annual report to the nasa administrator by the aerospace safety advisory panel on the space shuttle program

part II—summary of information developed in the panel's fact-finding activities

june 1976

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ANNUAL REPORT TO THE NASA ADMINISTRATOR

by the

AEROSPACE SAFETY ADVISORY PANEL

on the

SPACE SHUTTLE PROGRAM

Part II - Summary of Information Developed in the Panel's Fact-Finding Activities

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PREFACE

Part I provides an outline of the Panel's most significant observations and assessments based on fact-finding inspections this past year.

This volume, Part II, summarizes the information developed during these fact-finding inspections. It is organized along the lines of the Panel's eight Task Teams. The team approach was used this year to enable the members to focus on areas of Shuttle critical to mission reliability and crew safety. The intent here is to provide the reader with both (a) an accurate description of the data examined including its relevance to the achievement of a safe and successful mission, and (b) a status report on each area with particular attention to the resolution of technical and managment challenges.

Part II of this volume when used with the related portions of the Panel's last Annual Report (June 1975) provides the reader with substantial background on the Space Shuttle's design and expected performance, and many of the critical management systems and organizations. Since the Panel's reviews are cumulative, the statement in last year's Annual Report continues to be true: "This material will be utilized by the Panel in further reviews during the coming year as a baseline and reference manual."

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1.0 INTRODUCTION

1.1 Operational Mode

The Panel's operational mode since its inception has been to conduct monthly inspections by the full Panel. These are held at both NASA and contractor sites. With the completion of the Apollo Soyuz Test Project in July 1975, the Panel was able to focus on the Space Shuttle. As a result, the Panel agreed that they would augment the full Panel inspections with individual fact-finding in areas requiring more intensive review. Thus the Panel held inspections and/or reviewed data at Rockwell International, Downey, California on October 29-30, 1975, at Monsanto Research Corporation in St. Louis, Missouri on December 8, 1975, and at the Johnson Space Center, Texas on February 9-10 and May 24-25, 1976. Members used the time normally allocated for full Panel inspections in September, November, January and March for fact finding research.

1.2 Operational Scope

The Panel's use of a "task team" fact-finding approach as well as full Panel inspections enables the Panel to cover a large number of significant tasks in much greater depth while continuing to monitor the status of the program as a whole. The task areas have been stated in broad terms so that each member can define the specifics of his task based on his analysis of the situation. The task areas are:

a. Systems Integration and Technical Conscience.

b. Space Shuttle Main Engine (SSME).

c. Avionics and its Management System.

d. Risk Management.

e. Ground Test Program and Ground Support Equipment.

f. Flight Test Program (Approach and Landing, Orbital, Ferry).

g. Orbiter Thermal Protection System.

h. External Tank Program and the Solid Rocket Booster Program.

Panel members have assigned themselves to more than one task team to reflect the interdependence or commonality between task areas. In each team one member has accepted responsibility for the team product to assure clear accountability.

The task teams use a variety of ways to obtain the information they feel is necessary to the completion of their tasks. In addition to specific fact-finding visits to the NASA Centers and contractors, they have been attending various in-house reviews as well. These include Quarterly Status Reviews and System Design Reviews. Also, the Panel uses telephone conferences and correspondence with the program offices to assure a thorough understanding of the area under consideration. This also provides the Panel's conclusions and recommendation to the program organizations so that they may make use of the Panel's findings as quickly as possible.

Full Panel inspections provide the forum for members to share their findings and observations.

2.0 SYSTEMS MANAGEMENT

2.1 Introduction

The Panel reviewed those management functions which integrate the project management elements into a program management system and assure integrated flight hardware and software systems. Particular attention was given to those management functions which provide a check and balance on the various project elements and assure a technical conscience. The Panel's last annual report recommended that the "check and balance" capability be further strengthened. The program's response to this recommendation is included as Attachment 2-1. The NASA Deputy Administrator asked the Panel to continue this review of the evolution of these management functions to assure that the program continues to develop a management capability appropriate to the challenge of this program.

Systems management as used here includes the following management functions:

a. Systems integration refers to the management functions which provide for systems engineering, technical integration, and test and ground operations. These management functions include the program level office for systems integration and a large number of technical panels

b. Technical conscience refers to those forums which provide people throughout the organization suitable opportunities to express their concerns to management. The Panel and review systems are classic examples.

c. Check and balance refers to the technical management capability outside of these day-to-day operations to provide independent assessments on key technical and management issues. The new technical assessment groups are an example.

2.2 Systems Integration - NASA

The systems integration office is involved in defining Shuttle-wide requirements such as (1) the flight dynamics, loads and structural dynamics environment for the total vehicle, (2) the design requirements for such Shuttle wide flight systems as propulsion and avionics, and (3) common requirements and specifications for materials, processes and manufacturing. They are also involved in managing the systems for development of the Shuttle specification and interface documents and monitoring the activities of the individual elements to meet these specifications. They develop trade studies and assessments of proposed engineering changes that affect more than one element as well as participate in working problems that are faced by more than one element.

The office faces a large responsibility and workload and so they have augmented their capability by establishing a systems integration support contractor, and developing a system of inhouse panels and system management reviews. Their approach is to develop a system which brings together knowledgeable engineering and other personnel from the "line" organizations to work common problems and critique each others efforts and then to manage this system by chartering each group, defining its task/product, and evaluating its processes and results. This also assures efficient use of manpower while giving up some degree of "independent assessment" capability. Among the major management steps this year, MSFC established a Space Shuttle Main Propulsion System Integration Office to review and evaluate the plans and activities for the design and verification of the individual elements and assure that there is an adequate basis for confidence in the end-to-end system from the External Tank to the SSME nozzle.

A "systems engineering plan" is also to be released this year. It will be the single source document on how the systems engineering function in the program is being implemented: (1) what needs to be done, (2) who is doing it, (3) how is it being accomplished, and (4) when it needs to be done. The main text will have the data on the management organizations roles and responsibilities, management techniques and interfaces, task descriptions and implementation, and the expected products and documentation. Appended to this main text will be a set of sub-plans detailing major integrated areas of concern, e.g., integrated schedules, flight performance, loads and dynamics,

d. Maintainability seeks to assure that the many elements of the system can be serviced and maintained in the shuttle operational phase once the DDT&E program is complete.

Their activities support and help to produce such items as:

a. System Requirements Definition. The JSC 07700, Level II documents, "Space Shuttle Level II Program Definition and Requirements" and the "Shuttle Master Verification Plan," Volumes I and II.

b. Requirements Analysis. The Contract End Item Specification, Requirements Definition Documents, Volume III of the Master Verification Plan "Orbiter Verification Plan," Test Requirement Requirements' Specifications, Test Plans, Shuttle Operational Data Book

c. Integration Analysis. Integrated schematics, Interface Control Documents (ICD's) for Level II (across elements), Master Measurements List.

d. Compatibility Analysis. Problem reports and their resolution.

2.4 Technical Conscience - Technical Panels

The Systems Integration Office identifies the needs for a panel, charters it and defines the task/product. The engineering organization staffs it, defines the approach and implements it. Over the years the number of panels has grown until there is now at least fifty-four panels. Since these are listed in Attachment 2-2 and the directives spell out in considerable detail the purposes, responsibilities and procedures the work of the individual panels is not described here in detail. However, one case study is cited here to illustrate how the system operates.

The Manager for Systems Integration is responsible for the integration of propulsion and fluid systems. He in turn has delegated responsibility to the Manager, Systems Engineering Office. The Systems Engineering Manager has established a technical manager for this area and the principal management mechanisms to help him. These include the Main Propulsion System Panel and coordinators to support the manager in the areas of integration of the solid propulsion system and integration of the auxiliary propulsion and fluid systems with other elements of the Shuttle. The Main Propulsion System Panel is responsible for assuring sufficient detailed understanding of the total vehicle to recommend specific overall vehicle requirements, allocation of these requirements to each major element and the interface relationships between elements. The panel by continuous assessment insures that test results satisfy system performance requirements. Through its periodic technical reviews and studies the panel identifies problems, determines corrective action and recommends such action to the technical manager. The systems engineering office maintains contact with the operation of this management system through a designated liaison officer.

Earlier it was noted that technical conscience implies suitable forums for knowledgeable personnel to raise questions and critique each others work. Many panels by their intercenter and interdisciplinary membership are such forums. The Crew Safety Panel is a classic example. The panel is chartered to assure (1) development of crew safety and crew-vehicle risk assessment requirements for the Shuttle and all its mission phases, (2) identification of individual and integrated subsystem failure modes and hazardous operating conditions which might lead to loss of vehicle or crew, and then (3) identification of modifications in hardware, software, and procedures to reduce or resolve these hazards. Thus they have both policy and operating responsibilities. The membership illustrates the scope of the panel as a forum for it is not limited to safety personnel. Members are drawn from the disciplines represented by the Systems Integration Office, the Operational Integration Office, the Orbiter Project Office, Engineering and Development Directorate, Data Systems and Analysis Directorate (software), Flight Operations Directorate and Life Sciences Directorate. In addition each of the three manned flight centers, as well as the Dryden Flight Research Center with its experience in experiemental aircraft and lifting bodies and the Air Force have members on this panel.

The Systems Integration Office continues to review the structure of the system as well as the operation of individual panels so they can adapt the system to current requirements. This past year they completed a comprehensive review and consolidated some panels where their activities had turned out to be interdependent. For instance, the avionics panel now has responsibility for lightning and EMI effects since avionics may be vulnerable to them. They also identified new needs and established the Ascent Flight Systems Working Group as a senior management group responsible for the trade-offs between the integration of the individual flight systems that are critical during the ascent phase.

The Panel monitors the operation of this system by evaluating the role and contribution of individual panels in areas under review by panel members such as propulsion, avionics and crew safety.

2.5 Technical Conscience - The Review System

The review system also provides a number of forums to bring together knowledgeable people to raise and work concerns rather than let them slip by without the appropriate management attention.

The Shuttle Program Manager has the responsibility to control and manage the overall integration of the vehicle. His personal management tool is the Program Requirements Control Board. The deliberations of this board are supported by the activities and resultant information provided by the Systems Integration Review (SIR) technical management system.

The SIR's, chaired by the Manager for System Integration, are to assure that specifications are in fact defined and met. These specifications may be for various areas of the environment such as the ascent phase or such integrated systems as avionics and propulsion. Here is a list of the functions to be accomplished by the SIR's.

a. Specification of the ascent flight vehicle systems integrated performance requirements for the Shuttle system and the analysis of integrated vehicle design and test data to assure compliance and compatibility.

b. Specification of the flight performance requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

c. Specification of the loads and structural dynamics requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

d. Specification of the guidance, navigation and control system performance requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

e. Specification of the integrated avionics requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

f. Specification of the integrated propulsion system and fluids requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

g. Specification of the requirements for the integrated vehicle attachment, release, and separation systems and the analysis of element design and test data to assure compliance and compatibility.

h. Specification of the integrated thermal design requirements for the Shuttle system and the analysis of element design and test data to assure compliance and compatibility.

i. The development of element-to-element and element-to-ground interfaces and preparation of necessary documentation.

j. Specification of the ground operations requirements for landing, turnaround, launch preparation, and major ground test, including GSE and facilities, and analysis of element design and test data to assure compliance and compatibility.

To exercise control over such a wide range of functions the systems integration office found it necessary to establish technical managers for specific areas. Thus there are managers for flight performance, loads and structural dynamics, flight control integrated avionics, integrated propulsion and fluids, mechanical systems, system interfaces, thermal design integration and ground operations.

The membership of the SIR Board is composed of these technical managers as well as representations from a variety of organization to assure all informed viewpoints are represented. Thus there are representatives from:

Space Shuttle Program Systems Engineering Office, JSC

Space Shuttle Program Operations Integration Office, JSC

Space Shuttle Program Management Integration Office, JSC

Space Shuttle Program Resources and Schedules Integration Office, JSC

Engineering and Development Directorate, JSC

Office of Aeronautics and Space Technology, NASA Headquarters

Space Shuttle Projects Office, Engineering Management Office, MSFC

Science and Engineering, System Analysis and Integration Laboratory, MSFC

Science and Engineering, Systems Dynamics Laboratory, MSFC

Space Shuttle Projects Office, KSC

Orbiter Project Office, JSC

Space Shuttle Main Engine Project Office, MSFC

External Tank Project Office, MSFC

Solid Rocket Booster Project Office, MSFC

Rockwell-Space Division

In addition to these reviews the Systems Integration Office monitors technical progress through attendance at such project reviews as the ALT design review and the Orbiter 101 and 102 design review. These reviews bring together the knowledgeable people to critique each others work and raise issues. Issues that cannot be resolved at one level are referred to a higher level of management. Management also has the opportunity to review significant decisions made at the lower levels.

For instance, the Approach and Landing Test Critical Design Review completed in April covered in detail the test and test support operations to be performed, the facilities and equipment to be used, and the management and working relationships of the test organizations conducting the approach and landing test program. Further, the ALT Critical Design Review covered the activation of the ALT capability, the conduct of the test program itself, and the deactivation of the program.

The design and manufacturing status reviews for a vehicle enables people to express their concerns about individual flight and ground systems as well as the status of systems integration and reliability, quality and safety work before proceeding to the next phase. These concerns, expressed in the format of RIDs, are officially tracked and formally dispositioned. To give the reader a sense of the issues raised and worked through this system, there were 2400 RIDs identified through the Preliminary and Critical Design Reviews and

Customer Acceptance Reviews on the first flight vehicle 101. Almost all have been worked and closed at this time.

The Panel monitors this area actively by attending selected reviews to evaluate the process as well as issues and their resolution.

2.6 Check and Balance - The Technical Assessment Groups.

It is through the system of technical panels and reviews that technical conscience can find its expression and because people from differing backgrounds can critique one anothers work there is a check and balance and independent assessment process at work. The Panel's recommendation was that this process be further strengthened by personnel outside day-to-day responsibility for the program. This last section describes what the Panel found this year.

Technical Assessment Offices have been established at each of the three manned flight Centers and Rockwell. These are small, well-knit groups of highly skilled engineers who are on the lookout for problem areas to prevent any significant problems from "falling through the crack." These personnel stay abreast of the program and determine their task areas by participating in day-to-day discussions with subsystem managers and working level reviews and discussions using their own personal experience for lessons learned that may be applicable to the current situations.

The program assessment offices are set up as follows:

a. JSC - The office reports to the Shuttle Program Manager and Center management. It defines its own tasks. It has been functioning the longest of the Center offices and has made substantial contribution in such areas as avionics and contingency abort requirements. Currently it has about ten specialists.

b. MSFC - The office reports to the Associate Director, Science and Engineering, and is particularly active in assuring integration of flight systems involving more than one project office. Thus they are actively involved in the work of the Main Propulsion Test Office and Ascent Flight Systems Integration Group. They are still in the process of staffing.

c. KSC - The office reports to the Manager, Shuttle Project Office and is staffed by experienced trouble shooters. The office is still in the process of staffing and getting fully underway.

d. Rockwell International - The Vice President identifies critical areas where foresight and planning now can preclude problems downstream and he staffs as he identifies the need and therefore the expertise required.

So the groups are in place and beginning to function. Next year's report will report on their evolution and their contributions. The Panel monitors this system by working with these groups.

ATTACHMENT 2-1

Systems integration management needs to strengthen "check and balance" capability.

Response: This comment is similar to that made by the Hawkins team. The actions that have been taken include:

a. A special group has been established at JSC to provide an overview of the system engineering/integration function and will report directly to R. F. Thompson, Program Manager.

b. Effort and scope have been increased on the RI/SD contract for system evaluation. A few highly competent individuals are being assigned to provide independent assessments and will report directly to W. Dean, V.P., Systems Integration. The scope of this activity specifically includes problem evaluation and avoidance options, trades, and alternatives; technical and programmatic interrelationships; and contingency planning.

c. A review of the JSC/MSFC panel relationships has been completed and selective changes in membership and panel structure are being made to improve integration across Center/Project interfaces.

d. Program and system level planning is being developed in more detail and will provide more visibility and support to the integration management and decision making process.

SPACE SHUTTLE PROGRAM DIRECTIVES THAT ESTABLISH PANELS, WORKING GROUPS AND SIMILAR OPERATIONS

Directive No.*	Subject
1	Simulation Planning Panel (for simulation activities)
4	Crew Safety Panel
6	Configuration Management Panel
8	Ground Interface Working Group
9	Crew Procedures Control Board
11	Information Management Systems Panel
14	Systems Integration Reviews (SIR)
15	Payloads Interface Panel
17	Program Management Information Center Integration Panel
18	Program Performance Management Panel
21	Flight Test Program Panel
22	Electromagnetic Effects Panel
23	Flight Performance:
	23.1 Ascent Performance Panel
	23.2 Integrated Entry Performance Panel
	23.3 Abort Performance Panel
	23.4 Separation Performance Panel
	23.5 Aerodynamic Performance Panel
24	Main Propulsion System Panel
25	Loads and Structural Dynamics
	25.1 POGO Integration Panel
	25.2 Loads and Structural Dynamics Panel
	25.3 Ground Vibration Test Panel
	25.4 Particles and Gases Contamination Panel
26	Mechanical Systems
	26.1 Spacecraft Mechanisms Panel
	26.2 Shuttle Vehicle Attachment and Separation SUBpanel
	26.3 Payloads Docking, Retention, and Deployment SUBpanel
	26.4 Landing Systems and facilities SUBpanel
27	Shuttle Training Aircraft (STA) Review Board
29	Communications and Data Systems Integration Panel
	29.1 Functional Requirements SUBpanel
	29.2 Vehicle Communications Interface SUBpanel
	29.3 Ground Based Data Systems SUBpanel
	29.4 Science and Engineering Data Processing SUBpanel
30	Flight Operations Panel (FOP)
31	Operations Integration Review (OIR)
33	Computer Systems Hardware/Software Integration Review (CSIR)
36	Training Simulator Control Panel

* Latest Issue

39	Guidance, Navigation, and Control Integration
	39.1 Ascent Flight Control/Structural Integration Panel
	39.2 On-Orbit Guidance, Navigation, and Control Panel
	39.3 Entry Guidance, Navigation, and Control Panel
	39.4 Guidance, Navigation, and Control System Panel
40	Safety, Reliability,and Quality Assurance Management Panel
43	Procurement Integration panel
45	Integrated Avionics Technical Management Area
	45.1 Shuttle Avionics Panel
	45.2 Flight Communications Panel
	45.3 Shuttle Avionics Checkout Panel
	45.4 Avionics Verification Panel
46	Thermal Design Integration
	46.1 Thermal Control Panel
	46.2 Thermal Protection Panel
49	DOD Shuttle Requirements Review Panel
51	Communications and Tracking Systems Ground Test Panel
52	Operations and Maintenance Requirements and Specification Control Board
57	Ascent Flight Systems Integration Group
58	Integrated Logistics Panel
62	Resources and Schedules Management Panel

3.0 SPACE SHUTTLE MAIN ENGINE (SSME)

3.1 Introduction

The Panel has given special attention to the challenges during the past few years, the concerns expressed by NASA management, and the fact the engines are critical to the accomplishment of the Shuttle missions. Specifically, the areas under current review are:

a. The use of new and in many cases unproven technology.

b. Adequacy of design margins to meet the requirements for repeated use.

c. Ability of the engine electronic controller to accommodate the environment and needs of the engine and the total Shuttle system.

d. Results of credible failures.

e. Hardware availability and the test program requirements.

The Panel considered the impact on the hardware and software development program of both (a) cost and schedule constraints, and (b) the numerous interface requirements involving other Shuttle elements such as the Orbiter, Solid Rocket Booster, Ground Support Equipment, and External Tank.

In meeting the objectives of this task the Panel and the task team has relied on briefings, face-to-face discussions with NASA and contractor personnel, participation in in-house reviews, and review of relevant documents. A part of this effort is a follow-up on open items in the NASA Shuttle Program Office's response to the Panel's annual report The Program's responses to the last annual report on the ngine is included as Attachment 3-1. This material reflects the degree to which analyses and test programs have evolved in providing answers to challenges in the areas of materials behavior under severe environments, weldments, POGO suppression, and controller performance.

A brief look at the Level I (NASA Headquarters) controlled milestones are valuable for they show the program's progress and the work ahead.

- Completed first preburner test	Accomplished April 1974
- Began fabrication of Main Propulsion Test Article (MPTA) Engines for the integrated test of the toal system	Accomplished May 1975
- Completed first integrated Subsystem test	Accomplished June 1975
- Complete first SL firing for a minimum of 60 seconds at Rated Power Level	Scheduled for Feb. 1976
- Complete first throttling test (MPL-RPL)	Scheduled for Mar. 1976
- Complete SSME "all-up" throttling test	Scheduled for Sept.1976
- Critical Design Review (CDR)	Scheduled for Sept.1976
- Delivery of Main Propulsion Test Engines (3 of) to NSTL	Scheduled for May 1977

- Deliver first flight engines (3) Scheduled for Aug. 1978
- Conduct first manned orbital flight Scheduled for Mar. 1979

3.2 Observations

There have been a number of changes in the Rocketdyne organization since last year's annual report. This is readily seen from the comparison of organization charts from September 1974 and October 1975 (Figures 3-1 and 3-2). These changes continue to strengthen the program management system. For instance an Associate Program Manager has been appointed for the engine controller and the engineering areas have been "beefed-up." Mr. Norman J. Ryker was appointed President of the Rocketdyne Division.

3.2.1 Review System

The management system holds a number of reviews on a regular basis. The Quarterly Technical Review for MSFC Senior Management and weekly telecons are two examples. In addition, a special SSME Design Margin Review was conducted in July 1975. Prior to this Design Margin Review, there had been a general concern about the safety factors on many of the components. The margin review showed that most of the components actually had more than the minimum safety factor of 1.4.

Attendance at SSME reviews and discussions with both NASA and Rocketdyne personnel indicate that the review system is working well in that it provides a forum for frank discussions of technical and management areas and provides necessary information on costs, schedules, and technical performance for day-to-day work and decision-making.

To further assure that nothing "falls through the crack," a technical assessment group has been established and is now being staffed. A Space Shuttle Main Propulsion Systems Integration Office was recently established at the Marshall Space Flight Center to serve as the responsible body for the review and evaluation of Main Propulsion System design criteria and to assure compatibility of Level II/Level III design and performance requirements. They are responsible for the definition and compatibility of mechanical, structural, electrical and fluid interfaces, and design verification of the system.

JSC established a technical manager's position in mid-1974 to oversee the integrated propulsion and fluids technical management areas (Program Directive 24).

To support the Technical Manager they also established the Main Propulsion System Panel. Finally, they appointed a Solid Propulsion Integration Coordinator and an Auxiliary Propulsion Coordinator. The Aerospace Safety Advisory Panel's interests are (a) the Propulsion Panel's achievements in identifying incipient failures including the means by which early clues to such failures may be determined, and (b) the extent to which prior review RID's remain open, are delinquent or have some further impact not identified previously.

3.2.2 Design Progress

Previously the Panel had raised some questions in the following four areas:

a. Allowable SSME Heat Exchanger Oxidizer Coil Leakage Rate.

b. Use of Teflon Balls in POGO Suppressor Unit.

c. Delays in Receiving and Testing of SSME Components.

d. Data on SSME Controller.

The Program's response to the Panel's concerns are shown in Attachment 3-2.

The Panel was one of those groups interested in getting definitive data on the component design margins to assure that, from a structural and thermal standpoint, the SSME was designed to meet the environmental and time requirements imposed by the overall Shuttle program. The SSME Design Margin Review established the following points:

a. The structural and thermal audits indicated that the current analyses were extensive and technically sound. A few items required further analyses, such as the low pressure oxygen turbopump housing. An example of the factors of safety arrived at during these analyses is shown in Table 3-1. As used on the SSME the definition of factor of safety is $\frac{\text{Failure Load}}{\text{Limit Load}}$. This accounts for those data points falling within 2σ on the pressure and 3σ on vibration.

b. Many of the design requirements of "one engine out" conditions are still under analysis and test. Consideration has to be given to the expected impact on both the engine that goes out and the other two engines which continue to operate. The following statements are a summary of what we understand the situation to be. It is known that a non-thrusting or shut-down engine will not be cooled sufficiently during ascent so that the engine nozzle will have to be replaced before another mission. This is based on analyses that show a nozzle metal temperature of about 1600° F. versus an allowable of 1200° F. The engines are designed to provide for sensing of critical parameters. The current challenge is to develop the engine controller and the Orbiter flight control procedures that will safely shut an engine down without damage to the other engines or the Orbiter.

c. This review produced a number of recommendations and action items that are currently under active consideration. Among the major ones are: (1) develop data review methods that can be used to identify incipient failures and devise a solution that is practical within cost, schedule and value received boundaries, (2) use maximum throttling ramp rate, (3) limit thrust for early flights to rated power level thereby achieving additional factor of safety

(See Table 3-1), (4) continue to obtain materials properties to assure understanding of the SSME hardware in various environments and in light of life requirements, and (5) increase hardware confidence by conducting tests at higher pressure and temperature levels with added instrumentation.

d. Other recommendations include (1) increase confidence in structural margin by specific burst tests throughout the program, (2) improve fabrication producibility and thereby confidence in the margins of the engine nozzle, the lines and ducts, the hot gas manifold liner and the injector, and (3) improve post assembly inspection procedures.

3.2.2.1 Mass Properties

As in every element of the Shuttle program both the weight specified vs. actual weight and the inertial properties are watched closely for their impact on performance and payload capability. While weights are discussed in terms of an individual engine weight, it is important to remember that these numbers must be multiplied by three since there are three engines on each Orbiter if one is to appreciate the full impact of any design changes. The program monitors three weight values - the contract end item (CEI) value, the design goal weight which is 99.5% of CEI weight, and the control limit weight used to manage the growth rate of the development weight throughout the program. The table below indicates the latest weight conditions at the time of the Panel's review in January 1976.

Specification Weight (CEI)	6445 lbs. (Dry)	6892 lbs. (Burnout)
Current Weights	6348	6790
Contingency (lbs/%)	97/1.5	102/1.5

This would indicate that stringent controls must be used to assure that by the time of the SSME CDR in September 1976 the weights are still within the specified limits, always keeping in mind that one pound overweight on an engine is in effect three pounds overweight for the Shuttle Orbiter and system.

3.2.2.2 Engine Integration

Not only must the many engine components be designed, assembled and operated as a system, but the engine and its controller must in turn be a part of a well-designed and operable Main Propulsion System within the Shuttle total vehicle. The Main Propulsion System (MPS) includes the External Tank (ET), the Space Shuttle Main Engines, propellant feed, propellant fill and drain, propellant conditioning and pressurization control and purge and the Orbiter interface components. This overall system is shown in Figure 3-3. The following is a brief description of how the MPS operates. The ET provides 1.55 million pounds of usable ascent propellants to the SSME's. Following engine thrust build-up, tank pressure is maintained with vaporized propellants extracted from the engines. The ET ullage pressures during boost are maintained at 20-22 psia in the LOX tank and 32-34 psia in the liquid hydrogen tank. Pneumatics are supplied by a 4000 psi helium storage system with 750 psi regulation. The helium is used for valve actuation, SSME purge and backup shutdown, expulsion of residual propellants after main engine cutoff. The propellant management controls propellant loading and a low level cutoff which is a backup to the normal velocity cutoff.

The Panel is reviewing the SSME interface to assess whether (1) there is compatibility between the SSME requirements and the MPS, (2) the system/subsystem test programs demonstrate hardware integrity and capability to meet system level requirements, (3) there is schedule compatibility between the design, development and test activities and the availability of hardware , and (4) there is the necessary degree of management and technical liaison between various elements involved in the MPS on issues related to the SSME. While the Panel, including its task team, has not completed its review, its observations to date are noted in both Volume I of this report and in the following sections dealing with the SSME components and assemblies and systems testing. Requirements compatibility will be examined later and the integrated test program will be examined in more detail. Part of this work will be accomplished by participation in Ascent

Systems Design Review Panel operations which are conducted periodically. The last ones were on January 14, 27, and 28, 1976. This was the third such review conducted for the First Orbital Flight Test (OFT-1).

3.2.2.3. SSME Redundancy Management Requirements

Redundancy management deals with control and decision-making necessary to assure the ability of the system to accommodate failures and operate properly. Terms used in this area are defined in Table 3-2. With regard to the SSME the Redundancy Management Requirements have been stated as follows:

a. Fail-Safe Design in the Propulsion System. In the event of any single failure in a functional component, the engine shall be capable of shuting down in a manner which will not damage the neighboring systems.

b. Fail-Safe Design for Electrical Assemblies. All electrical critical subsystems shall be fail-operational after the first failure and fail-safe after the second failure.

Implementation of these requirements can best be demonstrated by looking at typical designs. For the fail-safe design, shutdown of the hydraulic system occurs when a specified limit is exceeded such as pump overspeeds, turbine over-temps, loss of high pressure oxygen turbopump seal pressure or ignition pressure that is either too high or too low. Shutdown of the pneumatic system occurs when there is a loss of both electrical/data busses for over 50 milliseconds or with the loss of both segments of the engine electronic controller unit. As currently set up the Orbiter can inhibit all the sensors except the ignition pressure detection device and thus has an override capability. To meet the fail operationally/fail safe criterion redundancy has been provided for all critical electrical subsystems. A part of this fail op/fail safe design is the electrical hold-capability to control to the "last" valve position command and a hydraulic hold capability to continue operation at the last valve position. When there is a loss of vehicle/engine commands the system will continue operation at the last valid command and if necessary shutdown the vehicle. The comparison of thrust versus time for hydraulic and pneumatic shutdown are shown in Figure 3-4.

3.2.2.4 Engine Controller

The Panel continues to give the Controller particular attention. From the standpoint of design and development testing, the Controller posture at this time is very encouraging. The major areas reviewed by the Panel included the latest design configuration, test program and results, software and the integration of the Controller into the SSME and Orbiter systems. In addition the SSME throttling requirements and concerns were examined as a part of the SSME control system and Space Shuttle ascent performance.

The Controller design is basically completed with some redesign effort to alleviate problems as they have shown up during the development test program. While the hardware is proceeding through test the software programs are being developed that will both test and operate the SSME and interchange data with the Orbiter vehicle and ground support equipment. The software to hardware compatibility focuses on the computer/memory capability in terms of words and time-to-process input and outputs as well as the expected programming errors and deviations.

Controller design is well into the test phase. Development testing has been continuing using the structural thermal engineering model (SM-1). The production prototype controller (PP-1) has been undergoing a very thorough test process since early 1975 and is now being used in the software development program. Production prototype (PP-2) is now being used in the test program. The Integrated System Test Bed program has been using flight type hardware and the BT-1 rack mounted controller for the numerous test firings conducted over more than ten months at the National Space Testing Laboratory (NSTL). Since the Controller design is in the test and specific redesign period that comes after the basic design and assembly has been completed problems are expected. Most of these have been acceptably resolved.

A major challenge was to protect the Controller from the vibration caused by the total environment system. To screen the PP-2 controller from assembly and workmanship problems, it was subjected to the following environment: X_2 and X_3 axes at 2g sine sweep, 5 Hz to 2000 Hz up and down for 17 minutes; 6g random duration of three minutes; 2g sine sweep, 5Hz to 2000 Hz up and down for seventeen minutes. At the same time SM-1 was used to develop a vibration mounting for an environment beyond that of the PP-2 tests. PP-2 was then subjected to 25 hours of vibration testing with isolators (intended use) as follows: 22.5 hours (7.5 hr per axis) at 22.5 g RMS, 2.5 hours of transient and sinusoidal vibration, and 120 starts. The overall results were good. Four anomalies were found and all were attributed to assembly/workmanship problems. The causes were determined and the unit was repaired. PP-2 has been delivered to the NASA MSFC Simulation Laboratory for continued testing and SSME operational support. The PP-3 unit with isolators has been delivered and is installed on SSME engine 0002 and successfully operating on test stand A-2 at NSTL with 16 engine tests to date. The vibration test results for PP-3 are as follows:

a. In a soft mounted condition the unit successfully passed 30 minutes per axis of random vibration at 22.5g RMS, 25 starts and cutoffs, and side-load simulations.

b. In a hard mounted condition the unit successfully passed a 10 minutes workmanship test in one axis at 4g RMS and 2g sine.

c. An additional test of 9 minutes at 22.5g RMS was conducted successfully.

The PP-1 controller was subjected to the following vibration conditions earlier in 1975:

a. Thermal tests included 8 hours of operation at -50° F.

and 48 hours of operation at +95° F.

b. Vibration tests included: 3.5 hours sine at 2g and 6g random for acceptance test program; 0.75 hour with 18 to 22.5g random for diagnostic work; 1.5 hours of 22.5g random for Development Verification Levels; and, 8.5 hours of 22.5g random with isolators in place.

c. Functional performance tests to evaluate the "pre" versus "post" test performance ..... pre-thermal test and pre-vibration test followed then by post thermal and vibration tests.

A number of small problems, as noted before, have been encountered and resolved, such as memory noise, cracked solder joints, minor circuit design problems, problems with a number of jumpers and piggy-back components affecting circuit board reliability and some manufacturing difficulties. The problem of electromagnetic interference (EMI) emanating from the power supply may not be fully resolved as yet and will be followed by the Panel.

The current major redesign effort has been directed toward the broken wire problem where so-called "stitch-welding" of wires to pins has been used. The connection would break under the vibration expected on the missions. This is a problem found on both the outboard Master Interconnect Board and the inboard Master Interconnect Board.

The redesign program put into action in December 1975 was in two phases. The first phase completed in February 1976 defined the problem and requirements to the satisfaction of Rocketdyne and MSFC. The second phase, if implemented, is to develop a board design that could eliminate the wiring/weld breakage which has occurred in test vibration environments. Such designs would be directed toward development of multilayer boards to eliminate the wires and hence the wire breakage. If they are used, the multilayer board design can be used on the P-4 and subsequent controllers. If necessary a retrofit can be made on the pre-production units at a later date.

Controller software includes the operational programs, command and data simulator executive program, and controller acceptance test program. The software for the ISTB (Integrated System Test Bed) engine has been in use since May 1975 at the NSTL. The next software to be released is for engine 0002. The Operational Program is scheduled for May/June 1976 and the Command and the Data Simulator Executive Program for March/April 1976. Updates to the 0002 engine operational program is scheduled in two steps - the Block I update by the end of 1976 and a Block II update at an unspecified date.

Software and hardware compatibility aspects of the SSME controller will continue to be studied in an effort to provide proper margins and process times. The current situation looks like this:

SOFTWARE FOR	Memory Size (16,384 words) UTILIZED	BUDGET	Process Time (20 milliseconds) UTILIZED	BUDGET
ISTB	14,595	-	17.36 ms	-
ENGINE	15,270	-	18.4	-
BLOCK I (Pre Scrub)	20,040	14,000	18.265	16.0 ms
BLOCK I (With Scrub)	13,585	14,000	13.63	16.0
BLOCK II (Prel. Est.)	14,700	14,700	15.18	16.0

Software scheduling problems include the availability of Honeywell personnel and facilities to support NSTL operations on simulation runs and software changes for the ISTB program, and an even more severe condition when two of the NSTL test stands are operating at the same time. The available support for the current multiple software program (ISTB changes into the 0002 software and those within the 0002 programs) is also a problem due to manpower and facility availability. The impact of this scheduling difficulties will be an area of continuing review by the Panel.

3.2.2.5 SSME Hardware Components

A discussion of the design progress of the engine components and assemblies at this point in the program must focus on the development and acceptance test programs since the engine design is basically complete. What design work is still going on is more in the line of redesign and upgrading of designs based on test results. Therefore these areas of design are covered in the next section on "Test Program and Plans" or in the section on "Manufacturing."

3.2.3 Test Program Plans

The engine development program consists of a Design Demonstration Phase and a Certification Phase. The design demonstration activity is scheduled to be completed by the SSME Critical Design Review (CDR) in September 1976. This CDR will cover the completed and released design, the basic engine concept and the tests to demonstrate their validity. The certification activity will then include work necessary after CDR to successfully complete the Preliminary Flight Certification scheduled for November 1978 and the Final Flight Certification scheduled for Spring 1980.

Testing during the design development and demonstration phase includes laboratory testing as well as subsystem and engine hot-firing testing.

The laboratory testing is performed at all hardware levels to accelerate the verification process and to minimize hot-fire tests by detecting problems early at the fundamental part level. The test program includes basic mechanical tests to verify material properties, dynamic tests of turbopump bearings in the operating fluid at full operating speed, and simulation of engine operational checkouts and maintenance. Since laboratory tests are extensive, they provide confidence in many areas: (1) mechanical, (2) vibration, (3) flow, (4) environmental, and (5) functional.

Subsystem hot-fire testing is concentrated on the verification of those requirements and assumptions for which the engine environment is not required. Included in this test program are the ignition system, preburner, turbopumps and combustion assembly.

The third element in this test phase is the hot-fire testing using the Integrated Subsystem Test Bed (ISTB) - an engine with a development nozzle and breadboard controller. The ISTB program objectives are:

(a) Development of the engine control system.

(b) Extended-duration testing of the oxidizer and fuel turbopumps.

(c) Hot-fire verification of the engine hot-gas manifold.

(d) Verification of engine starts, shutdown, and throttling throughout the range from minimum power level (MPL) to rated power level (RPL).

(e) Supplementary verification of preburner and turbopump requirements.

The ISTB with its controller provides control system and transient performance verifications as a supplement to engine testing. Thus there is a demonstration of basic system integrity prior to the first engine test.

Following the ISTB tests, hot-firing tests are scheduled at NSTL to (1) test equipment, and (2) to extend the power level to full power level (FPL). Equipment to be included in these tests are gimbal actuators, inlet ducting, and interface panels for fluid, electrical, and thermal protection. Testing at sea level conditions will range from RPL to FPL. A test stand nozzle diffuser at NSTL allows operation of the engine between MPL and RPL.

An integral element of any test program plan, including that for the SSME, is the series of Design Verification Specifications (DVS) because these define the development plan for the engine system, subsystems and components. Table 3-3 lists all of the current DVS's. Section 3 of these documents contains the design requirements while Section 4 contains the verification methods, hardware levels, and other criteria necessary to demonstrate that each design requirement has been satisfactorily met. In addition to the DVS's development plans there are special plans for "life demonstration" tests to ensure that a conservative margin is maintained and plans for "hardware recycling" in which test components and assemblies are made up of "new" and "recycled" units. Also, there are materials evaluation plans for the selection, development, and specification of all materials and processes for the SSME.

3.2.3.1 Test Status and Results

The ISTB has been in a hot-firing condition since May 1975 at NSTL on test stand A-1. Engine 0002 has begun hot-firing at stand A-2. Engine 0003 when ready will take over the A-1 stand in midsummer of this year. All of these tests, on the ISTB and 0002, are expected to be nearly complete by the time of the SSME CDR in September 1976.

3.2.3.1.1 ISTB

Well over 60 tests have been conducted to date. The next significant milestone is the achievement of a sustained 60-second engine firing at rated power level. This test has been delayed somewhat because of the time required for the resolution of engine transient and high pressure fuel turbopump development problems as well as a flow-meter problem on an installation at the COCA stands at Santa Suzanna, California. As soon as these are resolved the 60-second test will be accomplished. Another milestone will be the throttling test to be conducted in the midsummer with the power level from MPL to RPL. Further throttling tests are also scheduled for the period starting about August 1976.

So far the ISTB has been run at 76% of RPL for more than 20 seconds.

Some of the problems that have surfaced have been resolved or are under intensive study, include the following:

a. The main fuel valve assembly follower bearing side-plate cracked during the ISTB tests. Cracks were found on the inner race section of the plate. The original 440C material was replaced with Inco 718 as an interim redesign. If necessary the redesign will be refined at a later date.

b. Electrical "pig-tails" are subject to environmental abuse and failures so a new connector design will be effective on engine 2004 and subsequent.

c. Preburner, LOX and fuel, temperature spikes were a problem during the conduct of the first 29 ISTB tests. Modifications have been made and proven on subsequent tests.

d. The low pressure fuel turbopump inlet/outlet duct consisting of a flexible bellows joint has had leak problems. Rocketdyne is investigating a number of fixes. For the present they have decided to incorporate a brazed design bellows on engine 0003 and subs, while continuing to use the existing ducts on the first two engines (ISTB-0001 , 0002). Indications are that the early-type flex ducts can withstand the rigor of continued firing in order to meet test requirements.

3.2.3.1.2 Engine 0002

This engine has just begun its test cycle at NSTL with 16 tests conducted to date. Early testing has evaluated the start characteristics, while the most recent testing has evaluated fixes to the high pressure fuel turbopump.

3.2.3.1.3 Component Tests

For our purposes the components of the SSME include combustion devices, turbomachinery and the controller. Previous sections have discussed the controller.

From a standpoint of the critical hardware for the 0003 and 0004 engines, the following problems exist. On the 0003 the bellows assemblies mentioned above have been brought "in-house" due to vendor problems which in turn has resulted in some changes to the schedule completion dates. However, there appears to be little or no impact from this delay since there is a pad of some six weeks available. Engine component problems on the 0004 include the high pressure fuel turbopump, the main combustion chamber, and the 77.5:1 nozzle. This engine is due for delivery around September 1976. To help mitigate these problems Rocketdyne has completely revamped its so-called "pump assembly room" at Canoga Park to do a more orderly and timely job on turbomachinery.

3.2.3.1.3.1 Combustion Devices

A testing summary is shown in Table 3-3 covering the following items:

Augmented Spark Igniter (ASI)	Oxygen Preburner (OPB) and Fuel Preburner (FPB)
Thrust Chamber Assembly (TCA)	Heat Exchanger
Nozzle with 35:1 Ratio	

The 40,000 pound thrust scale model was used for tests at MSFC.

In summary, the combustion devices test program indicates that the above items have been operating satisfactorily. Problems that have cropped up during the test program have either been resolved to the satisfaction of the designers or a resolution is now in process. For instance, the 35:1 nozzle TCA tests conducted at COCA 4B show an excessive pressure drop existing between the inlet diffuser of the main combustion chamber, the tubes, and the mixer at the outlet. The measured pressure drop was 544 psi while the predicted was 349 psi resulting in an excess of 195 psi. These measurements were at RPL. The impact on engine balance results in tube life decrease and engine temperature increases. This problem is under active investigation at this time with results expected soon.

The Augmented Spark Igniter (ASI) has experienced spark plug tip overheating resulting in erosion and cracking of the plug tip. This problem is being worked by developing a copper-plating process, controlling the ISTB hydrogen temperature on engine start, eliminating temperature spikes during any transient and using the copper-plated plugs on the engines when they become available.

Steps taken to prevent other combustion device fabrication problems include prevention of pitting in the main combustion chamber liner by revising tooling for the electroform process and prevention of the 77.5:1 nozzle braze and weld problems by redesign of the manifold shell and modified tooling for brazing process.

3.2.3.1.3.2 Turbomachinery

The significant results of the turbomachinery tests are:

Low pressure oxygen turbopump	Tested to Full Power Level
Low pressure and high pressure oxygen turbopump	Tested to RPL (Transition) Tested to 0.92 of RPL (Steady-State) Impeller performance defined
Low pressure fuel turbopump	Tested to FPL Performance Mapped Bearing failure experienced
Low pressure and high pressure fuel turbopump	7 tests, tested to 0.75 of MPL Axial thrust balance difficulties resolved; speed limitation on HPFTP because of subsynchronous whirl
High pressure oxygen turbopump Seals and Bearings	Borg-Warner wear problem investigated Testing initiated on "Sealol" Seal

The problems noted can be described as follows:

(a) The LPOTP housing had failures during the RPL proof test. Inspection of the casting is a difficult task. As a result, the problem is being approached from both a materials aspect as well as providing a more thorough inspection process.

(b) The HPOTP impeller performance has been lower than expected at the RPL condition. This appears to have resulted from impeller vane resonance and resulting lowered outlet head. Modifications of the impeller are being made and further testing will confirm the redesign.

(c) The HPFTP rotor axial thrust balance problem has been the cause of axial rubbing and damage during tests of this pump. The problem is recognized and understood. A step-by-step procedure has been followed to balance the rotor system such that during running conditions the system will be balanced by means of internal orifices and preclude overspeeding and rubbing of parts. The rotor system has been balanced in tests up to 75% of RPL. Additional tests up to full power level must now be conducted to confirm the design.

(d) The high pressure fuel turbopump subsynchronous whirl problem has been the cause of excess shaft vibration and turbine bearing load failures. A step by step procedure is being followed to reduce the vibration level so that long duration engine tests can be conducted above the 60% RPL. Moderate improvement from immediate fixes has raised the whirl inception speed and reduced the severity of the vibrations. However, to completely resolve the problem and enable the pump to run up to full power level, a stiffened rotor and support system plus moving the pump and bearing inboard will most likely be required.

(e) The HPOTP primary LOX seal has had inadequate life due to excessive wear. There is no immediate problem on the engine test stands; however, steps are being taken to reduce the load on the seal and provide a better seal material in the future.

3.2.4 Manufacturing

Since manufacturing is discussed in varying degrees in the preceeding sections on review, design and test of the SSME and its components, the discussion here is limited to four items that are of major interest at this time: (1) the increase in the turbopump assembly area and facilities at Rocketdyne, (2) machine tool requirements and rehabilitation program, (3) welding, and (4) pre-production in-house fabrication maturity. The turbopump assembly operation is being expanded so that it can handle eight assemblies simultaneously. This requires increased supervision, mechanics, and quality control; duplicate tooling; three-shift operations in most cases; and, a setting up of a standardized assembly or flow process to optimize the use of men and equipment. The machine tool study is also a step in making the very best use of on-hand equipment. Welding has been a consistent problem on the more complex configurations used in the main combustion components and some turbopumps as well as the full-size 77.5:1 exit nozzle. Quality of the welding is being improved by a program to use automatic welds rather than manual welds and upgrade the machines themselves. The following is a list of weld changes from manual to automatic in the course of the period between October 1975 and February 1976:

	10/9/75	1/15/76
Ducts	66	15
Turbopumps	7	0
Main Combustion Chamber	3	0
77.5:1 Nozzle	1	2
Hot Gas Manifold	3	2

It is understood that the first "good" 77.5:1 nozzle has completed its fabrication cycle with minimum weld distortion which indicates that particular problem may be resolved.

3.3 Addendum

ISTB testing with the reworked Low Pressure Fuel Turbopump was restarted at the end of May and testing at the COCA IB facility has been resumed as well.

Accelerations, vibrations and unbalanced forces on the rotating shaft and blades of the High Pressure Fuel Turbopump have caused premature engine shutdown a number of times. This appears to be the result of subsynchronous whirl effects or pressure oscillations at frequencies near 50 to 55% of the actual pump speed itself. To resolve this problem, outside specialists have been consulted; a literature search of hundreds of publications and speciality texts from several nations has also been started. The most promising fixes appear to be increased Coulomb damping on the bearing carrier; a tangentially vented pressure relief interstage seal; reduced interstage seal length; reduction in shaft hysteresis; decoupled axial and radial modes; and, of course, any combination of the above modes.

The SSME System Safety activities currently underway includes an update of the SSME hazard summary listing all identified hazards and causes; preparation of the final report on the NSTL hazard analysis for the A-1 and A-2 test stands; and the planning of an oxygen fire symposium to assure test personnel are up to date on the current safety provisions.

The P-4 engine controller assembly is on schedule. Power supplies for this unit have successfully passed a 10 minute, three axis subsystem vibration test. The P-4 controller is due at Rocketdyne in September 1976.

The major challenges of significance for crew safety on the Space Shuttle Main Engine are materials behavior under severe environments, weld integrity, POGO suppression, and engine controller performance and reliability. Therefore, the results of the test program will be critical to developing confidence in these areas.

Response: SSME Materials Behavior Under Severe Environments

(a) An extensive analysis and test program is well underway. The fracture mechanics test program has been expanded to include more materials and components. Fracture mechanics analyses include load cycling and environmental conditions, alloy/condition combinations, weld combinations, and the effects of coatings and weld overlays. These analyses will be verified by the test program. Minimum detectable flaw sizes will be established by non-destructive methods. In addition, an assessment of the structural margins in the SSME with regard to structural, weight, and performance requirements was conducted by a high level team composed of members from JSC and MSFC. All 117 components reviewed meet the engine safety factor requirement of 1.4 at full power level, and 88 of these meet a 1.5 safety factor at full power level.

SSME Weld Integrity

(b) Fabrication of the first engine and supporting components revealed areas requiring improvements in weld integrity. Extensive action has been taken in the area of weld analysis, redesign of some weld joints, converting from manual to automatic welding, evaluating of process parameters, upgrading/increasing staff, upgrading equipment and improvements in inspection and quality control procedures to assure good welds.

POGO Suppression

(c) A continuing analytical program is underway and being pursued to understand the POGO phenomenon and its implications to the SSME by NASA field centers and their contractors. A POGO integration panel, chaired by Dr. Harold Doiron of JSC, has been in operation since June 1973, to continually review analytical and test data. The POGO suppressor has been baselined and a comprehensive test program on individual component parts is already underway. Engine tests will verify the POGO suppressor system. Extensive use has been made of Saturn data in designing the test program.

Engine Controller Performance & Reliability

(d) High priority by top management at Honeywell, Rocketdyne, MSFC, and Headquarters is being applied in this area. Because of current problems with the controller interconnect system (inboard master interconnect system) and the fact that it is difficult to manufacture and reproduce, two studies have been initiated on an interconnect redesign effort as a product improvement. Furthermore, we are proceeding to mount the controller on isolators (shock mounts) which significantly reduce all vibration energy into the controller at frequencies above 100 Hertz. In addition, RTV potting and foam have been added to the inboard master interconnect board to reduce wire stress concentration and dampen the wires dynamics. It should be noted that the wire breakage problem we have encountered has been associated with the inboard half of the controller interconnect system, and not the memory plated wire.

ATTACHMENT 3-2

Allowable SSME Heat Exchanger Oxidizer Coil Leakage Rate

We are glad that they are keeping an open mind on this since a leak rate of 10^{-3} cc/sec helium during field operational leak test inspection sounds like a fairly large crack. This is a critical piece of gear. Is this a case where the 160 hour turnaround time is the driver?

Answer:

The heat exchanger leakage rate test requirement for launch operations has not been firmly established. The 1×10^{-3} cc/sec helium check is being used for planning purposes. The necessary leak check and/or any other inspection requirement will be based on the development experience and the assessed risk of a failure. The 160 hour turnaround requirement will no doubt be a consideration in all ground operation planning but will not be the deciding factor.

Use of Teflon Balls in POGO Suppressor Unit

What are the requirements for the ground tests to verify this design? How closely can they approximate flight conditions?

Answer:

The hollow teflon balls utilized in the POGO suppressor will be subjected to extensive testing as individual parts as well as in component tests. They will also be utilized and subjected to operating conditions during all engine testing subsequent to incorporation of the suppressor into the R&D program. Being an internal part of the engine system, the teflon balls should be subjected to operating conditions which closely simulate flight conditions. The only known difference will be operation in a 1-g environment as opposed to a flight environment of up to 3-g's. It is not anticipated that this difference will have an effect on the operation of the balls.