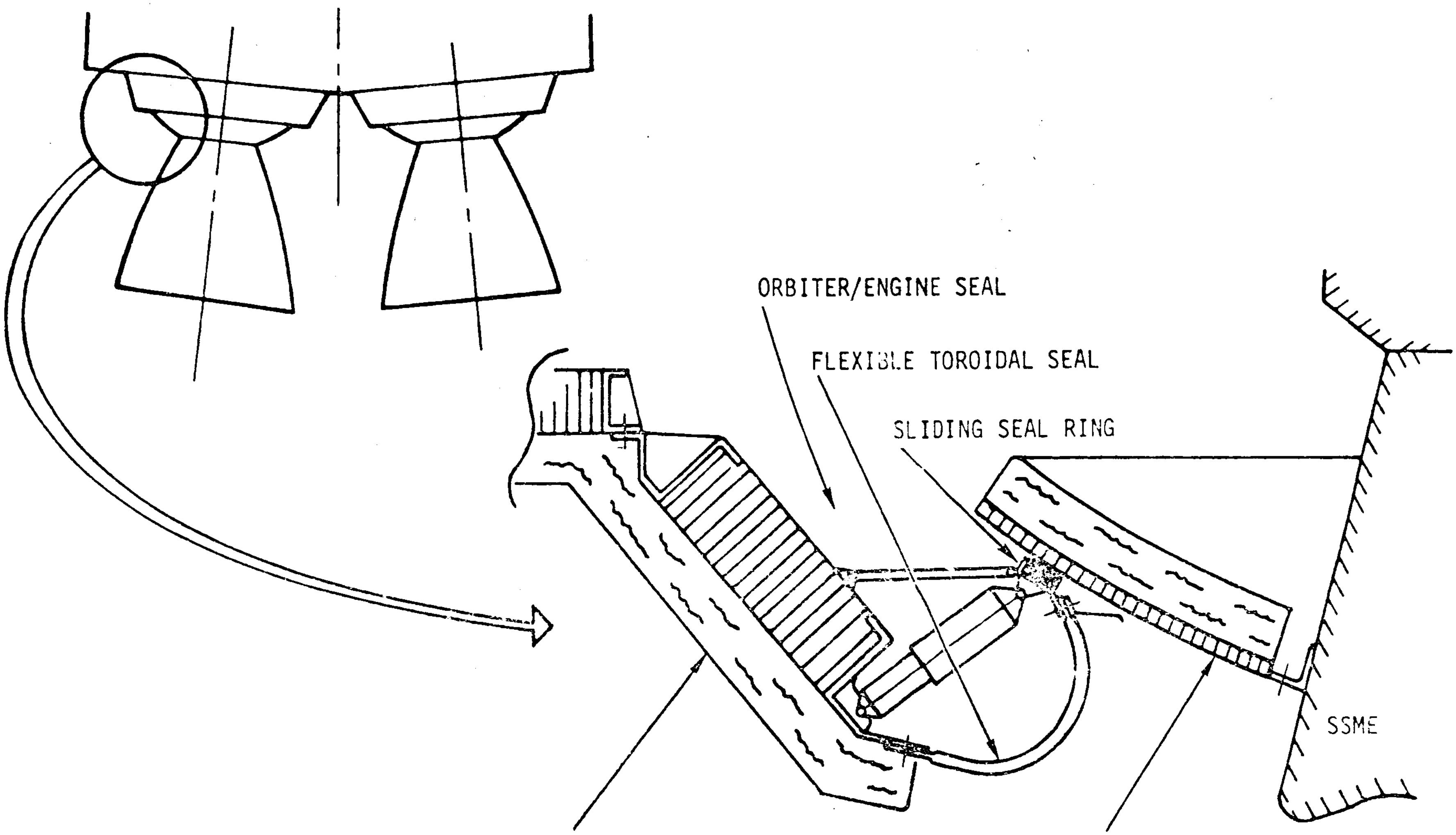


FIGURE 4-3 AFT HEAT SHIELD



# 5.0 AVIONICS MANAGEMENT

## 5.1 Introduction

The Shuttle avionics system provides command functions including their implementation, guidance, navigation, and control capability, communication, computation, displays and controls, instrumentation, and electrical power distribution and control for the Orbiter, External Tank, and the Solid Rocket Boosters. There are also provisions for the management and control of payload functions and for the communication of data to and from payloads.

Avionics was placed high on the list of areas to be examined and assessed by the Panel because the fabrication, test, and verification of the integrated system of avionics hardware and software is vital to the success of the current phase of the test program and later mission operations, and it is an area most likely to affect and be effected by resources and schedules.

Attachment 5-1 is the Shuttle Office response to the Panel's concern that the management system for avionic hardware and software should be reviewed by senior program management to assure it is adequate for the indicated complexity of the program.

Shuttle Orbiter avionics for the purposes of this discussion falls into two identifiable areas: (1) the Orbiter 101 avionics used during the verification testing and Approach and Landing Test project, and (2) the Orbiter 102 avionics used during the orbital flight tests and initial flights following DDT&E. The Orbiter 101 avionics system provides the necessary signal acquisition, handling, processing, display and powering to enable the navigation, control, and information interchange required for the approach and landing test project. Specifically, the avionics system for Orbiter 101 contains:

a. Guidance and Navigation

(1) Three Inertial Measuring Units (IMU).

(2) Navigation Base (NB).

(3) Software in the general purpose computers.

b. Air Data

(1) A sensory system to measure static pressure, total pressure, lower and upper alpha port pressures, and indicated total air temperature.

(2) Air Data Transducer Assemblies to provide digital inputs from the sensing system to the general purpose computers.

(3) Probes that are mechanized for stowage and deployment as required.

(4) Special aerodynamic probe mounted on a boom attached to nose of the Orbiter with a dedicated separate air data computer and panel mounted displays. This separate system is used to calibrate the operational system.

c. Flight Control

(1) Orbiter 101 has a backup flight control system using the independent air data sensors and dedicated general purpose computer as an alternate to the primary flight control function.

(2) Flight control components involved in the avionic-to-actuator interface are:

Rate gyro assembly
Accelerometer assembly
Rotation hand control
Speed brake thrust control
Rudder pedal transducer assembly
Aerosurface servo amplifier
Reaction jet driver forward
Reaction jet/OMS driver
Ascent thrust vector control driver

(3) Flight control digital autopilot software to provide the basic flight control functions.

d. Communications and Tracking

The RF, processing, and distribution equipment necessary to provide the many input, output and process activities.

e. Displays and Controls

(1) Controls

Rotation Hand Controller (this is noted above as well)

Rudder pedal transducer assembly (this is noted above as well)

Speed Brake Controller (this is noted above as well)

Keyboard used to interface with the CRT display and to manage the information displayed. It is also used to provide entry to send control commands to the computers.

(2) Displays

(a) Attitude Director Indicator (two-axis, roll and pitch).

(b) Surface Position Indicator (for aero-controls)

(c) Alpha/Mach Indicator

(d) Altitude/Vertical Velocity Indicator

(e) Horizontal Situation Indicator

(f) Orbiter Display Unit (CRT flight computer information)

(g) Computer Status Annunciator Assembly

(h) Fire Warning Annunciator Assembly

(i) Caution and Warning Subsystem

g. Instrumentation Subsystem

This consists of sensor transducers, signal conditioning equipment, PCM encoding equipment, frequency multiplex equipment, PCM tape recorders, analog recorders, timing equipment, and on-board checkout equipment.

The system is made up of two separate parts: (1) the operational instrumentation (OI), and (2) development flight instrumentation (DFI).

h. Data Processing and Software

(1) Five general purpose computers (GPC).

(2) Two mass memories - magnetic tape memories for

large volume bulk storage and organizational information.

(3) Eighteen Multiplexer/Demultiplexers (MDM).

(4) Remote interface units to convert and format data at system interface.

(5) Multifunction Cathode Ray Tube (CRT), three of these.

(6) Display System.

(7) Data Bus and associated equipment.

(8) Software for all computers.

i. Electrical Power Distribution and Control

This system provides power distribution and power control for all Shuttle Systems during operational phases. It interfaces with all subsystems that require signal power and operational power.

Following are the changes for the Orbiter 102 operational type vehicles:

a. The Star Tracker and Light Shade Units are added to the Guidance, Navigation and Control system.

b. Removal of air data components used for calibration of the system during Orbiter 101 test phase.

c. Addition of S-band.

d. The Engine Interface Unit used between the Orbiter controls and the SSME will be added to command and status the SSME during

Orbital Flight. A brief overview of the operational system is shown in Figure 5-1, and the Data Processing/Software arrangement is shown in Figure 5-2.

## 5.2 General Purpose Computer (GPC)

In the Orbiter 101 there are five GPC's in the Orbiter on-board computational complex. Four of the GPC's are synchronized, containing the identical primary program loads. The fifth GPC on the ALT phase of Orbiter 101 is dedicated to support the backup flight control system. This backup flight control system is a primary safety function in this phase of the program.

Each GPC is a modified IBM AP-101 microprogram controlled Central Processing Unit (CPU) with a unique Input/Output Processor interface to the serial data bus network. These two line replaceable units, the CPU and the Input/Output Processor, contain portions of main memory which are used by either the CPU or the Input/Output Processor on a nondedicated basis. The CPU initiates all input/output actions through the execution of instructions to the processor. These instructions and data words are transferred between the CPU and the Processor on a bidirectional, parallel word data bus. Except for initiation, the processor is independent of the CPU and executes its own programs, which reside in the common main memory. Read-only storage is used for controlling a fixed sequence of operations and internal data paths to be executed for each instruction.

5.3 Performance Monitoring System (PMS)

The PMS on Orbiter 101 is considerably less complex than the one on Orbiter 102 which is used for orbital missions. The Orbiter 101 PMS as used during the ALT project provides for automatic fault detection and annunciation, and subsystem measurement management. Additional PMS functions for Orbiter 102 OFT and operational missions include the following: (1) subsystem configuration management, (2) consumables management, (3) data recording management, (4) telemetry format selection, (5) payload support, (6) mission proper storage and retrieval, (7) performance evaluation and trend analysis, and (8) contingency planning aid. The smaller 101 PMS program is resident in each of the four GPC's used for the primary flight control system.

Automatic fault detection and annunciation detects subsystem failures at the functional path level, which is the level corrective action can be taken in flight. This system is implemented through the avionics software. When the failed parameter is one of the safety critical caution and warning parameter group items a backup caution and warning master alarm signal is generated. A PMS crew alert alarm consisting of a small blue light and a short duration buzzer is initated when any parameter is declared failed. Thus the PMS provides a backup capability for the hardwired Caution and Warning subsystem in alerting the crew to any detected hazardous or potentially hazardous condition which requires attention.

The Subsystem Measurement Management software enables the crew to call up on the CRT the measurement data so the crew can assess the degree of a problem.

5.5. Orbiter Avionics Installation

The major portion of avionics can be found in the flight deck, the three forward avionics equipment bays, and the three aft avionics equipment bays. All antennas, except those used exclusively for satellite tracking and EVA communication, are flush mounted on the top, bottom, and sides of the Orbiter forward fuselage. These antennas include:

a. Four S-band seven-element antennas for phase modulated (PM) communication with space/ground link system and STDN ground stations and the NASA tracking and data relay satellites.

b. Two S-band FM antennas.

c. Four C-band horns for the radar altimeter.

d. One UHF antenna for EVA/air traffic control voice communications.

e. Six L-band TACAN antennas.

f. Three Ku-band microwave scan beam landing system antennas.

g. One integrated Ku-band communications/rendezvous radar antenna and one Ku-band communication used with the NASA Tracking and Data Relay Satellite.

h. One S-band PM payload antenna.

## 5.6 Orbiter Radio Frequencies

The Orbiter carries up to 23 antennas for communication with ground stations, detached-payloads and crewmen doing EVA. They use S-, Ku-, L-, C-, and P-band frequencies. Table 5-1 shows the system function and the Orbiter frequency for transmitting and for receiving signals.

The Ku-band links the ground stations and the Orbiter via the Tracking and Data Relay Satellite System. It carries the same kinds of intelligence as the S-band subsystem, but at wider band-widths and higher data rates. The Orbiter rendezvous radar and the Multiple Scan Beam Landing System also works in the Ku-band. The Ku-band systems capabilities and vehicle locations are shown in Figure 5-3.

## 5.7 Microwave Scanning Beam Landing System (MSBLS)

The MSBLS will provide information to the Orbiter avionics computer during the critical autoland period of flight. The MSBLS is used during the last 75-seconds of Orbiter flight. While the nominal acquisition range is about 12 n. miles, the range in practice depends upon Orbiter flight path, attitude, and weather constraints.

The system consists of the ground station and an airborne navigation set. The ground station is divided into an elevation equipment group, Figure 5-4, and an azimuth/distance measuring group, Figure 5-5. The airborne equipment is divided into a decoder-receiver unit and a DME transmitter unit. Figure 5-6 shows the major elements and the radio-frequency links which are used in the MSBLS.

## 5.8 Avionics Laboratories and Test Plan

There are three laboratories of major significance to the avionics test program. In principal the Software Development Laboratory at JSC is for the development and verification of software. The Avionics Development Laboratory at Rockwell International is for the evaluation of avionics hardware/software. The Shuttle Avionics Integration Laboratory at JSC is for the validation of the integrated avionics hardware and software system. In practice the laboratories are also used as needed to work through technical challenges. The following sections describe each of the laboratories and the test program for validation of Orbiter 101 hardware and software for ALT.

### 5.8.1 Software Development Laboratory (SDL)

This facility at JSC is used for software coding, development testing and for verification of the flight software. It provides the capability for high fidelity execution of flight software, variable fidelity simulations of vehicle and avionic subsystems to provide nominal and off-nominal performance, diagnostic aids to force test conditions and collect/analyze results, and an automated and semi-automated set of techniques to provide rigorous software configuration management. This facility has been operating in support of the SAIL and Palmdale Plant checkout work.

5.8.2 Avionics Development Laboratory (ADL)

The ADL is an engineering tool with emphasis on avionics hardware development, subsystem evaluation and initial hardware integration. It is set up as shown schematically in Figure 5-7. This facility is located at RI/Space Division, Downey, CA. The major ADL flight control tests cover the test and checkout procedures for the Orbiter 101 at Palmdale; the Backup Flight Control System (BFCS) closed-loop performance; the primary to BFCS switchover; primary flight control system performance testing and actuator tests; and closed-loop testing with the Flight Control Hydraulics Laboratory (FCHL).

The status of work being done at ADL is summarized as:

a. Software evaluation tests are in process on those tapes to be used for test and checkout of Orbiter 101. The programs or tapes to be used include SU-1, SU-1A, VU-101/ADL-3A, FACI, ADL-3B, OPS-9, SU-89, and ADL-3. These tapes will also support the SAIL integration testing.

b. The ADL is using two production general purpose computers (GPC's) to support the dry runs of test and checkout procedures and memory loading tests for GSE support.

c. Both Single-string and Multi-string open and closed-loop engineering studies are being done.

d. Work load at ADL now and in the future will be quite heavy to meet the required evaluations and verifications. With proper scheduling and no major problems this work load should be accommodated.

### 5.8.3 Shuttle Avionics Integration Laboratory (SAIL)

The SAIL at JSC gives NASA the capability for extensive closed-loop mission evaluation of the avionics system as it will be used in flight. This capability includes testing for specific off-nominal conditions. After outlining the scope of the activities planned for SAIL, the differences between the equipment used in SAIL and the equipment to be flown on Orbiter 101 are discussed to provide an understanding of the capability of the SAIL to support Orbiter development and flight programs.

#### 5.8.3.1 Test Activities

To give an idea of the scope of the total SAIL test activities, a brief definition of the four test phases is as follows:

PHASE I TESTS - Activation and establishment of the operational capability of the SAIL checkout should be completed by July/August 1976 time-frame. A prototype/breadboard version of the avionics test hardware will be used.

PHASE II TESTS - Orbiter avionics software systems performance in support of the ALT program requirements will be verified during this phase. Priority has been placed on verifying the Backup Flight Control software and then utilizing this configuration to buildup and integrate flight systems. It is expected that the Software Development Laboratory (SDL) software will be utilized for the buildup of those flight systems not covered by the BFCS. The final flight system buildup, integration, and laboratory verification will be accomplished with those software tapes or programs designated as VU-101 CI, ADL-5/MS FACI, and OPS-01 Pre-release. This software is used in order to have SAIL ready to support closed loop testing in September/October 1976 period.

PHASE III TESTS - Testing will be conducted to support the orbital flight missions.

PHASE IV TESTS - Testing will support the Shuttle avionics operational requirements. Thus there will be update of SAIL to the required hardware/software configuration.

5.8.3.2 SAIL Equipment

5.8.3.2.1 Simulated Surface Actuators

A special purpose electronic simulator has been designed and is being built in-house at JSC to appear functionally equivalent to the real hardware and interface directly with the hardware aerosurface actuators. To assure the simulation is adequate, the system functions will be compared with those from hardware at the flight control hydraulic laboratory and from the Orbiter 101 vehicle. This comparison will cover (1) position gain and phase shift versus frequency, (2) secondary pressure monitoring, and (3) vehicle/flight control system closed-loop structural mode stability.

5.8.3.2.2 Functionally Equivalent Prototype vs Qualifiable Equipment

Where prototype equipment is used it is planned to recycle them after they have been modified and updated to maintain functional equivalency with flight-type hardware.

5.8.3.2.3 Development Flight Instrumentation Not In SAIL

Omissions are in the sensors and harness normally connected to the operational instrumentation multiplexers/demultiplexers. These do not affect the flight control system or the data processing system.

5.8.3.2.4 Use Of Special IMU Mount

Since SAIL does not test the structural dynamic environmental effects on sensors but does simulate structural dynamic coupling into the flight control sensor signals the Navigation Base is simulated with a special mounting provision for the IMU. The Navigation Base provides a rigid mounting for the three IMU's and the two Star Trackers, included in the Orbiter 102-and-on vehicles, whereby precision alignment of these critical navigation devices may be maintained throughout Orbital flight.

5.8.3.2.5 Backup Flight Control System (BFCS)

The G-meter and attitude indicator are simulated and it is not a SAIL objective to test this equipment. The SAIL, however, does need these functions represented in the system for the necessary system level functional evaluations.

5.8.3.2.6 Flight Harness

There are a number of differences between flight and SAIL electrical cabling or harnesses. These involve interfaces with simulated non-avionics equipment and DFI ommissions since EMI testing is not a SAIL objective. While SAIL uses single point ground due to lack of vehicle structure, the flight hardware uses the vehicle structure as ground. The interfaces with the dynamic motion simulator require non-standard harness to mount the IMU and other equipment.

5.8.4 The Test Program for OV-101 and ALT

The avionics verification program is now taking shape. The concept for the Approach and Landing Test Project (Orbiter 101) is shown schematically in Figure 5-8. The relative working relationships between the SAIL, ADL, etc. are readily seen here. Additional information concerning the SAIL system tests can be found in the following documents:

a. SD75-SH-0079 "Integration and Preflight Tests" (System Integration).

b. SD75-SH-0080 "Preflight, Taxi, Take-off, and Climb" (ALT Captive Tests).

c. SD75-SH-0081 "Cruise Mission Phase" (ALT).

d. SD75-SH-0082 "Separation Sequence/Mated Flight (ALT).

e. SD75-SH-0083 "Descent, Landing, and Post-Flight Taxi-Mated Flight Phase".

The factory checkout and integrated test programs at Palmdale for Orbiter 101 is scheduled between March and November 1976. It has the following objectives:

a. Verify manufacturing assembly operations by demonstrating Orbiter subsystem performance to engineering design requirements and subsystem and combined subsystem functional paths.

b. Demonstrate functional integrity of all systems when operated in various flight modes and selected backup, redundant, and abort modes as well as verifying intra-systems compatibility and electromagnetic compatability of subsystems.

## 5.9 Other Test Capabilities to Support Avionics Activities

### 5.9.1 Electronic Systems Test Laboratory (ESTL)

This facility at JSC is to be used for development tests, end-to-end compatibility tests, and performance verification of the Shuttle space communications and tracking system. It is to have an interface with SAIL by both RF and hardware. Support of the program is expected to begin with the orbital flight test phase.

### 5.9.2 Training Simulator Projects

Major items comprising the training simulator projects include the following:

a. Shuttle Mission Simulator - deliveries scheduled for Spring and Summer of 1978.

b. Shuttle Mission Simulator Computer Complex - delivery of the hardware/software is expected in Summer of 1976.

c. Orbiter Aeroflight Simulator - delivery is expected in September 1976.

d. Shuttle Procedures Simulator - it is an in-house development at JSC and currently in use there.

e. Crew Procedures Evaluator Simulator - it is also an in-house development at JSC and is in use there.

f. The Shuttle Training Aircraft (STA) - two aircraft have been built to simulate the flying qualities and trajectories of the Shuttle Orbiter. These aircraft are to be used to train the Shuttle pilots by duplicating, in so far as practical, the handling characteristics and visual cues expected to be experienced in flying the Shuttle Orbiter in the Terminal Area Landing Trajectory.

The management systems for the simulation activities emanates from the Operations Integration Office at Level II at JSC. The management scheme is shown in Figure 5-9. In addition there is a Space Shuttle Program Simulation Planning Panel established by Program Directive 1A, dated May 21, 1974 which is to provide the mechanism for accomplishing coordination, planning, and review of simulation activities.

## 5.10 Avionics Management

The Panel in examining this broad area spent some time in understanding the hardware, software, facilities and test programs associated with the avionics program. The Panel reviewed the organizations in existence which manages the avionics work: (1) Orbiter avionics systems office at Project Level III, (2) Technical Assistant and his division covering avionics in the engineering directorate, (3) data systems and analysis directorate, (4) integration and check-and-balance functions including the integration office at the program level; such technical panels as the Integrated Avionics Steering Group, the SIR and CSIR and associated Panels; hardware and software configuration/change control boards; and the technical review process including system design reviews on each mission phase. The following sections indicate some of management's actions to assure effective management of avionics development.

5.10.1 The Program Management Panel System for Avionics

Based on the Program Directive setting up the Space Shuttle Integrated Avionics Technical Management Area, the following responsibilities are given to the Systems Engineering Office at Level II;

a. Assessment of the technical adequacy of the overall performance of avionics systems for the Space Shuttle vehicle within the available resources.

b. Coordination, publication, and implementation of a plan, including task definitions and schedules, for the accomplishment of the technical manager's responsibilities including establishment of the membership of the integrated avionics panels.

c. Management of the activities of the integrated avionics panels to assure adequate communications and understanding between all personnel involved as well as program management. Membership on the Systems Integration Review (SIR) panel which supports integration activities across the program.

Four panels and a steering group were established as follows:

a. The Integrated Avionics Steering Group which brings together avionics management personnel from JSC, MSFC, KSC, and Rockwell Space Division.

b. The Shuttle Avionics Panel which serves as a technical planning, reviewing, and integration team for all Shuttle avionics interfaces. Their work includes conceptual studies, system analysis and syntheses, trade studies, preliminary design, and supporting technology essential for the specification of the functional and performance requirements of the integrated avionics systems.

c. The Flight Communications Panel which insures the compatibility, performance, and timely definition of communications and tracking system interfaces and identifies problems, determines corrective action, and recommends appropriate action to the technical manager.

d. The Shuttle Avionics Checkout Panel which serves as a forum for the integration of the avionics checkout and prelaunch testing requirements for the elements of the Shuttle system. Their work covers review of requirements, test procedures, avionics test software requirements, and the resolution of avionics checkout issues for factory checkout at Palmdale, ALT pre- and post-flight checkout, checkout and maintenance testing at KSC, and support of pre- and post-flight checkout for the operational phase of the program.

e. The Shuttle Avionics Verification Panel which serves as a special working group for planning and coordinating the test activities of JSC, KSC, MSFC, and Rockwell.

### 5.10.2 Special Requirements Reviews

Management has focused a great deal of attention on the hardware-to-software compatibility aspects of the avionics systems at every level of the program and at every major step in the schedule. For instance there have been a number of special reviews of software requirements for the ALT and the OFT phases of the Shuttle program. These have been termed "scrub" activities and they are planned as a continuing activities to assure requirements are well defined and can be met. The methodology used in these activities generally follows these lines:

a. Review the approach and the results of previous scrub activities along with the most current hardware configurations and performance requirements.

b. Establish the goals and basic capability requirements to be used as decision criteria.

c. Conduct reviews with pertinent managers and key technical personnel to assure a common understanding of the scrub groundrules and expectations, assess software module functional content requirements and agree on possible deletions with their impact.

d. Finalize the specific requirements modifications, deletion and additions as options to be proposed to management. Particular attention is given to assure they have not reduced the capability to protect against software generic failures and the like.

e. Present the options to management for their decision along with the backup material upon which decisions can be made.

### 5.10.3 Program Activities

In response to the Panel's reviews of avionics hardware/software the following areas are receiving special management attention:

a. Management is sensitive to the fact that establishing minimum levels of testing on which to base a flight worthiness decision is a difficult judgment. The avionics system, of course, must work because it is not tolerant of generic failures in the software.

b. Management has established teams to review the requirements and assess the impact of any changes suggested. The team approach is equivalent in purpose to the System Design Requirements Reviews. A team has JSC, Rockwell Internation Space Division and IBM members. The membership reflects the projects new approach on integrating Rockwell and IBM operations more closely on a day-to-day basis so potential problems can be worked out early.

c. The IBM schedule is tight and initial verification requirements are being reassessed. However, management is looking to the SAIL test programs to provide a more comprehensive validation of the software as a supplement to the IBM efforts.

d. Management is carefully controlling new requirements after the software requirements are authorized at the System Design Requirements Reviews. Currently only mandatory changes are approved.

e. Because of recent scrubs the software requirements for ALT are currently within the capacity of the memory.

f. The verification schedule for ALT is tight. The Level I milestone of completing the ALT flight software verification has been changed from July 1976 to November 1976. Management is now planning its response to this situation.

g. Plans are being made to validate late modifications to the software in the SAIL facility, but if these mods are much greater than planned for, there will be a schedule problem at that time.

## 5.11 ADDENDUM

### 5.11.1 ALT Project

The computer program end items (CPEI's) provide the capability for checkout of the Orbiter avionics subsystems at the factory perform the required preflight and flight operations. The basic programs associated with ALT and the Orbiter 101 of direct interest to the Panel are:

a. OPS 8 and OPS 9 - Systems Management

b. OPS 1 - Preflight Checkout

c. OPS 2 - Flight Operations

The requirements for OPS 1 and OPS 2 have been scrubbed to bring them well within the storage capability and processing rates (time to process) of the general purpose computer. The results of the latest scrub actions and an idea of available margins is shown below:

| ALT (Orbiter 101) | OPS 1 | | OPS 2 | |
|---|---|---|---|---|
| Before scrub | 64,060 wds | 107.0% rate | 67,270 wds | 91.7% rate |
| After scrub | 52,880 wds | 57.2% rate | 54,190 wds | 66.4% rate |

Current schedules have the software programs for tailcone off ALT operations to be completed first although such flights come last. Then through parameter changes the ALT tailcone on software programs will be completed. This, however, necessitates the verification and final checkout of the "ON" software to be accomplished late in the program at DFRC,very close to flight time.

5.11.2 OFT Project

The software program requirements for the ascent and entry phases have been scrubbed with the following results:

| OFT (Orbiter 102) | Ascent Software | Entry Software |
|---|---|---|
| Estimated Current Size | 56,900 words | 52,400 words |
| Estimated Additional words to be added as known today | 700-800 | 500-600 |

Program management is using the lessons learned in developing the ALT software to enhance the OFT software development program. As a result a more detailed OFT work plan to assure adequate and timely daily direction, visibility and control is being established. For example "Mode Teams" have been established to define, integrate and simplify software requirements and to work problems as they arise. Sixteen such teams have been or will be established to cover every major aspect of the mission phases. The first meetings of some of these teams was conducted during the last week of May 1976 at the RI/Space Division.

5.11.3 Further Actions

Program management has also instituted weekly telecons between

JSC, RI/Downey, RI/Palmdale to review status and progress on the avionics checkout being conducted on Orbiter 101.

A permanent scrub group is to be formed soon to assure that all requirements laid on avionics software and hardware will be compatible and that there will be sufficient margins to accommodate the growth in requirements as the OFT mission matures.

The management system for avionic hardware and software should be reviewed by senior program management to assure it is adequate for the indicated complexity of the program.

Response: The avionics management and development plan is considered a critical element of the Space Shuttle Program. In January of this year the avionics and flight control status was reviewed at the program director and Director of MSF levels. The areas of coordination of the hardware/software technical work and the degree of the contractor responsibility were identified, among others, as requiring further management attention. The Rockwell responsibility in avionics has been clarified and strengthened by emphasizing their areas of responsibility and objectives. Specific adjustments have been made. As an example, they have been requested to include the overall computer memory and operations duty cycle estimates and requiring them to establish bogies for each of the program elements of the software resident in the onboard computer. They have been required to prepare a cost effective overall avionics development plan utilizing engineering simulations at RI and NASA ADL, SDL, and SAIL facilities to support 101 and 102 schedules.

A review of the total flight control area was conducted and a single individual was identified as having total flight control responsibility for both Level II and Level III for the Space Shuttle Program. He prepared a total review of the status of flight control design, requirements, management, and required resources, together with a flight control development plan. This review and plan were presented to the center director who approved the plan in June of this year.

The Space Shuttle Orbiter Project Office avionics effort has been strengthened by clarifying responsibilities and by adding personnel. A weekly avionics system review working meeting has been established with the RI Associate Engineering Director of Avionics, the software contract manager, the NASA avionics systems engineering manager, and chaired by the Space Shuttle Project Office avionics manager. The avionics manager reviewed the center plans for integrating the avionics effort with the Space Shuttle Program Director and the Associate Administrator for Space Flight in June.

A single individual has been identified and established by appropriate directives as the focal point for all Space Shuttle avionics engineering. At this point, Level III and Level II hardware and software responsibilities are combined. The chief of avionics engineering and the Space Shuttle Project avionics manager are preparing an overall avionics development plan and a management plan to be presented to the Space Shuttle Program Director and the Associate Administrator for Space Flight on September 29.

TABLE 5-1

ORBITER RADIO FREQUENCIES

| FUNCTION/SYSTEM | ORBITER TRANSMIT | ORBITER RECEIVE |
|---|---|---|
| STDN PM-1 | 2287.5 MHz | 2106.4 MHz |
| STDN PM-2 | 2217.5 MHz | 2041.9 MHz |
| STDN/FM | 2250.0 MHz | NONE |
| DFI FM | 2205.0 MHz | NONE |
| NASA PAYLOADS | 2025.0 TO 2120.0 MHz | 2202.5 TO 2297.7 MHz |
| EVA COMMUNICATIONS | 296.8 MHz | 259.7 MHz |
| RENDEZVOUS (RADAR) | Ku-BAND | Ku-BAND |
| Ku-BAND COMM | Ku-BAND | Ku-BAND |
| RADAR ALTIMETERS | 4.3 GHz BAND | 4.3 GHz BAND |
| TACAN | 1025 TO 1150 MHz | 962 TO 1213 MHz |
| ATC VOICE | 225 TO 400 MHz | 225 TO 400 MHz |
| MSBLS | Ku-BAND | Ku-BAND |
| ATC TRANSPONDER (FERRY KIT) | 1090 MHz | 1030 MHz |

FIGURE 5-1

SHUTTLE AVIONICS SYSTEM

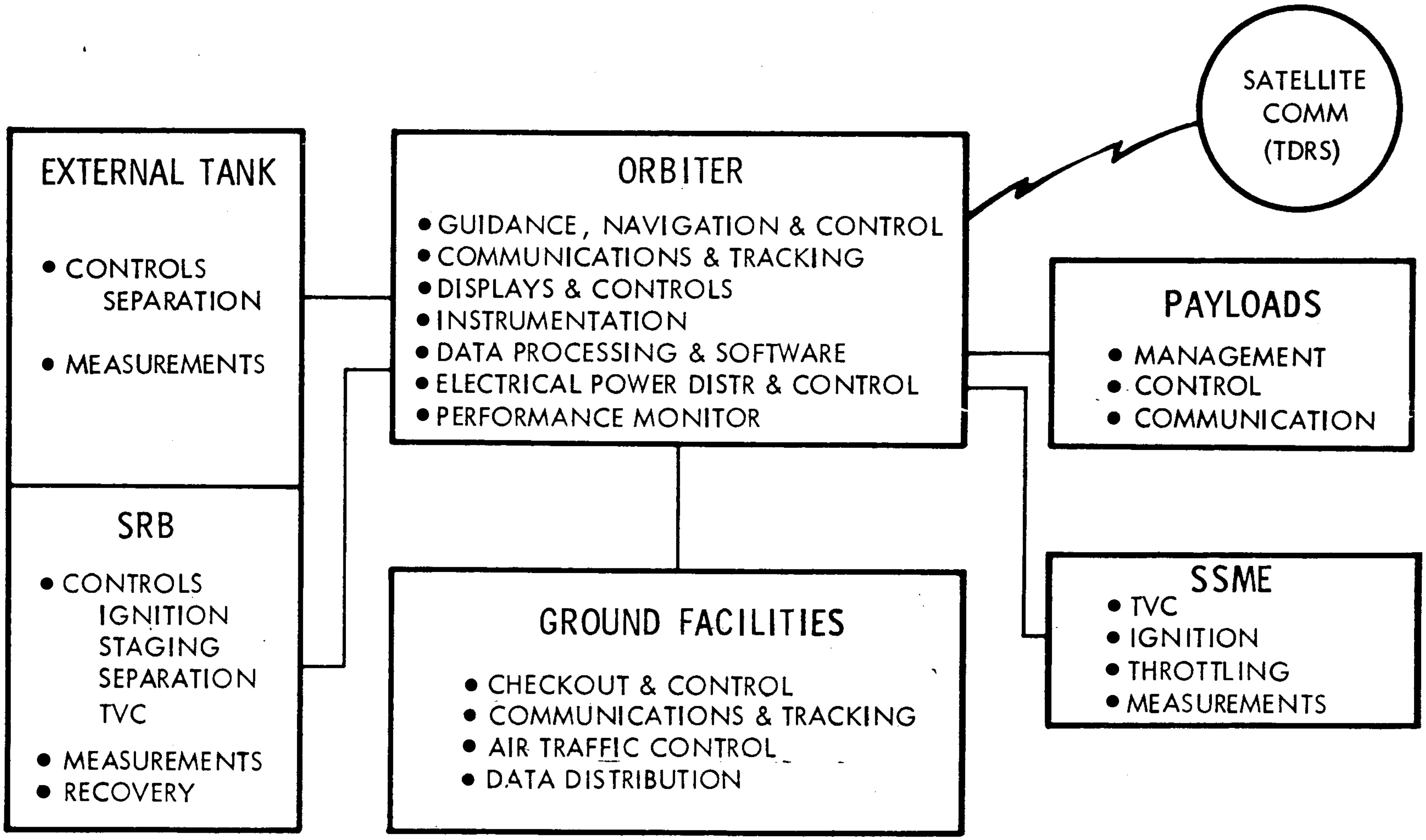
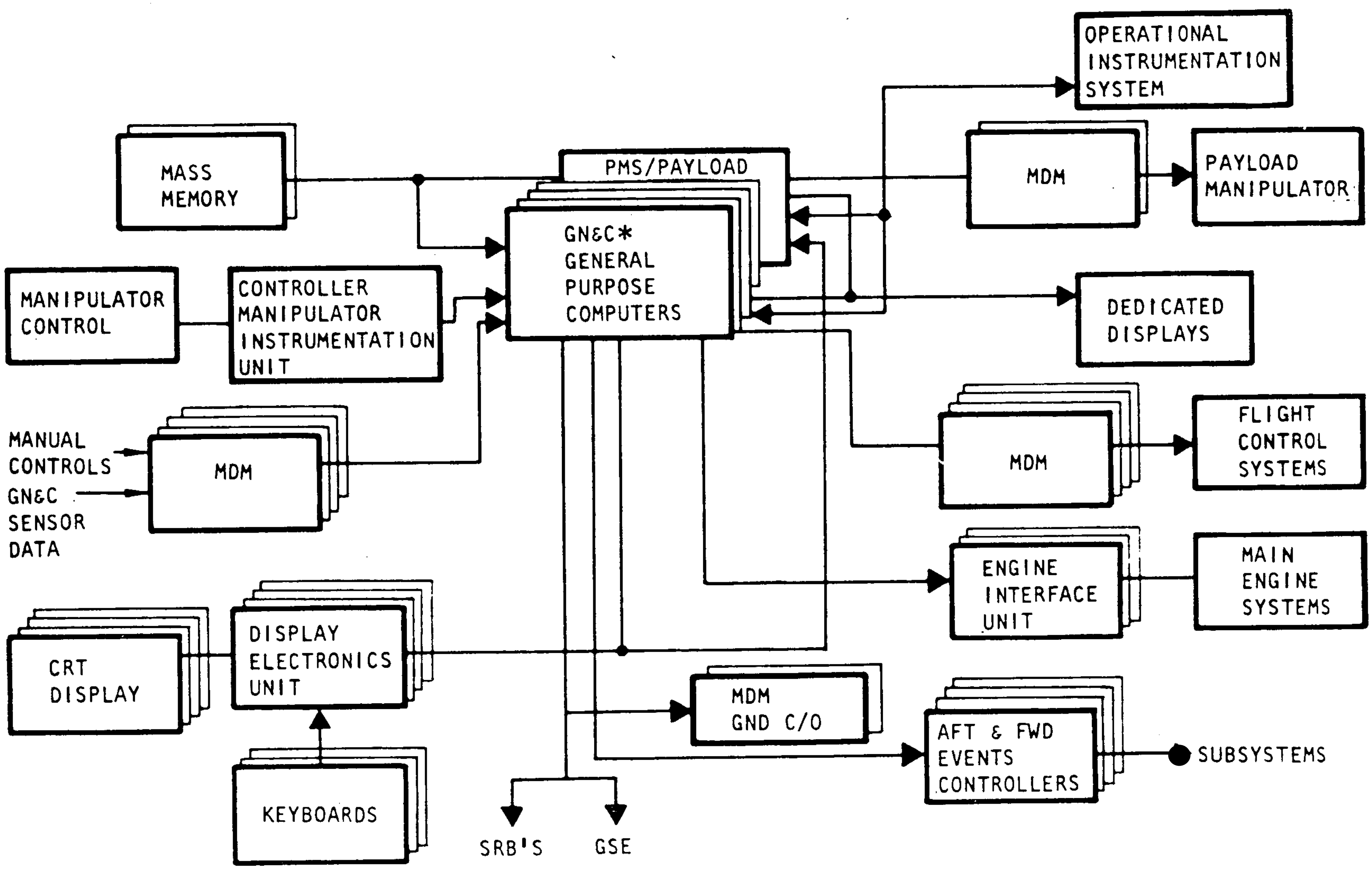


FIGURE 5-2

## DATA PROCESSING AND SOFTWARE SUBSYSTEM BLOCK DIAGRAM




* FOUR COMPUTERS DEDICATED TO GN&C DURING CRITICAL FLIGHT PHASES. ONE OR MORE CAN BE RECONFIGURED FOR OTHER USES DURING NON-CRITICAL FLIGHT PHASES

FIGURE 5-3

ORBITER KU-BAND RADAR/COMMUNICATION SUBSYSTEM

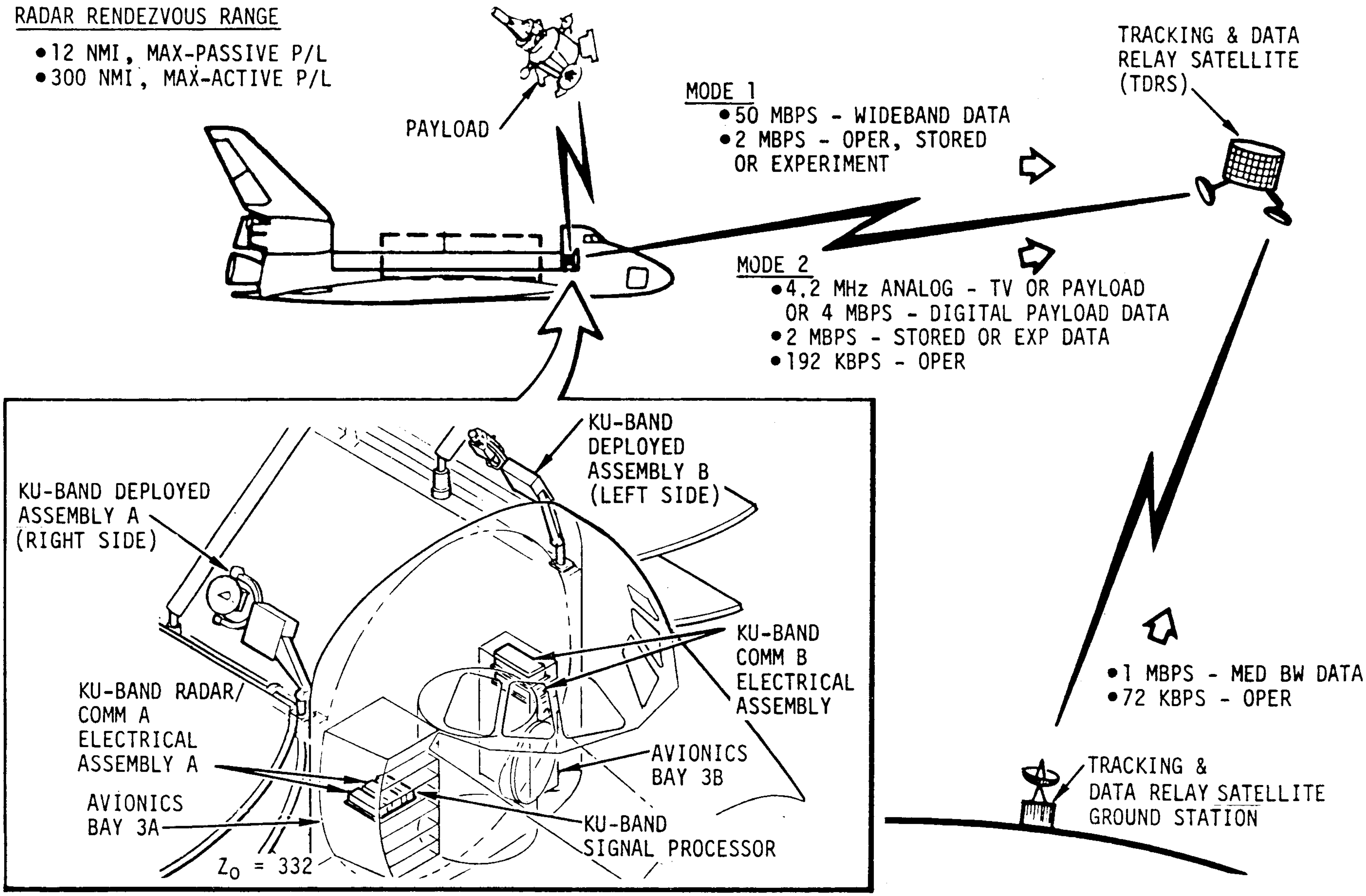


FIGURE 5-4

MSBLS-GS ELEVATION SHELTER AND EQUIPMENT

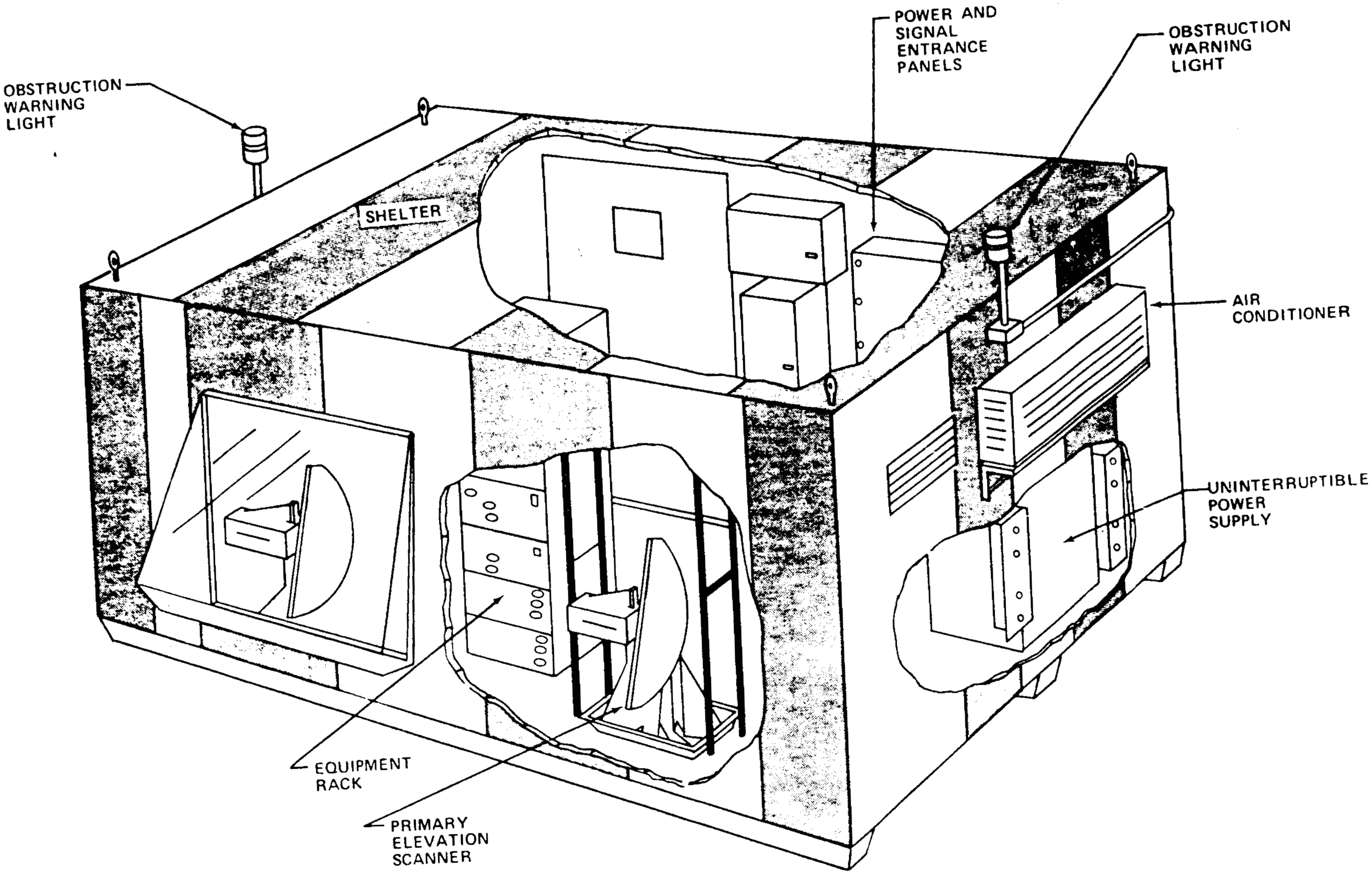


FIGURE 5-5

MSBLS-GS Az/DME SHELTER AND EQUIPMENT

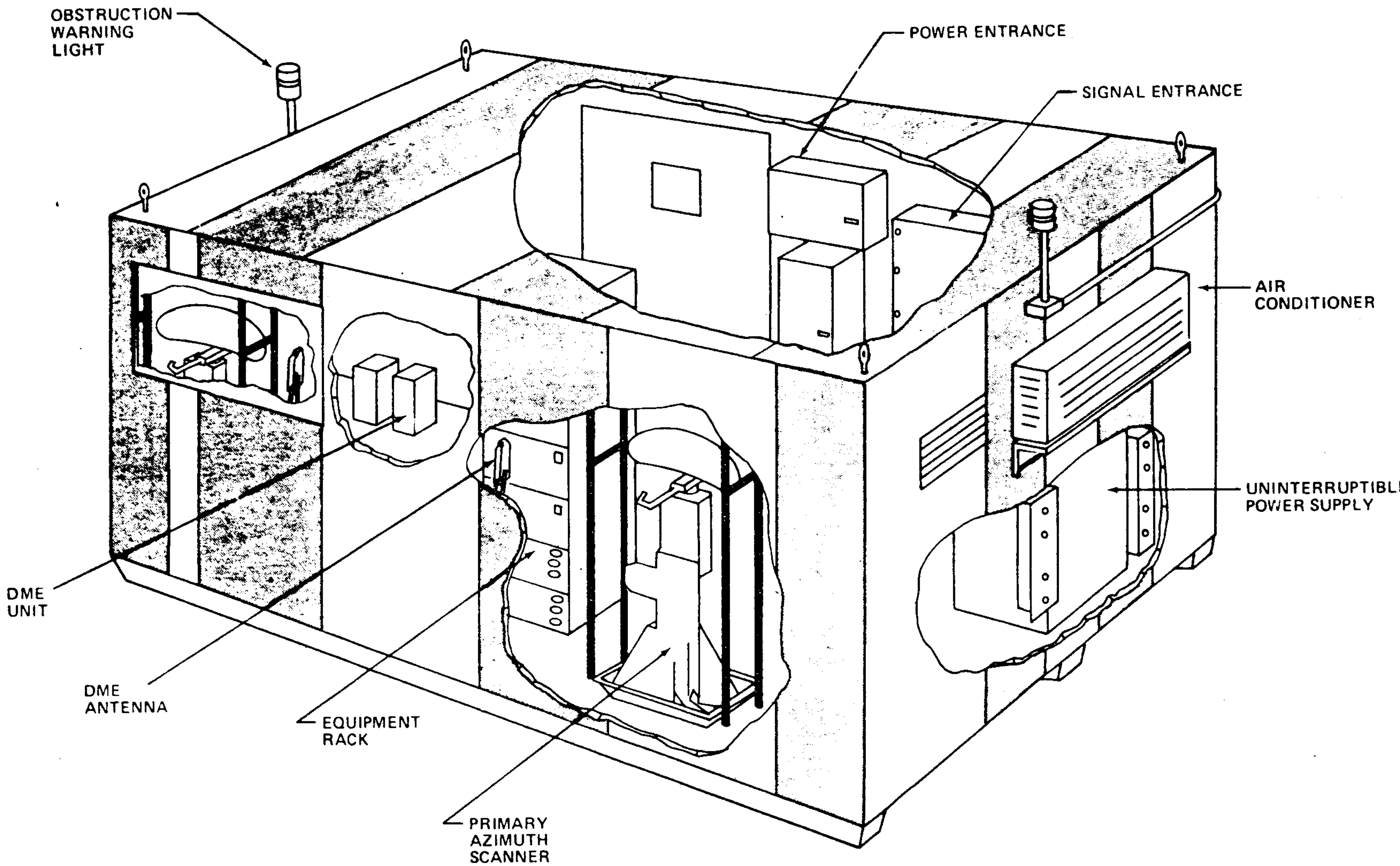


FIGURE 5-6

MSBLS MAJOR COMPONENTS AND rf LINKS

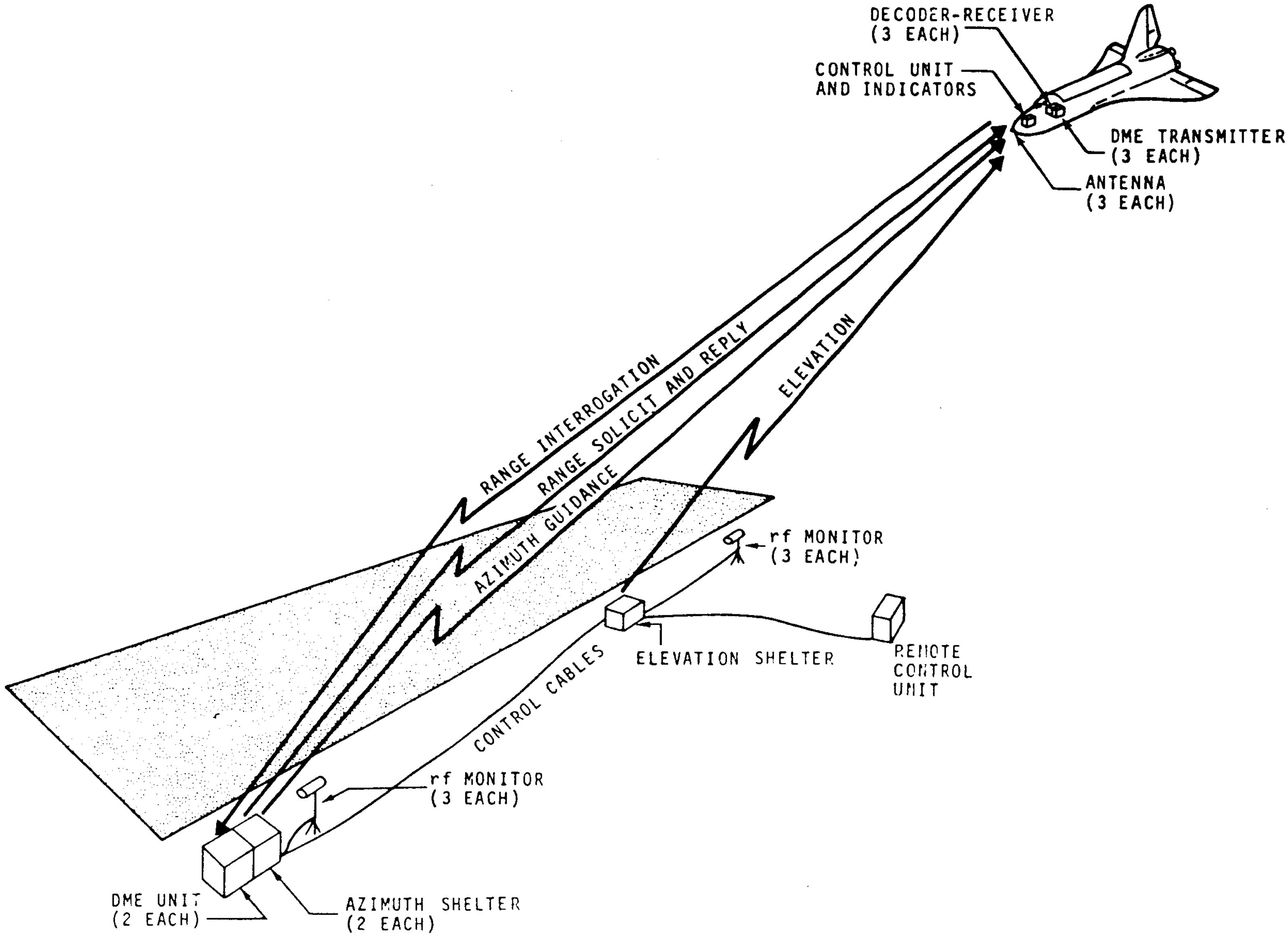


FIGURE 5-7

# ADL AVIONICS SYSTEM INTEGRATION

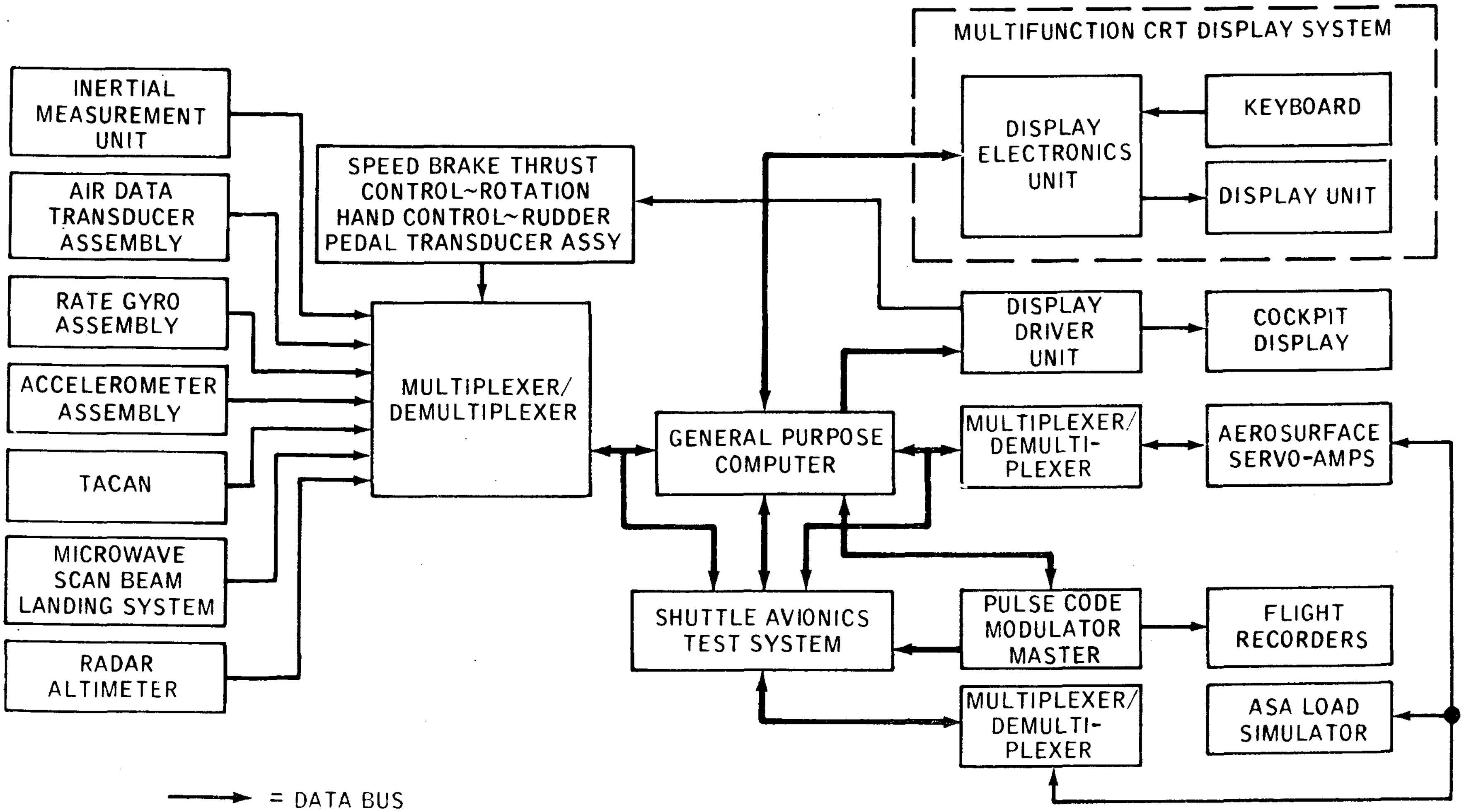


FIGURE 5-8

AVIONICS VERIFICATION CONCEPT FOR ALT

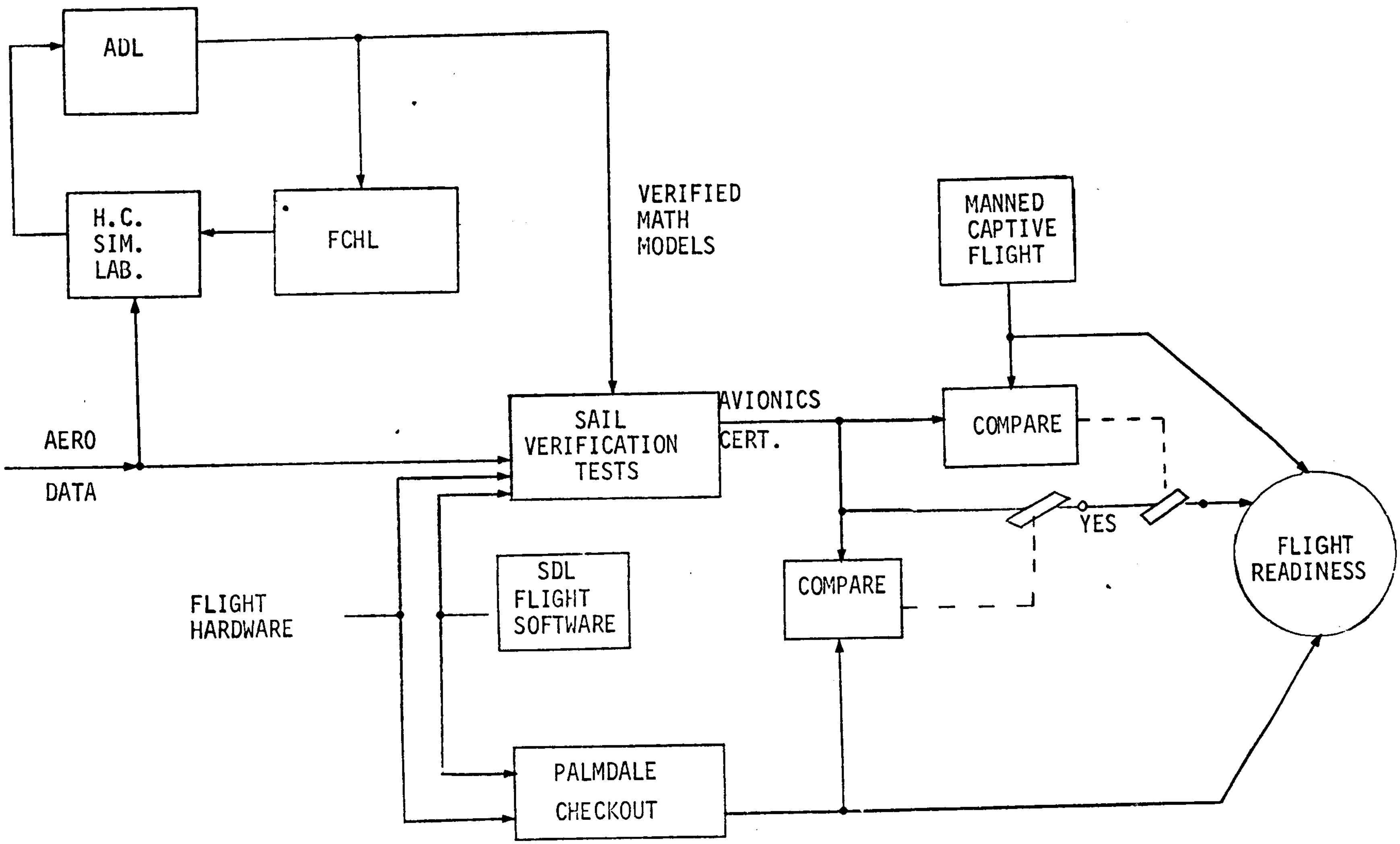
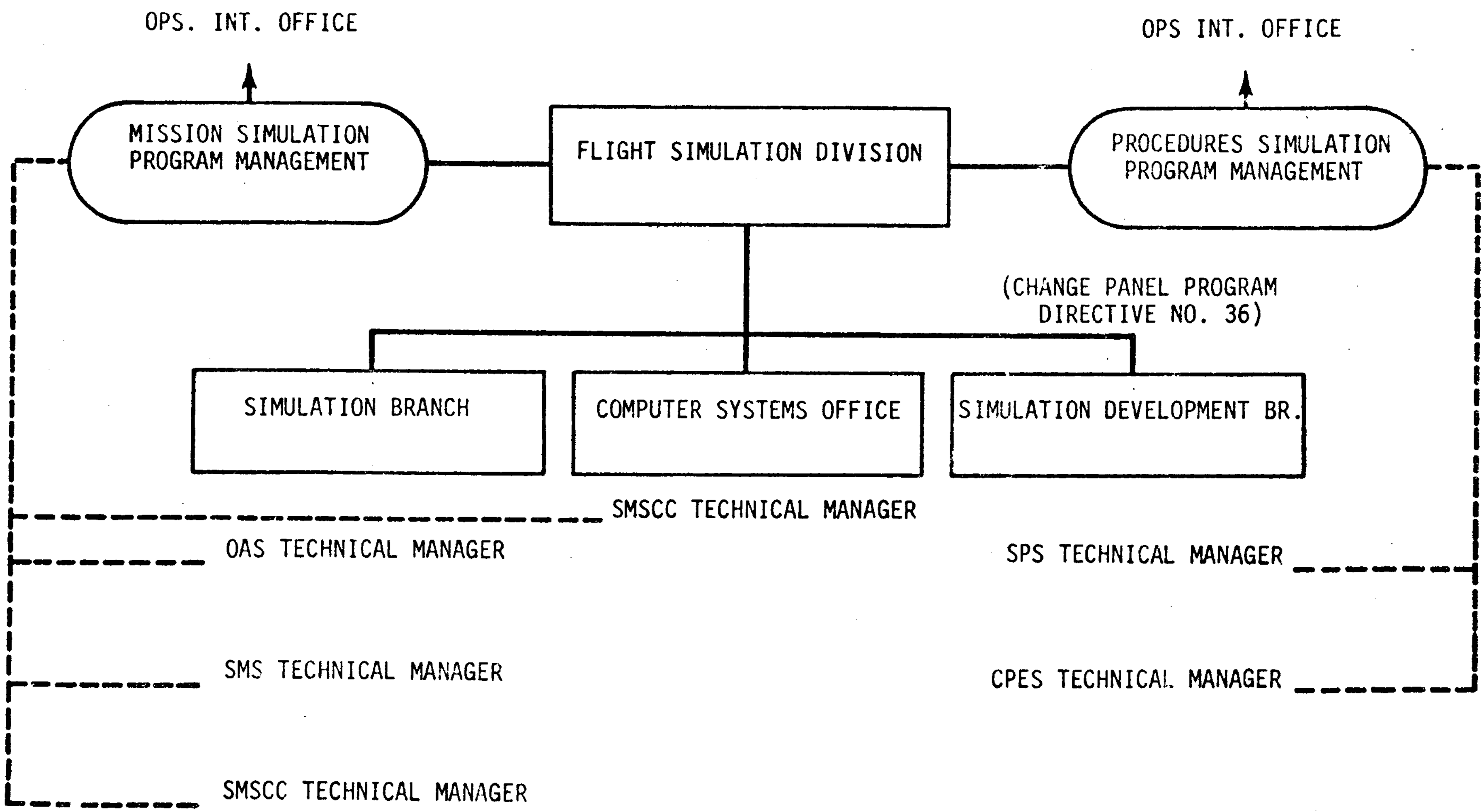


FIGURE 5-9

# SIMULATOR OPERATIONS AND MANAGEMENT PROCEDURES




WBS ASSIGNMENTS/SIMULATOR

SIMULATOR SPECIFICATIONS AND PLANNING DOCUMENTS

SIMULATOR MODIFICATION CONTROL PROCEDURES

SIMULATOR OPERATIONAL PROCEDURES

SCHEDULING DIRECTORATE/DIVISION/BRANCH/SIMULATOR

# 6.0 RISK MANAGEMENT

## 6.1 Introduction

The first captive flight of the Orbiter is scheduled for the first quarter of 1977 and the first free flight of the Orbiter is scheduled for the third quarter of 1977. These significant milestones indicate the importance of an adequate risk management program in support of knowledgeable flight readiness decision making by management.

At the top level of review the risk management program asks the basic question, "Is the sum total of all of the accepted risks, that is the aggregate risk, commensurate with the benefits to be sought (e.g., first captive flight)?" The term aggregate risk is used in the sense that it is the synergistic total of the individual risks accepted by management on a one-by-one basis. The question of whether the aggregate risk is acceptable is a matter of judgment and is the prerogative of line management who must have both the autonomy and responsibility for such a decision. The Panel's purpose is to review the management system and assess whether it has the capability to do the job. To do this the Panel covered the following areas to obtain an integrated overview of the risk management system.

a. The current safety system for the identification of hazards, tracking hazards, analyzing them for resolution, risk assessment and acceptance procedures, and aggregate risk analysis.

b. The products resulting from the above activities and how they are used within the program, by upper levels of management and others responsible for the oversight of the Shuttle program.

c. The management system and its implementation to assure the appropriate use of "lessons-learned" from prior programs.

d. The "check-and-balance" system to preclude items "falling in the crack" including the role and work of the Crew Safety Panel and the new technical assessment groups.

e. The ability of these review system elements of the management, such as configuration control boards and technical reviews, to assure that individuals throughout the program can raise responsible safety concerns.

f. The role of the Cost Limit Review Board in reviewing safety issues.

g. The ability of the review system to assure safety coverage of technical items while providing risk information to management. Some of the specific questions asked in the Panel's review of these areas include:

(1) The controlled use of Teflon in areas with potential ignition sources.

(2) The library and control system for tracking and understanding the use of non-metal materials.

(3) Reliability and Quality Assurance methods to assure that fasteners meet design requirements for their application.

(4) The controls to preclude wire breakage where the wire is subject to repeated handling and/or substantial vibration. Special attention was given to the use of 26 AWG copper wire because of prior Apollo experience on the Lunar Module development Flight Instrumentation system.

(5) The system for follow-up and closure of Review Item Dispositions (RID's) resulting from hardware and software reviews and panel operations.

(6) The extent of analysis accorded to critical single-point failure items such as Orbiter elevon actuators, thrust vector controls, fluid manifolds, and so on.

(7) The adequacy of the landing gear deployment system on the Orbiter.

(8) Adequacy of the many door systems on the Orbiter to open and close as required.

(9) The control of "mandatory" program items, requirements, tests, etc. to assure there is adequate management attention when they are revised because of changing resource and schedule constraints.

Many aspects of hazards identification and risk assessment have been discussed in other sections of this report. This is particularly true concerning "lessons learned" and their significance for safety of the design test and maintenance activities on the SSME, Orbiter TPS and software, ET insulation and SRB. This section, therefore, deals with the safety, reliability and quality assurance systems; how they are implemented; and typical examples of specific items to demonstrate these systems and to answer specific concerns raised by the Panel and NASA management during the past year.

Very little attention has been given by the Panel to the Shuttle-Payload interface and the associated safety implications because this is an area that will have to be covered at a later time.

## 6.2 Responses to Panel's Previous Annual Report

Almost all of the material contained in the Shuttle Program Office response to the Panel's Annual Report had some bearing on the safety aspects of the program. These responses, though have been distributed among the sections of this report as a part of individual element responses. However, one area is included here as Attachment 6-1 because of its broad scope.

## 6.3 The Risk Management System and Its Implementation

As would be expected the so-called risk management system is in reality made up of a number of on-going activities at various levels of the program and at various locations as well as those efforts made by the dedicated reliability, safety and quality assurance organizations and personnel found throughout the Shuttle program. Ultimately the decisions regarding risk acceptance lies with the project and program managers within NASA Centers and Headquarters. While it is an accepted fact that "safety is everybody's business," one must first look at the system dedicated by name and job description to the reliability, safety and quality assurance disciplines and then look at the many long-term and day-to-day activities that feed and are fostered by this central core of risk management activity.

Rather than approaching this subject from the academic point of view it has been approached from the "real-life" view. In doing this, risk management as it applies to the Approach and Landing Test project and the early DDT&E Manned Orbital Flights has been the subject of the Panel's examination. The basic Panel questions are "How does the system really work and what are the products of such activities?"

### 6.3.2 Approach and Landing Test Project (ALT)

#### 6.3.2.1 Background

The responsibility for deciding the acceptable degree of risk associated with the ALT flights is generally viewed as the exclusive province of senior management. From this standpoint, management focuses on balancing risk against benefits on a macro-scale, but down the line innumerable risk-benefit micro-decisions are quite naturally made without recourse to higher management. However, prior experience has shown that some of these are recognized to be of major significance when their effects become visible. Sometimes it is too late for corrective action or it is late enough that corrective action is costly. Therefore, the Panel has attempted to review each type of NASA and contractor risk assessment activity where the purpose of these efforts is to warn the program of the possibility of problems; the resources and time required to resolve the problem; or the implications of accepting the problem. This review includes such questions as supervision factoring "lessons learned" into their work - are test planners and test conductors aware of safety concerns relating to the hardware they are to test and to fly. Background on the ALT project itself is found in Section 8.0, "Flight Test Program."

6.3.2.2 Safety Assessment

The Space Shuttle hazard identification and resolution system has been well defined for scope of the Orbiter 101, the Boeing 747 Carrier Aircraft and the supporting facilities and operations for the ALT project risk management system includes hazard identification, failure mode and effects analyses, risk analysis beyond initial FMEA, hazard resolution, risk acceptance criteria, and ultimately the decision to accept or reject the risk. So one must review both the defined methodology as well as the day-to-day input which together produce the final risk assessment. In regard to the ALT project JSC and Rockwell are the primary managers with direct support from DFRC, Ames Research Center, Boeing Company, KSC and the JSC support contractor (MDAC). The following areas were sampled as being representative of the overall safety assessment/risk management "system."

6.3.2.2.1 Approach and Landing Test Critical Design Review (CDR)

The ALT/CDR was conducted during the period from March 11 to April 22, 1976. Many of the RID's and detailed discussions and decisions involved hazard identification and assessment of the overall safety system. This is, of course, a normal part of any major hardware/software review. In addition to this ALT/CDR, two other significant reviews were conducted on the Shuttle Orbiter 101 vehicle and they are important elements of the Alt safety assessment system. The Orbiter 101 CDR was conducted in October 1975 and the Orbiter 101 Configuration Review (Phase I) was conducted from February 23 through March 5, 1976. Because of their importance for safety all three of these reviews are discussed here from this point of view.

In support of the Orbiter 101 Rockwell provided a seven volume "Safety Analysis Report," SD75-SH-0135-001 through 007, dated 15 September 1975. These volumes covered six specific topics: (1) structures, mechanical systems, power systems, avionics systems, environment control and life support, crew stateion and equipment. In addition a summary volume for management was included with a copy of the detailed Rockwell "Reliability and Safety Desk Instruction No. 400-1" therein. Other documents used in the review include the following:

| | |
|---|---|
| SD74-SH-0004 | Shuttle Orbiter No. 1 Horizontal Flight Test SAR |
| SD74-SH-0168 | Shuttle Orbiter 101 Delta PDR SAR |
| SD74-SH-0323 | Shuttle Orbiter 102 PDR SAR |
| SD75-SH-0064 | Shuttle System PDR SAR |
| NASA NHB 5300.4 | (1D-1) |

The review team also considered the "Failure Mode and Effects Analysis and Critical Item List," time/cycle/age life control lists and requirements; EEE parts use and qualifications; specifications and procedures for identifying and controlling special processes and more specifically all pressure vessels; configuration control system, specifications and handling of suppliers and subcontractors; failure reporting system and its implementation, etc. The following review team comments indicate areas that needed work and the program response to them:

| | |
|---|---|
| FMEA/CIL | Suggested revisions to the hardware failure mode analysis regarding mode detection measurements and modification |

of mode effect. All comments have been incorporated into the FMEA system and documentation.

| | |
|---|---|
| EEE Parts | Required Rockwell to obtain sufficient documentation from suppliers such as parts lists, stress analysis, and submission of irregular parts requests to JSC. |
| Safety Analysis | Requested additional hazard analysis on the loss of Body Flap Control as well as updates and clarifications all of which have been accomplished. |
| Test Programs | Required that certification plans to identify those items of hardware to be used in development tests and in qualification tests. Assured that SR&QA personnel would be on the control board for such tests as the Horizontal Ground Vibration Test. |

A typical RID concerned the mechanical system in which the commander and pilot control pedals are linked together so that jamming of either station by debris can prevent operation of all pedal mechanisms. This safety concern was resolved by providing a protective boot for all affected linkages. Another RID covered the relocation of the Hazardous Environment Breathing System mask equipment to assure the crew quick access to breathing air. These were relocated from the mid-deck position to the flight deck position.

With regard to electromagnetic compatibility of the hardware the Orbiter was baselined with a single point ground for the AC power and a modified multi-point ground for the DC power. The forward bay avionics has a DC power ground at station 76. The aft avionics bag has a DC power ground at station 1307. Some loads in the nose and aft fuselage are grounded to the structure. The use of a structure return for the DC loads in the AFT fuselage area saved weight. Structure power grounding is used on many aircraft currently in service. A specification is being developed that identifies the various EMI levels, and the power quality environment for the Payload bay. Special EMI testing will be conducted during the Shuttle development program to verify this environment as has been done on previous programs, including a comprehensive test of the Orbiter's electromagnetic environment and lightning protection on Orbiter 102 at Palmdale Assembly Facility in late Spring 1978.

The purpose of the Phase I Orbiter Configuration and Acceptance Review was to assess and certify the readiness of the Orbiter 101 subsystems and related GSE for individual subsystem testing. An important part of this review was the NASA walk-through conducted at Palmdale to assess the condition of the vehicle. The walk-through team concluded that the hardware was very good and the personnel assigned to it were doing an outstanding job. The Phase II portion of this review concerned itself with the readiness of the Palmdale facility as contrasted to the readiness of the hardware subsystems.

An interesting RID from the CARR pointed to the hazard of shatterable materials in the Orbiter cabin. As a result, steps have been taken to resolve this issue by (1) compiling a complete list of all shatterable materials contained in the Orbiter 101 crew compartment, (2) performing a study to determine how shatterable glass can be protected so that it is contained if broken, and (3) determining if any of the items used in Orbiter 101 for ALT have found their way into Orbiter 102, and if so to assure an assessment of the hazard. When this data is in for management review, a decision will be made at a CCB meeting.

Further information on the Orbiter 101 CAR is found in SSV76-5-3 document dated 4 March 1976.

The Approach and Landing CDR conducted in April was followed by a Shuttle Carrier Aircraft (747) CDR in May 1976. Some items pertaining to the safety area that were brought out in this review are:

a. Prior to each SCA/Orbiter flight, a Flight Readiness Review will be conducted and supported by all elements of the ALT project including the Rockwell/Boeing flight safety support personnel. When the ALT Project Safety Plan is finalized this suport should be defined.

b. The following documents are in process: (1) safety plans for the ALT site, (2) safety plans for 747 test operations, and (3) safety controls for 747/Orbiter Mating and Demating.

c. As a result of a RID in the October 1975 CDR, an Orbiter 101 Delta CDR was conducted for the Separation Subsystem between Orbiter and 747. As a result of the Delta CDR the Orbiter ALT program verification plan (MCR 2031) is now in work and will include verification plans for end-to-end checkout of the separation system. This plan is to be available for NASA review about June 30, 1976.

6.3.2.2.2 ALT Mission Safety Assessment Document (JSC-10888)

This document defines the results of the total safety analysis and risk management process. It identifies operational hazards that could compromise crew safety or damage the vehicles involved, evaluates risks for each operational hazard, provides an overall assessment of the ALT mission with respect to crew safety, and describes the status and actions necessary to "close" identified safety concerns. This becomes a major input to the Flight Readiness Review system.

The closed-loop methodology used to fulfill the requirements of a Mission Level Hazard Analysis and the finalizing of the Mission Safety Assessment Document is shown schematically in Figure 6-1. The schedule for the ALT Mission Safety Assessment Report currently is:

| | |
|---|---|
| Initial Document Release | June 1976 |
| Final Document Release | February 1977 |
| Up-Date Addendum (captive flight) | March 1977 |
| Addendum for Free Flight | July 1977 |
| Up-Date Addendum (free flight) | July 1977 |

### 6.3.3 Safety, Reliability and Quality Assurance for Ground Test and Orbital DDT&E and Operational Missions

#### 6.3.3.1 Major Safety Concerns

There has been a need for a simple but useful means of providing program and senior NASA management sufficient visibility of Space Shuttle safety concerns, the means of resolution and the major accepted risks. This need is now being met by the "Major Safety Concerns Space Shuttle Program," (JSC 09990). This document is updated quarterly to reflect changes in status of major safety concerns and to add newly selected items. The latest issue available to the Panel, dated March 8, 1976 showed the following count:

| | |
|---|---|
| Open safety concerns | 19 |
| Closed safety concerns | 16 |
| Accepted risks | 7 |

Table 6-2 shows the listing of open safety concerns, closed safety concerns, accepted risks, and those design features that represent inherent risks which are considered to be justified. The details, of course, are contained in the referenced document.

This data enables the Panel to evaluate the process for determining which concerns are significant enough to place in this documen for management. The Panel has also indicated a continuing interest in all of this data because some continuing interest in all of this data because some safety concerns that have been closed or accepted may change in "value" due to other programmatic changes which impact them.

6.3.3.2 <u>Content of Level II S, R&QA Activity</u>

The work conducted at the Space Shuttle Program Management level (Level 2) at JSC is quite diversified. Table 6-1 lists some of the products of this work that have or will be published for information, analysis and control of various phases of the program from ground test through flight test and operational missions.

Some of the formalized plans such as the POGO Prevention Plan, JSC 08130 and the Contamination Control Plan, JSC 08131 play an important role in developing successful hardware that meets the requirements of the program specifications at Level I, II and III.

The materials control program, "MATCO," has been an ongoing pro-