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

part I —observations and conclusions

june 1976

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ANNUAL REPORT TO THE NASA ADMINISTRATOR

by the

AEROSPACE SAFETY ADVISORY PANEL

on the

SPACE SHUTTLE PROGRAM

Part I - Observations and Conclusions

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PREFACE

This past year the Aerospace Safety Advisory Panel has focused its attention on the Space Shuttle system, and has augmented its traditional on-site inspection approach with the assignment of task teams for more detailed fact-finding in specific areas of concern. This two-fold approach has enabled the Panel to cover a large number of tasks in greater depth while continuing to monitor the status of the program as a whole.

The Panel cannot, of course, review all activities of the program in equal detail. The following sections, which reflect the priorities the Panel felt were most deserving of its attention, were chosen on the basis of the importance of those elements, subsystems and management systems with respect to crew safety and mission success. Each section was written by a different team. The Panel recognizes a continuing responsibility for surveilance of Shuttle and will continue to submit appropriate reports when each phase of its review is completed.

Following is a statement of our general conclusions. These conclusions also serve as an introduction to the task team reports.

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1.0 GENERAL CONCLUSIONS

Mr. Howard K. Nason
Chairman

1.0 GENERAL CONCLUSIONS

This abstract is a prologue to the task team reports which follow this section. It begins with a general assessment of the program and then identifies those topics the Panel suggests be reviewed by various levels of NASA management as part of their continuing oversight of program operations.

I. The Panel is confident, based on the data we have gathered, that the Shuttle organization is developing flightworthy hardware and software systems. Program management has an adequate understanding of the significant ground and flight risks involved. This general statement is based on such observations as the following:

A. PROGRAM STATUS

The program is progressing as well as can be expected considering budget constraints. The majority of subsystems are proceeding through design, manufacturing and test as planned. However, there is no margin in the schedule to accommodate major perturbations. As in any research and development program, some subsystems are encountering problems. This situation is not unusual where new technology is applied in new situations. Problems are being aggressively worked by management and engineering. The Shuttle Main Engine and Orbiter Thermal Protection Systems are notable examples.

B. TECHNICAL CONSCIENCE

Program personnel have maintained their enthusiasm for raising questions of significance to the performance and safety of the Shuttle. There are adequate forums for them to express their concerns and judgments to management. The personnel in critical positions for decisions affecting flightworthiness and risk assessment are competent and experienced.

C. RISK MANAGEMENT

There is an independent and mature risk management system which considers all aspects of safety. The system also assures that design, manufacturing and test experience from prior programs is formally brought to the attention of people in this program and is being applied appropriately.

D. AGGREGATE RISK

Aggregate or total risk is difficult to measure. Nothing to date indicates the total risk is excessive at this phase of the program. The major basis for confidence in the flight hardware and software is the Shuttle verification program, since such a program certifies that the performance of the actual flight hardware and software meets mission requirements. Therefore, these tests are especially important, and their results will give a better understanding of the actual capability and limitations of the Shuttle elements.

II. The Panel suggests that senior agency management include the following areas in their reviews of policy and planning for information and control as warranted.

A. GROUND TEST PROGRAM

The verification and certification programs and the decision making system to establish minimum test requirements to certify flightworthiness and safety warrant continued attention.

Our reasoning is as follows. There is little schedule margin, funds or extra test hardware in any of the major test programs. If test results do not turn out as expected, management will need to reassess its requirements for certification of the flightworthiness of the elements, adjust the schedule, or accept greater risks. Decisions on what are minimum requirements are matters of judgment. Such judgments are properly a prerogative and responsibility of program and project management.

To assure that these judgments continue to be made with safety as the top priority, senior management will need to monitor:

1. The ability to meet minimum requirements where there are further reductions or changes in the major test program.

2. Progress in resolving problems in such critical manufacturing and test areas as the Main Engine nozzle and turbo-machinery, and the delivery and independent verification of avionics software.

3. The realism of plans and schedules for the remaining tests where there are significant problems so that decisions can be made early rather than under schedule pressure.

B. THE APPROACH AND LANDING TEST FLIGHTS (ALT)

Mission planning and vehicle checkout for the flight program have begun and will peak out this coming fiscal year.

The areas that warrant review now are:

1. The data required from ALT to support a flight readiness decision on the first orbital flights and therefore the current policy on mission planning to obtain this data.

2. The aggregate risk inherent in the "first flight" plan to assure it remains at an acceptable level. The ALT safety assessment document appears to be a good starting point for such a review.

3. The basis for confidence that the structural capability of the 747 tail section will not be overloaded during tailcone off flights and that vibrations will not exceed crew tolerance.

4. The test requirements and plans to give confidence that the landing gear will deploy and lock as required.

5. The plan to have adequate Ground Support Equipment at the proper place to support the ALT program.

6. The flight software requirements so there is an identical flight profile for autoland and manual modes.

7. The provision to allow the crew to adjust the gain of the control system.

III. The Panel suggests that the Office of Space Flight give particular attention in its reviews to the following management areas.

A. AVIONICS

The effectiveness of recent changes in the avionics management approach and the need for a software expert in the Technical Assessment Office as an independent advisor and check and balance. Among the challenges they face are potential overloading of software, timeliness of deliveries, and the adequacy of independent verification. Independent verification of software in flight configuration is considered to be very important. Fixes in hardware need to be assessed for their impact on software. Potential rearrangement of core memory by lightning or static discharges must be assessed.

B. SYSTEMS MANAGEMENT FOR CONTINGENCY ABORT PLANNING

The management system to assure that contingency abort analyses are given the proper priority now so that changes, particularly in the software, are being made while there is still the capability for changes.

C. SOLID ROCKET BOOSTER

The total or integrated management plan to assure SRB reliability by appropriate controls during design, manufacturing, checkout, recovery and reuse. There are currently plans for the various phases but since we are dependent on the extremely high degree of reliability of the SRB there has to be both an overall plan and an appropriate management system to assure nothing is overlooked or "falls through the crack."

IV. The Panel recommends that program management follow closely the following specific technical issues as well as the policy, planning, and management areas mentioned above.

A. EXTERNAL TANK

The selection of a material and its method of application for the external insulation, so that the program gets the flight performance it needs.

B. SOLID ROCKET BOOSTER

The safeguards to protect the auxilliary power unit from sea water entering the catalytic bed of the fuel system after splashdown.

C. ORBITER THERMAL PROTECTION SYSTEM

1. The provisions to assure that installation procedures and tools will maintain the required gap and step between tiles and

so avoid the problem of an early tripping of the boundary layer.

2. The provisions to adequately protect vehicle openings during entry with insulation, while assuring this insulation will not obstruct the operation of doors.

3. The data from further aerodynamic and flight tests be utilized to insure selection of proper materials.

The following Task Team Reports contain the details on all of these recommendations as well as additional recommendations not listed here.

2.0 SYSTEMS MANAGEMENT

Hon. Willis M. Hawkins
Mr. Herbert E. Grier
Hon. Frank C. Di Luzio

2.0 SYSTEMS MANAGEMENT

I. BACKGROUND

In recognition of the complexity of the Shuttle system and the need to have many back-up and fail safe or redundant systems to attain a high degree of safety, the Aerospace Safety Advisory Panel has endeavored to understand NASA's approach to systems management and to assess the success of these efforts. During the last year the Panel has had numerous briefings from major element and systems integration managers at NASA Centers and from contractors. The Panel also reviewed the management system for contingency and abort planning. Finally, the Panel reviewed the NASA Program Office's response to earlier recommendations from the Panel and from the Hawkins Committee.

II. OBSERVATIONS

The systems management function exercises oversight of the requirements for the total flight vehicle and integrates the work on the major elements toward meeting these requirements. Thus, "systems management" includes both systems integration and the independent assessment of the various elements in the program.

The Panel found that earlier models were not used by the Shuttle team because of such factors as complexity, re-usability of major components, limited back-up resources and NASA'S management experience. The system management approach is still evolving because it is designed to be responsive to changing needs. Thus the Panel has had to understand and appreciate the differences in approach before judging its effectiveness. In order to know what to expect in terms of performance, the Panel focused on the structure and operation of the management system and on the circumstances that will continue to shape and constrain its evolution. In the recent past the relative responsibilities of the program office and the principal systems contractors have been renegotiated so the program office has taken more direct responsibility for the definition and implementation of the requirements for systems integration. Since the Systems Integration Office at JSC remains comparatively small, it has developed a number of mechanisms for getting its work done. One of the most important is the comparatively complex system of fifty panels and working groups. These, where needed, are chartered by the Systems Integration Office through the Program Manager when more than one project element is involved or an inter-disciplinary technical approach is required to define requirements and assure they are met. They are staffed by the same personnel who are involved at the project level in getting the work done. This approach has the advantage of assuring that the people who work the systems integration problems are familiar with the working details, but it also means that there is a need for an independent assessment function as a check and balance on this approach. This was recommended by both the Panel and the Hawkins Committee. The

Program Manager instituted such a function this past year.

A. SYSTEMS INTEGRATION

Our current observations on systems integration can be summarized as follows:

1. The management structure for systems integration is cumbersome but comprehensive and appears to work.

2. We have been asked to review the system for technical conscience and we have found that the panels and working groups are an important element of it. These provide a forum for knowledgeable technical personnel to alert management to questions considered important for crew safety and mission success.

3. The staff of engineers in the systems engineering office may need to be increased. As noted, systems integration is being done by project engineers under the oversight of the systems engineering office. Because of the workload and the possible difference in perspective between the two disciplines, management regularly should review the staffing of the systems engineering office to assure that its capability is appropriate for its responsibilities.

4. In terms of documentation it appears that most of the directives which describe the system have to do with responsibilities for monitoring and evaluating Shuttle progress rather than with specifying how the daily work gets done or how the daily integration

decisions are made. Further, some of the directives do not clearly define or describe responsibilities. Using SSPM Directive No. 45A as an example, it is not clear how the Systems Integration Manager works with the Systems Engineering Office, nor which instructs the "doer" organizations.

5. The Program Office also has been working on a systems engineering plan to assure that delivered vehicles meet the total requirements for flightworthiness and to specify the relative roles and responsibilities of the organizations involved in meeting these requirements. Such a plan helps insure both an efficient organization and that significant requirements are not lost sight of. Work on this plan has been delayed further. If the plan is not to be available in a timely fashion then management will have to assure that the basic need that required such a document is met in another way.

6. The Panel and the Hawkins Committee have emphasized the need for program management to continue to review the panels and working groups, to assure that the system anticipates emerging program needs and does not lag them, and that individual groups are operating effectively. This year program management partially responded to this recommendation with a review which resulted in consolidation of some panels to reflect changing work requirements and the chartering of new ones for recently identified needs.

7. In monitoring such areas as integration of the main propulsion system, the Panel reviews the work of the groups involved. In one such review the Panel found that the newly established Chief Engineer at MSFC for the Main Propulsion System was not a member of the integration panel (e.g., Systems Integration Review Panel) activities at JSC. The Panel believes that he should have direct participation and membership in the Systems Integration Review Panel activities, as well as be a part of the approval cycle for Level II and III documents pertaining to his area of responsibility.

The Panel has not yet completed consideration of other important system integration issues such as configuration management, interface control and interaction between Shuttle system elements.

B. INDEPENDENT TECHNICAL ASSESSMENT

The Panel also has reviewed the evolution of the independent assessment groups, giving particular attention to the evolution of the group at JSC. This group became operational at the first of the year and began detailed discussions with each of the critical subsystem managers. Based on these discussions, and their past experience, the group identified the areas where they would make detailed studies. The results of these studies were to be provided management in forms that appeared appropriate to the situation. In some cases the judgments were offered as informal advice to managers and engineers. In other cases, the studies were written for senior program and center management's consideration. It is too early to assess how these groups will evolve or their effect on the program. Our thoughts at this time are:

1. The technical assessment groups either can focus on identifying problems for program resolution or can take on the role of trouble shooter and work the resolution of the problem. Both roles are acceptable. However, the Panel favors the role of identifying problems so the assessment groups can cover more areas of the program.

2. Studies of the program assessment group at JSC indicate the value of such groups. For instance, they have made significant studies in such areas as contingency abort planning and possible Orbiter failure that would shut down the Main Engine. Given the potential workload for these groups, one of their real problems will be the establishment of priorities. The Panel suggests that priority be given to safety issues rather than non-safety issues that may seem more pressing.

C. ABORT AND CONTINGENCY PLANNING

The Panel reviewed abort and contingency planning from the perspective of system management because there needs to be a clearly identifiable system dedicated to this area. This would include the integration of hazard assessments for various elements, so that the vulnerability of one element to the hazards of another is understood. Where practical the margin of safety should be enhanced, but whether the margin is sufficient is, of course, a matter of management judgment.

The Panel seeks to assure that the pertinent facts are reviewed at the right levels prior to such decisions. For example, the program carefully considered how the Orbiter could be protected against Shuttle system failures during the Solid Rocket Booster burn period. Both the abort systems that could be used in the advent of an SRB failure and experience with reliability of solid rocket systems were reviewed. The conclusion was to depend upon quality control on the SRB rather than an abort system with its complexity and potential failure modes. Also, ejection seats will be used during the early test flights to enhance crew escape in case of aborts. Emphasis is on intact abort planning rather than contingency abort planning; intact abort requirements dictate hardware design requirements. Effects of a failure in a system or subsystem causing the loss of a critical function should be compensated for through appropriate safety margins or redundance. This allows design of the vehicle so that the Orbiter and its crew may return safely if such failures should actually occur. The rule on failure modes and hazards, other than critical ones, is that they shall be eliminated by design or by workaround only where this is both feasible and cost effective.

The Panel's review this year was comprehensive in order to define where we should focus our attention in the coming year.

In reviewing the possible abort conditions, it appeared to the Panel that the following system reviews are in order since we want to make a determined effort to remove or minimize the risk of as many of these contingencies as possible.

1. The explosion of a solid rocket booster, a main engine, the external tank, an orbit maneuver engine, or a reaction control system would, in all likelihood cause the loss of an orbiter. Thus, all possible measures must be taken to prevent such an occurrence or to provide warning so that such an explosion could be prevented.

2. The failure of the solid rocket boosters or the external tank to separate constitutes a hazard that is difficult to evaluate. There is no program in the control system to handle the failure of the solids to separate even if they were finally ejected at the external tank ejection signal. The crew should know what to do in such a contingency or a program should be developed.

3. In the early flights there will be no shuttle to perform rescue services, so effort should be made to minimize contingencies which might cause rescue to be needed. These include doors (payload

bay doors, or umbilical door) which cannot be closed prior to reentry or the failure of the external tank to separate.

4. A thorough analysis of thrust vector controls has not been completed but it would appear that, with four computer channels for such control, there is little likelihood of one power plant (solid or liquid) going hard over by itself. The solids, if the system fails, go to a previously selected neutral position in order that control can be maintained. The main liquid engines do not "fail" into such a position and interference would exist with other "swinging" engines if such a neutral position were held. Since the four computer channels appear to be adequate for thrust vector control safety, it is suggested that input and output devices and the mechanisms for moving the engines be reviewed to be doubly assured that no "hard-overs" can exist inadvertently.

5. It would appear that two APU failures in the orbiter would make a reentry and a normal landing extremely marginal. Due to the long storage time on orbit, it can be argued that two APU failures on any given flight might be statistically conceivable. Thus the adequacy of test and APU system design should be reviewed.

6. Loss of pressure in the cabin appears to be a singular and important hazard. There are two cabin air supply systems and three fuel cells which provide cabin air pressure and conditioning. The system

must operate for the entire mission and total failure would be fatal. It is suggested that a concentrated review take place, seeking once again, the strong confirmation that this is a remote enough risk to take. A third air supply system might be feasible, and valuable.

7. There are several essential systems characterized by having "3 engine" safety - the control system, the APU system on the Orbiter, and the reaction control system. Since the loss of any of these total systems would incapacitate the Orbiter, constant reevaluation is in order. The common tankage for the RCS should be reassessed and particular attention should be paid to the APU's since the Orbiter would not be able to return on one APU unless initial conditions were perfect.

8. The decisions regarding launch "destruct" have been made for OFT. The decisions for operational flights: whether destruct is needed, what it needs to destroy, who is in charge of specifying its characteristics and actually commanding destruct are still to be confirmed. Inherent in any such system where pilot escape is planned is the problem of how to warn the pilot so that some escape may be initiated.

In this coming year the Panel will review the management system as it operates in working each of these eight points and the conclusions so far. We, of course, will also try to make suggestions that would reduce each risk that did not seem to be sufficiently controlled.

Finally, the "twin engine" characteristics of the cabin pressure system and the consequence of sequential failures of the orbiter APU's should receive priority attention. In addition a thorough search of the logic of how the computer based thrust vector control protects against hard-overs that are not commanded needs to be made but currently the Panel does not have that degree of technical software expertise to serve the Panel. A similar detail review should be made of the crossover capability which exists on the control system to maintain hydraulic pressure in the event of APU failure with specific focus on the adequacy of maintaining hydraulic pressure in the main engine control valve system. If an APU shuts down there will be an automatic shutdown of that engine being served.

D. RESPONSE TO PRIOR RECOMMENDATIONS

The Panel has reviewed program response to other recommendations, including those of the Hawkins Committee. The Panel's observations are:

1. The authority for decision to accept these recommendations properly resides with program management, who have responsibility and accountability for the program.

2. Program Management gave the recommendations careful consideration. As can be expected there are some differences in judgment between program management and the advisory groups. Management is trying to meet the intent of the majority of recommendations.

III. RECOMMENDATIONS

A. Comprehensive review of integrating groups' operations should be conducted regularly to insure responsiveness to program needs.

B. The Chief Engineer for the Main Propulsion System should be a member of the Systems Integration Review Panel.

C. Individuals at the systems integration level at JSC and at Rockwell's Space Division should be given appropriate management responsibility, authority and resources for contingency analysis and planning.

D. Analysis and evaluation of the vehicle capability for off-design cases should be done now, rather than later when any necessary changes would be prohibitively costly. Staffing needed for this effort should be provided.

E. Since the program has decided to depend upon reliability of the SRB as the major safeguard against failure, the management system should have an integrated plan to assure there are appropriate quality controls during the life cycle of the SRB, i.e., manufacturing, checkout and reuse.

F. Since there is a potential for hazards to the SRB from the aerodynamic environment or failure modes elsewhere in the vehicle, a hazard assessment report on this area should be prepared for management.

3.0 SPACE SHUTTLE MAIN ENGINE

Dr. Seymour C. Himmel

3.0 SHUTTLE MAIN ENGINE

I. BACKGROUND

Task team activities were concentrated on the specific concerns identified by the Panel during previous reviews and those resulting from NASA in-house meetings and the Hawkins Committee efforts. The areas singled out for examination included:

A. New and still to be proven technology.

B. Design conservatism to meet requirements for engine reuse.

C. Adequacy of the Electronic Controller, including its ability to operate reliably in the engine environment.

D. Engine control capability and the results of credible failures.

E. The test program and its adequacy for achieving the engine program objectives.

F. The Engine and its integration into the total Shuttle system.

This interim report provides a "snapshot" of the program as viewed by the Panel and, where appropriate, assessments, recommendations, and future plans for further reviews of the Space Shuttle Main Engine.

The Panel has had this critical Shuttle area under review on a fairly continuous basis over the past two years, as shown in Table 1. Attention has been focused on: status of design, test and fabrication development; current and projected problems; dominant uncertainties in the design and expected performance; and technical and managerial resolution of program problems and uncertainties, including trade-off studies. The sensitivity of the engine hardware/software development to cost and schedule influences is a part of the review process.

Pertinent background is found in the Space Shuttle Program's response to the Panel's 1975 Annual Report. Those responses relating directly to the SSME are provided in Appendix A. These comments were provided to the Panel in October 1975.

In the coming months, the task team will continue to monitor and examine the engine and component test programs and the Controller and its software at both contractor and NASA locations. Members of the Panel and task team will continue to attend in-house meetings and reviews.

II. OBSERVATIONS

A. Management

There have been a number of organizational changes at Rocketdyne Division of the Rockwell International Corporation with the objective of strengthening their in-house efforts as well as to better meet the current program needs. Among the more important changes were: the establishment of an Associate Program Manager for the Controller and the strengthening of engineering activities, particularly those in support of the manufacturing effort.

The review process and system integration activities are derivatives of those developed for the NASA Saturn engine programs.

From the material provided to the Panel, it appears that both the formal and informal channels are operating well and the information flow to those charged with the decision-making process appears adequate. A number of working-level panels and groups have been established to meet special needs of the Shuttle program and the Main Engine in particular. These include:

1. "Space Shuttle Integration Reviews," Program Directive 14A, which provides technical inputs necessary to establish and maintain system specifications and to verify design compatibility of the integrated vehicle.

2. "Space Shuttle Integrated Propulsion and Fluids Technical Management Area," Program Directive 24, provides for technical management and for a "Main Propulsion System Panel."

3. "Space Shuttle Ascent Flight Systems Integration Group," Program Directive 57, which supports the Systems Integration Review (SIR) particularly in the ascent phase when the engines are utilized.

B. **Technical**

The more recent major reviews of the program include "SSME Design Margin Review," in July 1975 and MSFC's Quarterly Reviews of January 1976 and April 1976. The results of these review efforts are included in the following sections of this report. The SSME Critical Design Review currently is scheduled for the September - October

1976 time frame.

The SSME Design Margin Review was the culmination of an extensive long-term review initiated in the fall of 1974. It provided a much needed in-depth review of such items as the design criteria, load calculations, assumptions used, methods of analysis, analytical results and their meaning, concepts for increasing margins, and flight constraints. It produced, as expected, a number of action items and recommendations. Typical of these were: (1) review methods that can be used to identify incipient failures and devise a compatible resolution; (2) use maximum throttling ramp rate; (3) limit thrust for early flights to Rated Power Level; (4) continue to obtain materials properties; and (5) increase hardware confidence by conducting tests at higher pressures and temperature levels with added instrumentation. All of these items are either under active consideration or in-work.

The Engine Controller posture at this time appears to be encouraging. Functional testing of the rack mounted BT-1 unit operating with the Integrated System Test Bed engine firings, and environmental testing of the structural thermal engineering model (SM-1), and the Production Prototype unit (PP-1) indicate that, with the resolution of some design problems, the flight configuration controllers should meet system requirements. This will require a continued, determined, effort on the part of NASA, Rocketdyne and Honeywell (the Controller contractor). Most of the problems that surfaced during the test program to date have been resolved or are in the process of being resolved. These include, for example, memory system noise, cracked solder joints, minor circuit design problems, manufacturing problems, and electromagnetic interference (EMI) emanating from the power supply. A major problem was the breaking during vibration testing of wires that had been "stitch welded" on the Master Interconnect Board. A concerted effort by NASA and contractors resulted in a decision to examine a parallel design/development activity to employ Multilayer Boards which would eliminate the wires and thus wire breakage. The Multilayer Board change, if used, would be applied to the P-4 controller and subsequent units depending upon funding constraints.

Because the Controller is attached directly to the upper engine structure, the severity of the vibration environment has required the design and installation of a vibration isolater (shock-mount) system. This work is progressing rapidly now and appears to provide the necessary attenuation as evidenced by the test results with an early mount design. These results of tests with this early isolator design indicated proper Controller operation after vibration testing at 22.5 g in each of 3 axes for 30 minutes per axis. Using a revised design mount (isolator) the PP-2 Controller unit has been subjected to test inputs of 22.5 g's for 7.5 hours in each of the three axes. Although anomalies did crop up they do not appear to be major in that redesign is not required, but that assembly and drawing compatibility may require further attention. After completion of this test series additional hours were run at the 22.5 g level to reconfirm the overall acceptability of the current design. These appear to have been successful.

The Controller software programs have progressed a great deal over the past year, but much is yet to be done. Software has been in operation on the ISTB program and under laboratory tests. It is planned to have the software delivered during 1976 with operational updates made in 1977. It is noteworthy that the Controller system (the combination of software and hardware) has to date been able to shut down the engine safely under normal and abnormal testing circumstances.

The SSME top priority items receiving major Rocketdyne management attention at this time are:

1. High Pressure Fuel Turbopump Subsynchronous Whirl
2. High Pressure Oxygen Turbopump Performance
3. The 77.5:1 Nozzle Fabrication
4. Hot Gas Manifold Liner Excess Pressure Differential
5. Test Program

Briefly, the status of these items is:

1. The High Pressure Fuel Turbo Pump axial thrust balance system appears to be resolved. Modifications have been incorporated that have balanced the system up to 85% RPL to date. In addition, the rotor is exhibiting subsynchronous whirl. These matters are under active attack by the Project.

2. The High Pressure Oxygen Turbo Pump performance exhibited performance (head rise) 20 percent lower than predicted. A design change in the impeller has been implemented that should overcome this deficiency.

3. The full scale engine nozzle, expansion ratio of 77.5:1, has encountered numerous fabrication difficulties caused by material distortion in the welding process. Changes have been made in the design and the welding procedures that appear to provide a solution to this problem, albeit at a projected increase in weight. Two redesigned nozzles have been through a braze cycle and appears to have been successful. Hot fire testing of nozzle #1 is scheduled for August 1976. It appears that some further changes may be necessary since flight nozzle jackets #3 and #4 experienced buckling.

4. The hot gas manifold coolant liner is the oxygen turbo pump side of the hot gas manifold was found to have buckled as a result of excessive pressure differential. It would appear that this had occurred during the last high-power ISTB run. This problem occurred as a result of contamination on the backside of the injector causing an excessive pressure drop across the hot gas manifold liner. Additional

holes were drilled in the primary faceplate of the injector to reduce resistance.

The test program is still in its early stages both at the component and engine system level. Notable progress has been made with all components with the exception of the full scale nozzle having been operated to at least minimum power level and at least half having reached rated power level conditions. The durations at higher power levels have been, generally, short but do represent progress.

A serious incident occurred at the COCA 1A Test Site on February 4, 1976, during which the oxidizer turbomachinery subsystem under test suffered substantial damage and significant damage was done to the test stand and its facility equipment. Conclusions of the incident investigation indicated that a facility oxygen flowmeter failed, resulting in elements thereof breaking loose, moving downstream, and impacting the seat of the facility LOX discharge throttle valve, causing ignition and burning. The resulting pressure rise fed back to the turbomachinery under test and initiated cutoff. Before this could be effected, however, the changes in machinery operating point, resulting from the facility failure, caused the high pressure pump to cavitate, lose balance piston function and fail.

This incident triggered a review of test facility design, configuration, hardware, etc., throughout the engine program. The results of these studies and the experience gained will be transmitted to other Rockwell divisions and NASA. Corrective action has been initiated and it is anticipated that testing at COCA 1 will be resumed in June. The impact of this incident is a test schedule slip of some ten weeks.

The principal objective of the March 1976 review meeting with Rocketdyne was to discuss the engine test program rationale and philosophy. The program is very well documented in a "document tree" that has at its apex the engine Program Development Plan and provides a comprehensive picture of the test program. It covers both development and certification test plans culminating with the Final Flight Certification of the engine.

The testing is governed by Design Verification Specifications that provide details of test requirements and objectives and cross-references, as to the source, each requirement and what constitutes verification. The system also includes a "constraint map" called Bench Mark Control Points that establishes requirements for successful lower level test completion prior to initiating tests at higher assembly levels.

All told, the test program is well documented and contains built-in feedback management control mechanisms to insure that constraints are not violated. The documents are evidence that much effort was expended in planning the program and that it is a tightly integrated and austere effort. If the documentation is to be faulted at all, it would be that the rationale for the decisions/criteria reflected in the program documents is not apparent therein. This will require further discussions between Panel members and the design groups involved.

III. ASSESSMENT AND RECOMMENDATIONS

The reviews and observations of the task team led to the following current assessment of the engine program:

A. The program is in its early testing stage and is experiencing the sorts of development problems that were not uncommon in previous engine programs at this stage of the program. The engine is, of course, a venture into a new area of technology and without the benefit of experience it is difficult to predict where all the pitfalls may be. However, they may be expected to lie in the area of how to design rocket engines for "long" life.

B. Most of the components are exhibiting performance near predicted values. The key elements that will be investigated this coming year are stability and durability of the components and higher assemblies.

C. The test program as currently planned will accumulate about 56 hours of engine testing at FFC (Final Flight Certification). This is about the same test time accumulated on the F-1 and J-2 programs at a comparable point, but these programs had about ten times the test hardware available. When pressed, and with the benefit of retrospective visual acuity, the Rocketdyne people will acknowledge that they could probably have gotten along with one-half the hardware in the earlier programs. This still leaves a disparity of a factor of five in available test hardware for the present program. This decision was made knowingly, the belief being that the more thorough planning, drawing and design control, etc., of the current program would obviate the need for more test hardware. It is important to note that the die is cast, the lead time for added test hardware is such that if it were ordered today it would probably not become available soon enough to help overcome problems and maintain the current schedule.

TABLE 1

PANEL ACTIVITIES RELATED TO THE SSME PROJECT

* December	1973	Rocketdyne Div./RI, Canoga Park, CA	First Major Briefing/Orientation
June	1974	SSME Quarterly Review, MSFC	Controller Special Review, MSFC
* July	1974	Honeywell, Inc., St. Petersburg, FL	First Major Briefing, Controller
* September	1974	Space Division/RI, Downey, CA	SSME Program Update
January	1975	SSME Major Management/Technical Issues	Telecon from MSFC to JSC
March	1975	SSME Associated Work at KSC, KSC	
* April	1975	SSME Subsystem Detailed Briefings, MSFC	(Part of Total MSFC Project Picture)
May	1975	Space Division/RI, Downey, CA	Special Topics Relating to SSME
August	1975	Space Division/RI, Downey, CA	Special Topics Relating to SSME
* October	1975	SSME Quarterly Review, MSFC Rocketdyne Div./RI, Canoga Park, CA	 Major Briefing/Discussions
January	1976	SSME Quarterly Review, MSFC	Staff Attendance with Briefing for Task Team
* March	1976	Rocketdyne Division, Canoga Park, CA	Major Discussion on SSME Test Program
* April	1976	SSME Quarterly Review, MSFC	Panel member attendance

* Major reviews were conducted during these sessions.

APPENDIX A: RESPONSE TO PANEL'S ANNUAL REPORT

STATEMENT

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 under way. 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 nondestructive 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 under way 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 under way. Engine tests will verify the POGO suppressor system. Extensive use has been made of Saturn data in designing the test program.

Engine Controller Performance and 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.

4.0 ORBITER THERMAL PROTECTION SYSTEM

Dr. William A. Mrazek
Mr. Howard K. Nason

4.0 ORBITER THERMAL PROTECTION SYSTEM

I. BACKGROUND

During 1975 and the first half of 1976 the Panel and the Orbiter Thermal Protection System (TPS) task team conducted detailed fact-finding sessions at JSC, Rockwell Space Division, and Lockheed, Sunnyvale. During this period, special attention was paid to the following areas:

A. Current requirements which dictate the type and coverage provided by the Reusable Surface Insulation (RSI), and the Leading Edge Structural Subsystem (LESS).

B. Tile materials and coatings.

C. RSI and LESS installation and maintenance, with emphasis on protecting doors and protuberances, and on sealing of aerodynamic control surface openings.

Our most recent meeting with those personnel responsible for the management and integration of the Orbiter TPS was on May 24, 1976 at JSC. Because of the interactions between the Orbiter TPS and other Shuttle elements it has come under review by other task teams to varying degrees, e.g., Ground Test and Flight Test task teams, Risk Management task team, etc., resulting in supportive efforts.

The following Orbiter TPS development milestones are noted in order to place the current state of the TPS in perspective.

A. TPS Design Review was conducted August 1975.

B. TPS Delta Preliminary Design Review was completed May 1976.

C. TPS Critical Design Review is scheduled for May 1977.

D. Certification for the first manned orbital flight test is scheduled for the first quarter of 1979.

II. OBSERVATIONS

Requirements for the design, fabrication and maintenance of the Orbiter TPS components have been firmed-up to the extent that basic materials have been selected, the TPS "design to" baseline for OFT #1 has been defined to assure a safe first mission, TPS failure effects have been explored, installation methodology is evolving, and development tests are supporting all of these efforts. An interesting example of RSI requirements are those for mission life for HRSI, LRSI and FRSI as noted below:

A. High Temperature Reusable Surface Insulation (HRSI)

100 missions for "acreage" tiles with maximum temp $\leq$ 2300°F

1 or more missions for elevon and nose tiles, temp = 2300° to 2500°F

1 mission for the body flap tiles, temp = 2500° to 2800°F

B. Low Temperature Reusable Surface Insulation (LRSI)

100 missions for all tiles with maximum temperature $\leq$ 1200°F

C. Flexible Reusable Surface Insulation (FRSI)

100 missions with maximum temperature under 700°F during entry

30 or more missions with maximum temperature under 750° F on entry, 830° F on ascent and over temperature capability on a single mission to 900° F.

Updating and refining of aerothermodynamic analyses has resulted in heating predictions which relax the requirements (heat loads and temperatures along with times of application) in some areas while tightening them slightly in others. The net effect is the increase in the area which can be covered with the FRSI (coated Nomex felt), and a decrease in overall TPS weight.

Substantial progress has been made in tile moisture proofing, coating, bonding and installation. The method for depositing the moisture prevention material has been changed to vapor deposition thus expanding the kinds of materials that can be considered. A new polymer, vapor deposited, has been sufficiently tested that its timely full qualification can be expected. The unexplained cracking of the Lockheed 0050 coating has resulted in its being replaced on the HRSI by the Ames Research Center (NASA) RCG coating. Lockheed 0050 coating still is to be used on the LRSI tiles. After early problems with the manufacture and storage of the basic glass for tile production, Johns Mansville has now produced material that appears to be satisfactory, with a substantial reduction in voids and inclusions. It is emphasized that this is not a hazard or safety problem, but a problem of producing smooth surface tile which affects bonding and installation time. A method has been evolved by Rockwell's Space Division to provide computer-based contours to Lockheed, which are used to machine the external (exposed) faces of the tiles. In addition, a system of grouping tiles in an assembly fixture has been worked out so that the entire cluster can be machined to proper contours as a unit. The same fixture is used to transport the tile and to hole it in arrays for attaching to the Orbiter skin. Finally, the assembly system includes the masking of one row in the fixture so that this row is not glued to the surface. It is removed to provide edge room for the adjacent fixture and the retained tiles are then inserted and fixed to the surface after the arrays are installed. An improved system for bonding the tiles to the Strain Isolator Pads (SIP) and then to the Orbiter skin should be verified by September 1976.

Orbiter penetrations, doors and dynamic seal areas continue to receive a great deal of attention. Such locations include: payload bay doors, vent doors, main and nose landing gear doors, LESS to RSI interfaces, wing/elevon, aft fuselage/body flap, and rudder/speed brake gap areas. In resolving the problems associated with these dynamic areas, a "brush" type seal using silica fibers was tried and has been found unacceptable and alternate designs are being investigated. The nose gear door has been redesigned to eliminate some problems experienced with sticking due to thermal sealing.

III. ASSESSMENTS AND RECOMMENDATIONS

At the present time, a number of previously nagging issues have been resolved yet a good number remain. These are caused in part by the technical problems and in part by the schedule-budget tradeoffs that have had to be made.

A. Current experience with the RSI shows that is has low resistance to ground handling damage, but a good capability to sustain damage without catastrophic failure during induced environmental exposure. The RSI installation is cost-schedule sensitive with respect to (1) tile gap and step criteria, (2) tile geometry, and (3) installation techniques.

B. The tile material itself appears to be satisfactory from the standpoint of production and processing. However, the program to fully characterize structural capabilities has been delayed. This can result in the delivery and installation of tiles on the Orbiter before full confirmation of its adequacy. The risk appears to be acceptable from a safety standpoint as long as the data for confirmation are obtained before first flight.

C. Concerns associated with the LESS include the ability to maintain required gaps and steps between the Reinforced Carbon-Carbon material (RCC) segments and the interfacing HRSI tiles (concern about early tripping of boundary layer). Additional concerns include mission life capability, and cracks on the nose cap shell observed during development testing.

D. The ability to adequately protect vehicle openings from the high energy plasma during entry has yet to be proven. This appears to be receiving adequate attention, but may require some redesign effort, prior to the first OFT, which is not contemplated at this time. This may also serve to expand the current Development Flight Instrumentation requirements.

E. The first orbital flight test mission, OFT #1, is to use trajectory shaping to minimize the total heat load and structural bonding layer temperature, and at the same time to accommodate trajectory dispersions, early boundary layer transition and the uncertainties associated with the TPS predicted performance. This should assure first mission safety.