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

part I —observations and conclusions

june 1976

AEROSPACE SAFETY ADVISORY PANEL

Mr. Howard K. Nason (Chairman)
President
Monsanto Research Corporation
St. Louis, Missouri

Hon. Frank C. Di Luzio
Assistant Director for Planning
University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Mr. Herbert E. Grier
Consultant and former
Senior Vice President
EG&G, Inc.
Las Vegas, Nevada

Dr. Charles D. Harrington
Board of Directors
United Nuclear Corporation
Pasco, Washington

Hon. Willis M. Hawkins
Senior Advisor
Lockheed Aircraft Corporation
Burbank, California

Lt. Gen. Warren D. Johnson, USAF
Director
Defense Nuclear Agency
Washington, D.C.

Mr. John L. Kuranz
Senior Vice President
G. D. Searle & Co.
Des Plaines, Illinois

Mr. Lee R. Scherer
Director
NASA Kennedy Space Center
Florida

CONSULTANTS

Dr. Seymour C. Himmel
Associate Director,
Flight Programs
NASA Lewis Research Center
Cleveland, Ohio

Dr. William A. Mrazek
Former Director of Engineering
NASA Marshall Space Flight Center
Huntsville, Alabama

STAFF

Mr. Gilbert L. Roth
Special Assistant
NASA Headquarters
Washington D.C.

Mrs. V. Eileen Evans
Administrative Specialist
NASA Headquarters
Washington, D.C.

Mr. Carl R. Praktish
Executive Secretary
NASA Headquarters
Washington, D.C.

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.

CONTENTS

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.

5.0 AVIONICS MANAGEMENT

Mr. Herbert E. Grier
Hon. Willis M. Hawkins

5.0 SHUTTLE AVIONICS SYSTEM

I. BACKGROUND

The Avionics System for the Shuttle is the combination hardware/software system which controls and directs the Shuttle flight. Through its sensors, computers, and interface units it coordinates and implements all functions of the flight except for the specific control of the engine which is done by a separate computer system built onto the engine. The computers of the Avionics system are the nerve center of the Shuttle, and hence must function for the flight to be performed. Appropriate redundancy is built into the system and provision has been made for manual as well as automatic input. The matter of redundancy is not simple, in that the software system itself is a single point failure item except in part for the backup guidance program. This fact is the driver that makes the verification and testing of the software so important in order that the postulated redundancy will be realized.

Because of the criticality of the Avionics System and the inherent challenges in managing this area, the task team meets frequently with the various organizations at the Johnson Space Center and the hardware and software contractors. In addition the team meets with the technical assessment group at JSC and the Chief Engineer to discuss their reviews of this area. Inspection trips are made to both ADL and SDL integration laboratories.

II. OBSERVATIONS

The current state of the system is that the hardware has been designed and procured. Equipment is coming in and is being de-bugged and operated in the ADL and SAIL laboratories both at Rockwell and at Johnson Space Center. There are hardware and system problems that are being worked diligently and that should be monitored, (e.g., the limitation on Avionics cooling), but the quality of the hardware seems to be very good in light of the stage of the program.

With the hardware in the stage it is in, emphasis has gone to the integration of the various elements and the requirements for their proper operation which, in total, constitute the specification for the software system. There has been an initial design of a software system, but as specific component data become available and mission requirements become more firm, variations or new input must be expected in the software system. These variations are the basis of our concern with the Avionics System.

The computer system in the Shuttle is complicated, and verification of the software is difficult to quantify. In fact, the confidence in software verification is directly proportional to the time spent in such verification; that is, the thoroughness and extent of the verification procedures. In general, one is not confident to say that a software system is reliable unless it has been extensively used.

The criticality of the software system and the difficulty of quantifying its verification make it mandatory to have an independent assessment of the software. Current proposals are to program the testing at ADL and in SAIL so as to perform a complete, independent check of the software. This is a good plan and it must be implemented in a timely manner, and then changes must be rigorously controlled.

The major problem with the Avionics software system is two-fold. First, the tendency of hardware people to solve anomalies in their hardware by changes in the software; and, second, the better definition of the specifications for mission operations which results in a greater software requirement than was initially contemplated for the system. Both of these factors, and particularly late timing, affect the degree of confidence that one has in the formal verification. It is imperative that the computer groups have sufficient time for the software verification, and the simulation laboratories have time to check as deadlines approach. While the first orbital flight is some time away, the ALT flights are almost upon us. The organizational structure to police and drive this program is not readily apparent.

In the course of our discussions several factors became obvious. The first was that the NASA management system is geared to establish communications and coordinate the activities of a number of entities at different locations. However, it does not adequately identify a specific Avionics responsibility. This system, through its various reviews and panels does, in fact, successfully accomplish a major task of integration, but it is ponderous and time consuming when it must respond to specific, immediate problems in real time. The people in the total system are for the most part very experienced, and an informal system of coping with the real time technical problems has grown up. This system is absolutely vital in that it rings the bells to alert the formal system and supplies the input necessary for the more formal deliberations. This informal system should by no means replace the formal system, but it should be recognized, directed and integrated if the overall structure is to be optimized. From an academic point of view an informal system, with its undefined responsibilities, can sometimes result in balls being dropped, particularly with inexperienced people. We must hasten to say that we feel because of the quality of the personnel the present system is working well. It could perhaps be better defined. We feel that program management recognizes this, that the recent strengthening of the Avionics integration activity will help and that the recognition by the technical assessment group of the importance of the Avionics problem is a good sign. In discussions with the technical people it is quite clear that the integration laboratories (ADL and SAIL), wherein hardware is operated in systems of varying configurations, are very useful tools. These laboratories provide a real communication channel between all the elements involved in the particular system or subsystem being tested. The joint experience gained here is essential in establishing confidence in the Avionics system and is absolutely necessary as an independent check on the computer software verification.

The whole matter of computer programming and verification is perhaps the element of the system most difficult to assess. The nature of the system and of the current stage of the program inhibits the development of firm computer program requirements. As more simulation experience is generated, for instance, the detailed requirements of manned versus automatic flight undoubtedly will change, resulting in program changes. In addition, the ALT flights will certainly produce data which will require modifications to the programs. As these modifications or new requirements are defined, a continuing effort must be established to police the overall computer program. There is a limit, and there are indications that requirements may exceed the computer capacity. The response to such a situation must not reduce the redundancy built into the computer system.

Verification of a computer program is a subjective and iterative process and it is not easy to assign a confidence number in the same sense that one does with hardware. It is particularly difficult for the Panel to achieve an assessment in this field. It would be helpful if a single individual were placed in charge.

III. ASSESSMENT AND RECOMMENDATIONS

The conclusion of reviews to date is that the hardware in the Avionics system is in reasonable shape and that it will perform properly. The software system is currently in a state of flux and is now being given attention, in an effort to scrub down or assign priorities to the requirements and to examine opportunities for simplification. We feel a centralization of control of the software in the program would be beneficial. It is quite clear that because of the reduced requirements on the system for the ALT tests, the load on the computer system is eased. However, confidence in the adequacy of the software, even for this simpler flight program, has still not developed and the Panel must monitor the software program assiduously between the present time and the ALT test.

One conclusion is positive. The Shuttle team, on both the contractor and government side, is composed of experienced, competent people. This fact establishes confidence in the overall program, and assures us that given enough time any contingency can be dealt with properly.

Our recommendations are:

A. A competent, knowledgeable person should be assigned at the

Program Office level to perform the function of Chief Engineer-Avionics. This may well be the recently appointed Manager, Orbiter Avionics Systems, if he has the central responsibility for the software and the system that it knits together.

B. The program of testing and simulation of the Avioncis system should be given a high priority as it forms an independent verification of the software. An additional important benefit of such testing is that it involves a great number of subsystem designers and will form a valuable, real-time communication link in the technical management and integration system.

C. The technical assessment group should establish an appropriate effort to quantify and assess the degree of confidence one can assign to the planned software verification. In our opinion this group should be supplemented by outside experts in the software systems verification field.

D. The recent emphasis on the responsibility of the Avionics Integration Office was a move in the right direction and, if appropriate, further efforts should be made to more clearly define specific software responsibilities.

E. Future actions of the Panel should be limited to monitoring progress of the system so as to judge the state of readiness prior to ALT and the first orbital flight. Should the Panel be expected to assess in detail the software verification, it will need to be supported by an expert in that specific field.

6.0 RISK MANAGEMENT

Dr. Charles D. Harrington
Mr. Herbert E. Grier
Mr. Willis M. Hawkins
Mr. Lee R. Scherer

6.0 RISK ASSESSMENT

I. BACKGROUND

A task team has been formed to review the risk management system and its handling of specific challenges. The task team obtained its information by meetings at JSC and the principal contractor with both managers and the specialists working for them. These meetings were held in September and November 1975, and February and May 1976. Numerous written reports also were provided to substantiate decisions and to demonstrate the procedures used to assure that safety problems are evaluated adequately.

II. OBSERVATIONS

The areas reviewed included the management system for application of lessons learned from prior programs to Shuttle and the specific cases of the controlled use of teflon insulation, of 26 gauge electrical wiring and of threaded fasteners. The Panel also reviewed the approach to crew and range safety. Finally, we reviewed the approach to assessing and controlling the aggregate or toal risk on the program.

A. Lessons Learned

The subject of lessons learned is a complicated one. Obviously, a lesson must first be identified as such and there must be agreement as to the proper steps to avoid further occurrence. Once these two steps are properly taken it appears that adequate procedures exist to track the correct application.

Retention methods are:

a. JSCM 8080 - Standards and Criteria

   These are imposed when applicable on subcontractors.

b. AFSC Handbook DH-1-6

   This contains checklists and safety techniques and is used by JSC safety division for checklist inputs.

c. Various JSC Experience Retention Documents

   Examples are:

   84 Apollo experience retention reports
   JSC 09096 Lessons Learned Skylab
   JSC 0134 B Space Flight Hazards
   JSC 02681 Non Metallic Materials
   JSC 08980 Field Experience Data
   Mission Assessments (Safety), Apollo 7 through ASTP

In addition a lessons learned document has been prepared which states whether the lesson is applicable to Shuttle and how it is to be dispositioned. This document should be continuously updated and safety reviews of Shuttle compared with it. As of June 10th, 1975, the document showed 476 lessons applicable. The question of the proper steps to take to avoid further occurrence is a much more difficult one. For example, the question of man-in-the-loop versus full automation appears to be subject to fine tuning decisions, with some differences of opinion still existing.

B. Use of Teflon

The use of Teflon is being carefully tracked. It is felt to be the safest insulation material available (where the requirements suggest its use) as long as it is not exposed to temperatures high enough to cause decomposition. There appears, therefore, to be little effort to restrict its use where it is otherwise advantageous. A possible exception is the use inside the oxygen tank of the External Tank. This was originally felt to be safe since only instrument signal current is carried by these wires. However, at the time of the task-team meeting on February 9, 1976, consideration was being given to replacing this section with stainless steel coated, ceramic insulated wiring (as was done in the Apollo oxygen tanks) despite the appreciable weight penalty. Since then the possible acceptability of TFE plastic is being investigated. This reconsideration is occasioned by updated thermal analyses which showed that high temperatures ($500^{o}F$) may be encountered in use. This item had been closed out in the December 10, 1975, Major Safety Concerns Document (JSC 09990) based upon engineering data and, when appropriate, initiation of new or more extensive engineering analyses. It also illustrates the necessity to maintain a vigilance over revised data and the effect on closed hazards. In this instance, the review system worked when the hazard was reopened.

The cold flow characteristics of Teflon are said not to cause any problems for Shuttle applications. This issue arose during Apollo fabrication days because of a bad batch of Teflon which was not typical of good quality material. Since then, acceptance tests have been introduced to apply to each new batch of Teflon to assure that no material will be accepted and used in Shuttle which may be deficient in cold flow characteristics. As a result this will no longer be considered a limitation on the places where Teflon may be used. In addition there are firm controls and requirements (Rockwell Space Division Specification ML-0303-0029A and ML-0303-0013 , and Martin Specification STP 6506) which relate to minimum bend radius, clamping force, sharp edges, wire bundle sleeves for protection, harness routing, etc. Rigorous inspection verifies this. Thin walled Teflon has a protective top coat of polyimide resin which restricts cold flow.

C. <u>The Use of Small Gauge Copper Wire</u>

Because of the problem on Apollo with breakage of 26 AWG copper wire the use of this has been largely eliminated, replacing it with 22AWG or heavier. However, in an appreciable percentage of the total footage (2%-8%) it has been found impracticalbe to use wire this large and stiff. Where 26AWG wire has been used it has been made of an alloy of copper having considerably higher tensile strength. It has also been bundled together so that no individual strands can be flexed and broken. OV 101 is being built in this manner. The Panel feels that this problem has been handled properly.

It should be noted that there are many manufacturers' items such as instruments and black boxes which may contain much finer wires. However, these are firmly attached and protected and are not subject to flexing or other mishandling during installation or use. The Panel is satisfied that the design is proper.

D. The Controls on Threaded Fasteners

The Panel found that NASA and its contractors procure fasteners from a variety of sources which meet NASA and DOD specifications. In the manufacture of these fasteners the single element method of gauging is almost always used because it identifies, for the manufacturer, changes in the shape or quality of the threads and alerts the manufacturer to tool and roll wear before the fasteners get out of specification. It is to the manufacturer's economic advantage to use this system since his rejection rate is decreased (i.e., product consistently is of high quality). In addition to gauging, the manufacturer invariably uses an optical comparator and does metallurgical and physical tests on the materials. This whole procedure, statistically applied, insures shipment of high quality fasteners at the minimum price consistent with that quality.

After certification the user, i.e., NASA or its contractors, is primarily concerned with whether a fastener falls within an acceptable envelope of tolerances which can be measured quite rapidly with go-no go gauges. If the fastener does not meet this test it is returned to the vendor for analysis and replacement. While this might appear to be an arbitrary procedure it is not, because the major factor affecting the failure of a fastener is the proper application of that fastener. Proper application is the facet of the problem that NASA and its contractors must control. Such factors as out of tolerances of parts, insufficient radii at corners, and improper torquing of the fastener more often are responsible for failure than are minor variations in the shape of the thread. We do not believe that one can document a single failure due solely to the threads themselves when they have passed a go-no go inspection. Failures almost always are due to improper application of the fastener and, in a few cases, to a material or metallurgical problem. The improper application of a fastener is prevented first by proper engineering design and review, and second by assembly inspection to see that the proper tolerances are present in the fastened parts and that the correct fastener and torque have been used. The metallurgical aspect of the problem is taken care of by chemical and metallurgical tests as a part of incoming inspection.

The experience of NASA and the DOD, over many years, has resulted in a statistical testing program on fasteners which NASA and its contractors observe. An analysis of these procedures has been made by NASA and the Panel has reviewed it. In our opinion the program being followed by NASA and its contractors is appropriate and results in the proper degree of safety. We feel that this has been demonstrated by the performance of past NASA projects and by the immense experience of DOD. We further feel that should a fastener failure occur, it almost always will be traced to causes not controlled, or indicated, by the gauging systems.

E. Crew and Range Safety

During launches of the initial Shuttle missions, ground command and destruct capabilities exist on the External Tank and on each SRB. The Orbiter Main Engines cannot be shut down by ground command.

The crew cannot inhibit ground destruct, but are provided warning in advance of such action. Two ejection seats are provided for the crew. Use of ejection seats and of ground destruct devices after the initial missions still is the subject of considerable controversy. There is no precedent in previous programs, since the Shuttle system is a combination of launch vehicle and transport aircraft. Additional complexities result from the split responsibilities between Shuttle program managers and national range commanders, and from the fact that later operational missions will carry "passengers", for whom ejection capability probably would be impracticable.

It is the opinion of the Panel that planning for future missions should proceed with a fundamental ground rule that the capability for destruct by range safety personnel and the capability of escape by all people onboard go hand-in-hand.

Under current plans, adherence to this ground rule would mean that both ejection seats and destruct systems will be removed when more than two people are on board. It seems reasonable that removal of such devices will be an acceptable risk after demonstration by a few successful flights.

F. Response to Recommendations on Hydraulic Fluid

The Panel earlier had recommended that the choice of hydraulic fluid be re-examined.

On November 18, 1975, detailed presentations were made on the comparison of Yellow Oil (MIL-H-83282) and Red Oil (MIL-H-5606) for use as hydraulic fluids. These comparisons showed that Yellow Oil appeared superior to Red Oil in regard to flammability over a narrow temperature range and under certain physical conditions. In some other respects, such as corrosion and low temperature viscosity, Red Oil was superior. The decision has been made to stay with Yellow Oil due to its lesser fire risk. Precautions will need to be taken to keep out water (corrosion) and to avoid excessively low temperatures.

G. The Risk Management System and Aggregate Risk Assessment

The Panel found a well-developed independent hazard identification and risk assessment system, the members of which participate in program decision making. They provide formal reports to program management such as summaries of major safety concerns and of the actions being taken to assure management awareness. They have also just completed the initial mission safety assessment report for the ALT flights.

The Panel gave particular attention to management control of both the total or aggregate risk on the program as well as the control of specific hazards.

Aggregate risk has been defined by the JSC Safety Division as the sum of the effects of hardware and operational hazards upon the event, series of events, or mission, and is measured in terms of adverse impact on personnel or critical equipment. The management approach to this assessment is through the safety concerns procedure. In this procedure all inputs to safety questions, including RID's are examined through System Level Hazard Analysis, in preparing the Shuttle level SAR, and screened by a Criteria Committee. They are either resolved through modifications or accepted as risks. They become part of the Safety Concerns Index and Safety Concerns Summary Report and as such are direct input to the Mission Safety Assessment. The latter becomes the true evaluation point for aggregate risk assessment. It appears that this procedure is adequate from a management point of view to assure that all safety issues, once identified as such, are properly tracked and assessed.

While major hazards are brought before management for their evaluation there is also the question of how you control minor risks and evaluate their impact on the level of aggregate risk being accepted in the program. This is no simple matter because management cannot review every decision and there are not the resources to work every "what if" situation. Therefore, the task team has been in discussions with the safety offices on how to strengthen controls or audits in this area. As a result additional controls have been instituted.

The Screening Board for the "Major Safety Concerns Document" has been passing judgment only upon those issues which are considered significant safety drivers and hence has not reviewed those having little impact. To perform a check of the disposition of these minor risks, the Screening Board has instituted a new procedure whereby it will include an audit of twenty minor issues at each Screening Board meeting to determine that they have been properly evaluated and dispositioned. If the audit reveals deficiencies, a more extensive investigation will be completed. It should be noted that Board membership has been recently revised to include KSC and MSFC representation. The method of assessing the total impact of these risks is to track the safety issues for satisfactory closeout and to report on them in the Mission Safety Assessment Documents. These documents contain the Safety office's judgment on the acceptability of the "aggregate risk." This is a subjective, rather than quantative, evaluation of the cumulative accepted risks and actions being taken to resolve open items.

The Panel met with senior program management to review their approach in developing policies that determine the criteria for risk assessment and decision making at subordinate levels. These discussions also included senior management's approach to decision making at their level where it has been their judgment to accept risks. The Panel was both reviewing critical decisions that have already been made and re-inforcing management's controls to assure that safety not slip from its normal top priority because of cost and schedule pressures in the period ahead. Among the points made by management in these discussions were:

1. Decisions involving any significant reduction in program requirements are reviewed by senior management to assure a judgment that is objective and sensitive to the requirements of public accountability. This is evidenced by the way the decision was made on contingency abort capability during the SRB burn period.

2. Any decision on safety is a judgment on how far

to go to enhance or guarantee safety. There are specific areas where safety margins have been reduced but the management judgment is that the margins are still sufficient.

3. Redundancy is not synonymous with safety because the complexity of a redundant system may introduce new hazards that reduce the overall safety of the system. Excess redundancy, or appended protection systems, may cause engineers to produce designs that are not optimum but depend upon these additions to make them acceptable.

4. The number of single failure points that could cause critical situations are not greater than in Apollo or Skylab. In fact, Shuttle has a higher safety factor because of the flexibility available to terminate the mission.

5. Aggregate risk is hard to measure but the program is making a conscious effort to identify the magnitude. The Mission Safety Assessment document is one judgment. The program SR&QA people are preparing a form of aggregrate risk assessment associated with the program requirements review results.

6. The ground test program provides the best assurance that we understand the system, its capabilities and limitations. While some changes have been made in the test program, piggybacking tests or deferring them, basic requirements have not been compromised.

7. The ALT flights and the subsequent orbital flight

program will develop confidence in the vehicle. They provide for moving into situations of greater risks in carefully considered increments, so that the new risk on any one flight is acceptable or cannot reasonably be reduced further.

III. ASSESSMENT AND RECOMMENDATIONS

The Panel's judgment as to whether the total aggregrate risk is acceptable can only be arrived at over the course of time after careful study of the mission assessment documents and other pertinent data. Once the program is beyond the development flights and is in the operational phase, aggregate risk should be minimized by experience and by the repetitive nature of the flights. Safety questions which the Panel considers significant are being worked, although the resources available may not permit in-depth investigation of all minor issues.

The concept of re-usability introduces a new type of risk in the Shuttle program which was not encountered in previous, single-shot programs. For example, the TPS and the landing requirements introduce a number of safety problems for which experience is lacking.

The final aggregate risk assessment should focus heavily on "what if" questions.

7.0 GROUND TEST AND GSE PROGRAMS

Lt. Gen. Warren D. Johnson, USAF

7.1 GROUND TESTS

I. BACKGROUND

The Aerospace Safety Advisory Panel has studied NASA philosophy pertaining to the entire Space Shuttle System, the "Space Shuttle Verification Program" and particularly the ground tests aspects of that Verification Program. Since the Panel has been in existence for several years and was involved in Apollo, Skylab, and the recent joint US-Soviet Apollo-Soyuz space flight, an inevitable comparison with these programs is made and, indeed, the uniform approach to testing reflects NASA experience. Past NASA programs have been eminently successful. Yet even NASA has suffered temporary failures, and the Panel was created as a result of a disastrous accident. The Panel is conscious that NASA faces a need for major cost reductions in order to stay within programmed costs for the Space Shuttle program. This cost reduction effort could impact on safety unless management review is thorough. A part of our examination focused on this possibility.

The Panel is examining the Ground Test Program as it pertains to preparation for the Approach and Landing Tests, to the Orbital Flight Tests and eventually the operational orbital flights. Activity to date has concentrated on the pre-operational phases. The major effort has been to assist NASA in assuring the Space Shuttle System will fly safely as a space vehicle and as an aircraft when it reenters the atmosphere to return for landing. In gathering data we have studied the planned Space Shuttle Verification Program, some individual ground tests, and the Hawkins Review to identify possible problem areas. Based on those studies, visits to Rockwell and the Johnson Space Center have been made.

As previously indicated the Space Shuttle Verification Program, and specifically the ground test portion, is based on past highly successful NASA programs. Experienced NASA management has designed and tracked the program since the go-ahead for Space Shuttle was given in 1969. There is a strong reliance on this past experience and an excellent use of "lessons learned." However, major NASA programs in the past have dealt with Space Vehicles, one time flights, and better funding priorities. Moreover, past programs were experimental in nature as opposed to operational. Thus, new problems can be expected.

The Ground Test Program is extensive. Obviously, the Panel cannot examine all details, nor is that desirable or necessary. The Panel's contribution should be to identify areas in which there are risks not faced in past NASA programs and/or areas in which previous difficulties have been encountered. Activities to date have identified these priority areas for Panel examination.

II. OBSERVATIONS

The Ground Test Organization appears adequate. The Test Organization is sufficiently distinct from the organization which designed the Shuttle. Thus, testing objectivity should be assured.

It also appears that there is a reasonable mix of space vehicle and aircraft experience. Rockwell is applying its considerable aircraft expertise to the Space Shuttle Systems, as well as its space experience. They realize the Orbiter must perform as a space vehicle and an aircraft. NASA has an adequate mix of Space experts and pilots who have flown and tested aircraft, including "lifting bodies" with shuttle-like characteristics. The astronauts are deeply involved in the planning and the ground test programs. Throughout NASA there is a reasonable balance of scientists, engineers, engineer-pilots, and other skills. Cost reduction efforts and ensuing personnel reductions have, as yet, not destroyed this core of capability.

An adequate interface between Rockwell and subcontractors appears to exist. The Rockwell organization indicated a realization of the responsibility for monitoring tests conducted by subcontractors. Any test failure must be reported within 24 hours and Rockwell monitors compliance. This will be further checked by the Panel in visits to subcontractors.

Because of funding constraints, some tests have been cancelled.

It appears, however, that management has provided an adequate review of the risks involved in each such reduction.

III. ASSESSMENT AND RECOMMENDATIONS

The Ground Test Program as originally envisioned had a larger scope of full scale model tests. In the reduction a greater reliance was placed on quarter (1/4) scale model tests. Additional cost reduction efforts have led to some modification of 1/4 scale model tests. Also, some originally scheduled test conditions changed due to lack of availability of components. Planned full scale model tests were directly related to 1/4 scale model tests - designed to provide a one-to-one comparison in such areas as Influence Coefficient and Stiffness Characteristics. The lack of these one-to-one comparisons could have an adverse impact. Management is aware of these reductions and has assessed the risk.

The Panel was concerned with the adequacy of structural testing prior to ALT and has inquired into this at some length.

A. Structural testing of the Orbiter was compared to the testing of the Boeing 747, the Douglas DC-10 and the Lockheed 1011 (similar wide body aircraft). The two former were tested to a greater extent. The 1011 testing was more limited and would tend to indicate that the Orbiter test plan is adequate.

B. ALT will not include thermal and ascent stresses which will be encountered in orbital flights. Structural analysis prior to ALT assumes these stresses are present, thus creating a margin of safety. However, actual structural tests will not be completed prior to ALT.

C. The Orbiter will be limited to 75% of structural loads (limiting weight and G-forces), during the ALT. The extent of ground tests in this respect is somewhat less than that to which wide body aircraft have been subjected prior to first flight. Perhaps requirements for wide body aircraft are not appropriate for Shuttle. On the other hand, even higher standards might be appropriate. It is suggested that this be a subject for a later meeting of the entire Panel.

There is concern about the testing for the Payload Bay Doors. It is clear that failure to close these doors would preclude safe reentry. Many steps are being taken:

A. NASA (JSC) is making a comprehensive study of the history of "jams."

B. Conservative "overreach" is planned.

C. Many tests are planned.

D. EVA capability is being planned. Tools are being considered and an EVA working group exists.

1. However, some payloads could preclude access by EVA.

2. There is some indication that test payloads during early Orbital Flight Tests are being considered that could interfere

with manual back-up for closing payload bay doors. Recommend no such payloads be permitted during early OFT.

No schedule margin exists in the event any major problems are encountered in ground testing. This is a success-oriented program and any major problems will impact dollars and schedules. This could induce shortcuts that have safety implications. The Panel should examine any major test failure and/or change in the test program in order to act as an additional safeguard to the normal NASA management review.

The review of changes and deletions to the Ground Test Program appears to have been adequate to date. Further budget constraints or a major problem could induce more changes. The Panel believes the "point of diminishing return" must be close for changes in the Ground Test Program. Thus, such changes should be brought to the attention of the Panel as soon as they are defined.

7.2 GROUND SUPPORT EQUIPMENT

I. BACKGROUND

Planning for and acquisition of Ground Support Equipment are largely management problems as opposed to safety issues. However, the Panel notes that such equipment acquisition for various past programs traditionally has been the first to suffer in budget cuts. Moreover, planning is difficult in the early stages of a program, pending development of a firm maintenance baseline. Thus when cuts or changes are made, little time remains to adjust, and equipment deliveries often lag operational requirements. Some safety impact may then result, especially when ground handling and turn around are so dependent on specialized and sophisticated equipment.

The planned turn around of 160 hours would be made more difficult to attain if equipment were not available in the configuration and numbers required.

Orbital Flight Tests could be hampered if Ground Support Equipment were not available. Delays in flight tests could be costly and/or could impact on safety if shortcuts are attempted.

It appears prudent to examine whether the pressure to achieve the 160 hour turn around could create safety problems.

If inherent safety problems exist in the interface between Ground Support Equipment and flight hardware, the Panel wishes to identify them and assure itself these hazards are given adequate attention.

II. OBSERVATIONS

JSC and KSC are aware of the criticality of Ground Support Equipment and of their responsibility for integration. Both are developing detailed planning for such equipment, considering life cycle requirements and hazard analyses across the interface with flight hardware. Both centers are working closely with the Air Force, which eventually will operate the Space Shuttle System from Vandenberg. Air Force personnel are on hand at JSC and KSC for this purpose.

All seem to be aware that the 160 hour turn around forces better planning for support equipment. However, they assert that they are guarding against the possibility that the turn around requirement could influence shortcuts. They clearly state that the 160 hour turn around is a goal for the operational phase and that it will not be attempted in the orbital flight tests or in early operational flights.

Planning is tied to vendor (subcontractor) availability. If a vendor's production line is planned to be closed or reduced, JSC plans to review the need to acquire support equipment prior to any such action.

Most testing during Orbital Flight Test and in later operational flights is planned to be accomplished on-board the Orbiter, as distinguished from bench checks in a separate facility. Before attempting to repair a black box the malfunction will be clearly identified.

III. ASSESSMENT AND RECOMMENDATIONS

The Panel should continue surveillance of Ground Support Equipment and should examine the interface of some of the more critical items with flight hardware.

Panel interest should focus initially on equipment required for auto land tests. (Subcontractor equipment is planned to be used to cover most requirements for this and Orbital Flight Tests.)

The Panel also should follow changes and/or reductions planned for support equipment, assuring that NASA reviews of such actions consider all risks involved. (The NASA review process should equal that for changes in the ground testing program.)

The Panel should question planning for Ground Support Equipment as it visits selected vendors (subcontractors) and NASA centers.

8.0 <u>FLIGHT TEST PROGRAM</u>

Mr. John L. Kuranz
Mr. Lee R. Scherer
Lt. Gen. Warren D. Johnson, USAF

8.0 FLIGHT TEST PROGRAM

I. BACKGROUND

The Panel undertook to study the Approach and Landing Test Project for the purpose of assessing the value and risks, in order to determine if programming and/or management system changes should be recommended to meet the primary test objectives. We believe these objectives to be valid; they are:

A. To verify operational capability of the mated ferry configuration.

B. To confirm the subsonic aerodynamic characteristics of the Orbiter and verify piloted and automatic approach and landing concepts.

C. To correlate wind tunnel data and flight data. An integral part of the Panel's study was the examination of potentially hazardous conditions associated with the design or operation of both the flight and ground systems.

The Panel's most recent meeting with ALT management was May 24-25, 1976 at JSC. This was preceded by the following activities:

A. Met with ALT and Carrier Aircraft project officers at JSC on November 18-19, 1975. Detailed discussions on the 747, Orbiter 101, mated configurations and most current test and analytical data supporting the ALT requirements and management decisions.

B. Session with ALT project personnel at Rockwell International at Downey, California on October 29, 1975. Discussions related to

Rockwell International's participation and implementation of their role in the ALT project.

C. Shorter but significant fact-finding sessions were conducted in Washington at NASA Headquarters on August 28, 1975 and at KSC on December 3, 1975. These served to provide an overview of the ALT project and indicated where further examination would be fruitful.

D. Attendance at the Orbiter ALT Critical Design Review conducted at JSC on April 21, 1976.

E. Panel review and task team sessions at JSC, February 9-10, 1976.

These activities served to provide a well detailed and up-dated background for further fact-finding and gave an integrated perspective to the Panel. Included were major achievements that contribute to program management's confidence in achievement of ALT objectives.

In addition to these face-to-face sessions, numerous program documents were supplied, including the ALT Project Management Plan which, together with the candid and helpful dialogue with program managers and engineers, allows the observations and assessments which follow.

Before reading the section of this report covering observations and assessment, it is worthwhile to review the ALT Project background. ALT covers only a small portion of the Shuttle Verification Program.

Orbiter 101 and a modified Boeing 747 will be used for these tests. Orbiter 101 configuration will be oriented toward the subsystems required for subsonic atmospheric flight. For the most part it will not include subsystems required for space operations. Although not carrying actual payloads, the Orbiter 101 will employ simulated payload structure adequate to demonstrate the effects of payload weight, center-of-gravity, and inertia on approach-and-landing performance. The ALT project includes vehicle ground tests before the first drop flight, preliminary flight evaluation, flying quality investigation of the launch combination, the separation and the Shuttle subsystem verification, and demonstration of the unpowered approach and landing.

II. OBSERVATIONS

The Shuttle program by nature of costs and schedule constraints is a success-oriented program. This is exemplified by the assignment of a single Orbiter and a single carrier aircraft to this program and the use of the carrier for all future ferry-type operations. Major schedule perturbation would result from mishaps or system failures which could occur during the ALT process. The goals of the program appear to be proper, however, and the tight planning does not at this time imply any increase of risk to the crew during this test series, in ferry operations or in the orbital flight tests that follow the ALT.

It appears that the flight performance data and overall experience to be gained during the ALT activities as currently planned do justify performing this series of tests. This viewpoint is based on an assessment of the risk of performing the ALT versus the risk in eliminating it. While the Panel believes that no single flight test requirement for ALT would in itself justify the program, we believe that it is justified by the aggregate results.

The continuing effort of Shuttle management to utilize the ALT project to its fullest has been a forcing function in establishing details of the ALT. For example, the configuration of the hardware and software is such that it will have the capability of meeting alternate configuration options, tailcone on, tailcone off, etc., depending upon the results of the first few captive and free-flight tests.

Current plans now call for five tailcone on and three tailcone off free flights in addition to the original captive inert and inactive flights. The use of the tailcone on the Orbiter is the result of wind tunnel tests and detailed analyses which show a high degree of 747 tail buffet with tailcone off as the Orbiter is being carried on top of the 747. Significant effects of this buffeting are:

A. Fatigue of the 747 tail area P. However, based on wind tunnel tests and analyses, the structural capability will not be exceeded.

B. The possibility that the mated configuration buffeting will adversely affect flight control, as well as the 747 crew's ability to accomplish required maneuvers.

The ALT management system was discussed in some detail with both the NASA and contractor personnel during the fact-finding sessions. It appeared that the management system, including the reviews and information flow, has been effective in supporting the ALT project; however, there was some indication that not all current information had been communicated on a timely basis. The ALT CDR identified this problem and adequate steps are being taken.

III. ASSESSMENT AND RECOMMENDATIONS

A. The Panel agrees that an adequate Approach and Landing Test Project is necessary to the orderly and safe development of the Orbiter, the ferry utilization, and other aspects of the overall Shuttle program, both ground and flight.

B. The information gained from the ALT is important to the confidence level required in making the first manned orbital flight with the full Space Shuttle system. The value of the ALT project though, is wholly dependent upon the results of each individual step within the project. A willingness to alter the test program flights as data is collected is expected, which will enhance the synergistic results from all tests.

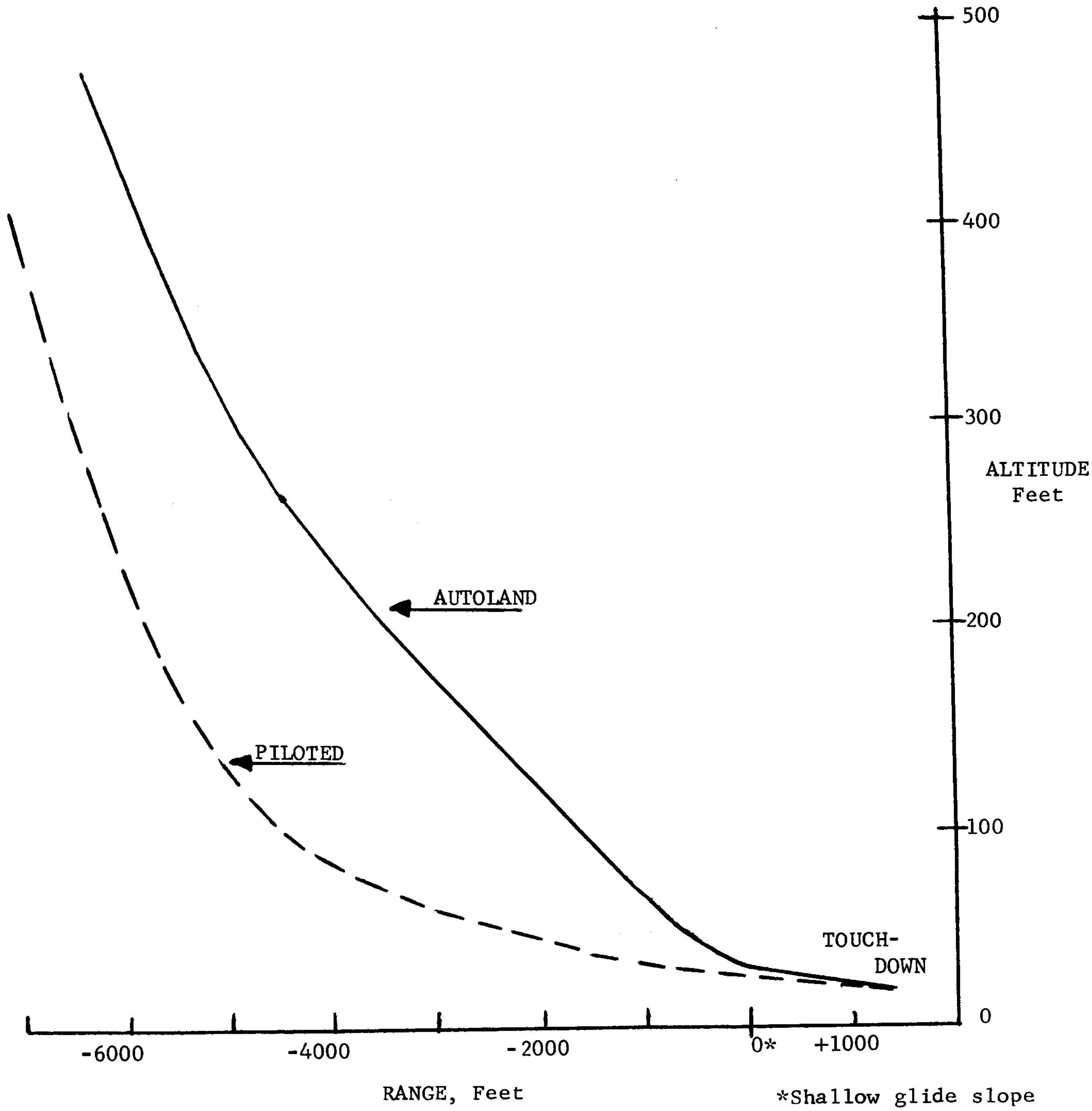
C. As an aerodynamic vehicle, the Shuttle aircraft is new in many ways. It may exhibit some characteristics in various flight conditions that are not accurately predictable from wind tunnel or other data. The Panel believes that the flight control system, if provided with a cockpit gain variation, would add to the safety of the first flight tests of the Orbiter vehicle. The Panel is aware that the ALT CDR considered this problem; however, we suggest further review.

D. If the Orbiter L/D is to be simulated when it is flown with tailcone on, the Panel recommends that extra caution be employed to assure there is sufficient attitude control available when drag devices are deployed. It is realized that currently such maneuvers are not planned.

E. The profile or energy management for approach, flare and landing are different for autoland and manual control modes. Figure 1 shows this difference. Effort is now underway to make the automatic and manual profiles identical. The Panel believes this to be essential. This will make it possible for the crew to follow the progress of an automatic landing, and, if necessary, accomplish the transition from automatic to manual with a minimum of exposure to error.

F. Lifting body flight tests show that successful unpowered landings are best achieved following float profiles that are much flatter than is now planned for ALT. The Panel recommends further review of the planning and training for the float segment of the ALT.

FIGURE 1 - Altitude versus Range (Typical trajectory)



*Shallow glide slope

9.0 EXTERNAL TANK

Dr. William A. Mrazek

9.0 EXTERNAL TANK

I. BACKGROUND

The External Tank appears to be simple in concept. The liquid oxygen and hydrogen tanks are basically of a conventional design. However, the Tank has turned out to have significant engineering and manufacturing challenges. There are also the challenges of designing the fore and aft Orbiter attachment hardware, the external insulation and lightning protection systems. Thus a Panel member was assigned to this important area.

Information on the status of the External Tank has been obtained through formal presentations at JSC and Rockwell International and through detailed review of the system at MSFC. Also, a visit was made to Martin-Marietta at Michoud earlier. In addition, a study was made of the Hazards Analysis Report, MMC-ET-RA01-A, dated October 17, 1975.

II. OBSERVATIONS

The hazard status summarized in October 1975 was:

A. 58 hazards identified.

B. 31 hazards submitted to NASA for evaluation.

C. 2 residual hazards proposed for acceptance as continuing hazards by NASA.

D. 25 hazards resolved.

At the Quarterly Review on May 6, 1976, the list of hazards was revised to show the following changes:

A. 67 hazards identified.

B. 33 hazards submitted to NASA for evaluation.

C. 2 residual hazards proposed for acceptance as continuing hazards by NASA.

D. 32 hazards resolved.

It would be premature of the Panel to comment on the detail deliberations among the contractors and the NASA Centers until firm decisions have been reached. It should be pointed out, however, that the classification above of "Residual Hazards" corresponds to the concept of a "Risk List" as suggested in 1975 by the Hawkins Committee for the entire Shuttle system. The Panel concurs in the concept that such a list should be the prime focus for reviewing the readiness for operation of a subsystem of the Shuttle such as the External Tank and commends the Shuttle management and Marshall for this method of monitoring the hazards inherent in the system.

Several hazards described in the above-referenced report should be addressed in subsequent studies.

A. The breakdown of the hazards into the functional list selected caused a great deal of cross referencing. Some other breakdown might make a review by outsiders simpler and more productive.

B. The problem of flammability of the Thermal Protection System in the presence of gaseous or liquid propellants suggests that a complete review of propellant leakage and possible spillage may be of value. The toxicity of the polyurethane foam with a flame retardant needs more study and a systems decision. The addition of the flame retardant makes the residual ash and the gas emmision more objectionable, perhaps unacceptable, if a fire should occur. A fire may be avoidable and unlikely, but if one should occur, the questionable improvement of a fire retardant makes the insulation material in use more dangerous. The effectiveness of the retardant in case of an oxygen leak is questionable. There is the additional fact that the external, or bonding, insulation of the External Tank is temperature sensitive. Any lengthy exposure to direct solar heating might degrade the integrity of the Thermal Protection System (CPR 421).

C. There was no discernable reference in the reports to previous NASA or contractor experience on launch vehicles which must have been subject to similar fire hazards. Solutions which were reached on such vehicles must be equally applicable to the External Tank and would be far more convincing to reviewers than some of the test programs or explanations which were offered to mitigate or remove the hazard.

D. A series of lightning tests performed recently showed that the protection system problem is not yet solved; specifically, the bonding of multiple spray-on paint strips to a single path solid metal in the form of the vent line. In addition, the selection of the proper spray-on conduction paint itself needs more test and studies.

E. The occurrence of geysering during filling of the long suction lines has to be thoroughly tested, and the baffles inside the tank must be protected. Tests are still forthcoming.

F. Large cryogenic separation fittings subject to water and nitrogen icing might be troublesome to guarantee a proper disconnect. To date, no ground separation test (even simulated) is planned.

III. ASSESSMENT AND RECOMMENDATIONS

It is the opinion of the Panel member who reviewed the External Tank status, that there are no insurmountable risks that cannot be adequately controlled for safe operations. It is suggested that the Panel participate through its individual members, in subsequent critical design or normally scheduled reviews and that the entire Panel be exposed to the final "Residual Hazards" which the program managers believe should be accepted for first orbital flight and subsequent operations.

A. The target performance data of the orbiter systems were quoted and finalized as a point in time when finalized loads, aerodynamic, thermodynamic, vibration, and vibro-acoustic, were in a preliminary state. Weights and propellants have only minor allowances for variations. Finalized date in all environmental fields will not be available until late in the test program and may result in a costly redesign and, sooner or later, performance variations may well result.

B. Critical mechanical activities like the complex separation of the External Tank and Orbiter will be experienced for the first time under environmental conditions during the first orbital flight. If at all possible, it would be prudent to include an environmental separation ground test in the program. A flight failure can neither be observed nor measured and could well lead to a total loss of the Orbiter.

C. A reasonable consistency in the quality of the External Tank in order to achieve maximum reliability and safety of the manned flight is best assured by continuing production. Shutdown and the subsequent reopening of the production line will interrupt the learning curve and compromise a reasonable, low price of the throw-away External Tank which is best achieved by an acceptable continuous production rate. The actual use of the External Tank is governed by entirely different aspects. A launch delay, weather, mechanical difficulties, payload availability, or other unpredictable events, will create a possible storage problem for the External Tank. It would be advisable to assure suitable limited storage space for these large External Tanks. Storage conditions would have to be controlled to insure against degradation.

D. Lightning tests have shown some weaknesses of the test specimen representing the intended External Tank design. It is suggested that a "Lightning Protection Committee," or "Study Group," approve the finalized lightning protection measures, not only for the launch pad, but for the vehicle in flight as well. These reviews should include proper bonding and prevention of static charges.

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10.0 SOLID ROCKET BOOSTER

Dr. William A. Mrazek

10.0 SOLID ROCKET BOOSTER

I. BACKGROUND

The technology of large solid rockets is well developed, and many operational units have been found to be reliable and trouble-free. The Panel recognizes the importance of this element and the need for high reliability. The development program on this element is now reaching the stage for more intensive review.

Several Solid Rocket Booster Quarterly Reviews were attended and, in addition, insight was gained by visits with the project management staff. Up to this date, contractor visits have not been made because of the early status of the project. The last contract for the assembly of the booster is about to be let as of the date of this report.

Nevertheless, the latest issue of the JSC Report #09990A published March 8, 1976, titled "Major Safety Concerns of Space Shuttle Program" lists two open safety concerns , INTG-11 and INTG-12, pertaining to the Solid Rocket Booster.

INTG-11 - "A Nozzle Extension Separation Failure" will be disposed of prior to the first launch.

INTG-12 - "Ignition Overpressure" Completion of a comprehensive study is scheduled for July 1976. It is evident that late adverse study results might have a considerable impact on cost, performance, and schedule.

II. OBSERVATIONS

Despite the diligent application of available experience and data, the project recognizes major uncertainties in design criteria. Lift-off loads, thermal environment and changes will have an impact on cost, schedule, and performance. Twelve concerns were recognized by project management and discussed in detail. To obtain a conclusive picture of the progress made, it was suggested by the Panel members that at following reviews, the status of the above concerns, as well as others, be monitored.

III. ASSESSMENT AND RECOMMENDATIONS

A. The auxiliary power unit supplying oil pressure to the actuators of the boosters uses as its prime mover a hydrazine-driven turbine to operate the pumps. The exhaust stacks of all four units located in both boosters allow the entry of sea water into the catalyst bed of the fuel system after splashdown. To date eleven (11) mission duty cycle tests of the unit have been completed during which the catalyst bed was exposed to salt water for ten (10) hours each cycle. After retrieval from the water, the bed was flushed out and successfully fired in all cases. The "reconditioning" system must assure adequate flushing is accomplished after each and every salt water exposure.

B. A molded fiber-reinforced plastic cover of adequate strength could be designed and produced to enclose the entire APU for protection against sea water duncking. The savings in the long run could easily offset the initial cost.

The Panel will be devoting increased attention to the Solid

Rocket Booster system during the year ahead. Hazards associated with Shuttle system assembly in the VAB at KSC will be included in such surveillance.