ANNUAL REPORT

to

DR. ROBERT A. FROSCH, NASA ADMINISTRATOR

by the

AEROSPACE SAFETY ADVISORY PANEL

Calendar Year 1977

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The Aerospace Safety Advisory Panel's report for Calendar Year 1977 was given to Dr. Robert A. Frosch, Administrator of NASA, on October 12, 1977 at a formal briefing which was open to the public. The material was updated to February 1978 in testimony by the Panel to the Senate Subcommittee on Science, Technology and Space, chaired by Senator Adlai E. Stevenson. Hence, the transcripts of these two meetings (Appendices A and B) represent the Panel's report on its 1977 work and will form the basis of this written report. This procedure differs from that used in past reports and documents a more timely Panel interaction with NASA and the Congress. We expect to continue in 1978 with two public meetings to report to our constituency and then submit a record document in early 1979.

Recent Panel reports have been divided into two parts, the second volume of which was the data received by the Panel in its various meetings and briefings. In that this material duplicates that freely available in the Panel staff files or in NASA and its contractors' files we have decided that it will be more effective to list only the various Panel and fact-finding meetings that have occurred during the year, with date and place of the meetings, and a summary of the material covered (Appendix C). This procedure will allow retrieval of the data upon request and at the same time produce a more readable report.

During the course of the year the Panel has been almost exclusively concerned with the Space Shuttle. However, at the end of 1977 we prepared to investigate some of NASA's non-space activities that have significant safety implications. Our 1978 report is expected to reflect this activity. We will continue our policy of bi-monthly formal meetings with fact-finding scheduled for the intervening months and are turning a portion of our attention to the area of Shuttle payloads.

During 1977 there were a number of events that caused delays and changes in the Shuttle program, but the Panel feels the significance of the successful approach and landing tests should not be underestimated as a positive indication of the basic state of the aerodynamic qualities of the aircraft and the modeling and analytical work that went into the Orbiter design and particularly its control system. This test program exercised the Orbiter in its unpowered final landing mode. The tests uncovered minor problems which could be fixed without change to the basic design concepts and, more importantly, they provided a demonstration of the adequacy of the Orbiter design and in the quality of the modeling and analysis on which the design was based. While this does not directly verify the eventual orbital flight performance, it lends credence to the analysis methods by which new problems can be approached with a degree of confidence not before justified.

The various concerns expressed by the Panel members at its public meeting are distributed through the transcripts and are summarized here for clarity. We should preface this by saying that the Panel is well satisfied by the NASA programmatic responses to its comments. During the course of the investigations we confer with the concerned people and develop an understanding of the technical depth leading to designs and test decisions. The resultant clarification in many cases relieves a Panel concern. The Panel's critique is believed to be objective and safety-oriented and is not constrained or influenced by the Shuttle program budgets and schedule. For this reason we do not expect that the program will implement all specific suggestions but will seek solutions that can be fit more easily into the program. The Panel's goal is to bring different viewpoints to the attention of the program directors to insure that all aspects of any problem are considered and to assure that any accepted risk is fully evaluated before it is assumed. The Panel is an advisory body, not a decision-making one.

During the year we were asked several times for our opinion on the readiness of the Orbiter for various phases of the ALT program. On all occasions we were of the opinion that the Orbiter was ready for flight.

In the Panel's review of the various aspects of the Shuttle program one caution is continually sounded: the necessary testing to establish confidence must not be slighted because of budget or schedule pressures. The budget and schedule are tight and pressure to reduce the number of planned tasks is inevitable and must be resisted. In light of this it is necessary to identify those test programs that are mandatory and make provision to see that they get done. Areas where this is particularly important are those which confirm Avionics software, main engine reliability, flight control systems (particularly the non-redundant elements) and the thermal protection system.

The Panel feels that as the Shuttle matures it will become a transport aircraft and that the design philosophies of that industry regarding redundancy of flight controls and concepts to achieve "fail operational" systems should be incorporated wherever possible. We acknowledge the problems of making changes at this time, but an independent review of the control system vulnerability to specific failures may well be in order.

A method of identifying and quantifying aggregate risk should be developed if at all practicable. It is not easy to get a meaningful numerical answer to this problem. The Panel has been working with the reliability and quality assurance groups and some headway is being made. The work should continue and should include specific detailed engineering input regarding potential subsystem failure modes.

The Avionics system used in the landing tests was adequate, but orbital flight control is more complex and will utilize a different computer. It would seem prudent to obtain an independent assessment of the software, including off-nominal situations that could affect all computers.

The auxiliary power units have had a history of troubles that make their reliability questionable. These can, of course, be developmental problems, but an overall review of these units, including hot restart and full assessment of environmental impact on reliability may well be in order.

The thermal protection system concept seems to be soundly based, but manufacturing and application problems need continued review and test confirmation if we are to get a better appreciation of the effects of steps, gaps, and potential handling damage on the tolerance to heat input. These factors greatly influence tile yield and the ease or difficulty of application. It is also important to review the planned trajectory of the first flight in order to minimize the combined heating rate and load on the thermal protection system.

The development of the main engine--a difficult task--has been slowed down by unexpected problems. The Panel does not believe that these are insoluble, but adequate time must be allowed in the schedule for real solutions--not questionable fixes--to be developed. Testing must then be done on individual engines before the main propulsion tests are begun. This could affect the schedule for orbital flight tests.

The severe technical problems that have been encountered in the development of the Shuttle hardware have properly occupied most of the time of the program reviewers and managers. It is now appropriate to evaluate the training activities of the many people involved in the preparation, launch, and maintenance of the Shuttle. Reliability of these activities requires adequate checklists, procedures, and training programs if they are to fully support Shuttle operations.

The Panel is of the opinion that the Shuttle program is in excellent shape when viewed in the context of the overall task, schedule and budget.

The Space Shuttle task assumed by NASA was to proceed from an experience of individual scientific experiments to the design, construction and demonstration of a routine transportation system. The conventional approach to this problem would be in a series of steps:

first, to establish performance; second, to establish life; and third, to establish routine operation. NASA chose to approach this multi-year, multi-billion-dollar project in one continuous success-oriented program. The Panel's reviews lead it to believe that no insurmountable technical problems are apparent at this time and that in the context of the whole the schedule delays and budget overruns have not been significant. We are now entering the crucial period of total system confirmation, and evaluators and development teams must be alert to potential unforeseen problems and vigorous in their complete solution. Now, more than at any time in the program, the momentum, the schedules and the visibility of any program problem will provide an environment within which less than complete solutions will be tempting. This must be avoided at all costs.

APPENDIX A

AEROSPACE SAFETY ADVISORY PANEL

ANNUAL MEETING

before the

NASA ADMINISTRATOR

October 12, 1977

AEROSPACE SAFETY ADVISORY PANEL

ANNUAL MEETING

before the

NASA ADMINISTRATOR

October 12, 1977

Agenda

Introduction................................	H. E. Grier
Mission Operations..........................	J. L. Kuranz
Orbiter Readiness for Orbital Flight Tests...	W. M. Hawkins
Space Shuttle Main Engine...................	S. C. Himmel
Avionics....................................	H. E. Grier
Thermal Protection System...................	C. A. Syvertson by H. K. Nason
Hazard Assessment...........................	F. C. Di Luzio
Human Error.................................	C. D. Harrington
New Projects................................	J. L. Kuranz
Retrospect..................................	W. D. Johnson

INTRODUCTION

The Aerospace Safety Advisory Panel was established by statute some ten years ago to provide an independent, knowledgeable identification and assessment of undue risks attendant to NASA's operations. Priority was to be given to manned flight, and the Panel, while it is to comment on the adequacy of proposed safety standards, does not have a responsibility to solve problems, set standards or alleviate risks.

Briefly stated, the Panel's role is to make use of its observations and experience to

1. advise where we see risks;

2. in areas of high risk, investigate adequacy of solutions;

3. in areas of excessive risk, recommend alternate solutions;

4. review the adequacy of the Management System to perceive and cope with risks; and

5. identify areas that need support in the solution of risk problems.

In any consideration of the role of the Panel it must be borne in mind that the composition of the Panel will, in fact, have a great effect on what is asked of it and what it can accomplish. The Panel consists of a group of senior persons, each of whom is experienced in the management of technically oriented or complex projects. The members are appointed by the Administrator of NASA and the Panel is congressionally chartered.

The value to the Administrator of the Panel's activities lies in the objective overview of NASA and its contractors' management system and their results, by a group without operational responsibility but with program continuity.

The Panel has developed the procedure of reviewing programs, selected hardware, and management procedures of NASA and its contractors for evidence that the proper management emphasis is placed on safety and the achievement of mission goals without undue risk. The Panel holds two-day formal meetings approximately bi-monthly; its members attend formal reviews and also talk informally with NASA and contractor managers and operating personnel. This mode of operation affords individual Panel members the opportunity to review specific program plans and selected hardware in the field of their special interests or expertise. From these investigations the Panel identifies what, in its opinion, are reducible risks and assesses the impact on

NASA's operations of making changes or accepting the risks. The Panel's work is presented to NASA management in the course of informal as well as formal discussions, and is recorded in an annual report for both Congress and NASA management summarizing the Panel's conclusions and data base.

We would propose to continue the fact-finding in areas that need attention, and then to draw conclusions from the facts and our experience that will be useful to NASA in the management of its work. We believe there are two past examples that are pertinent: we were instrumental in getting NASA to name a chief engineer; and also in establishing a technical assessment group. The Panel also fulfills its responsibility by expressing its opinion as to the risk involved in specific NASA operations that it has investigated. This has proven to be helpful in the past and we will continue with such assessments subjects, as before, to the limitations of our time and expertise.

With the advent of the Shuttle program with its goal of a reusable transportation system, the Panel found it necessary and desirable to divide up the fact-finding workload by assigning certain Panel members to various aspects of the Shuttle, taking into account the experience and interests of the members. They then report to the Panel in full session and a consensus is developed. We propose to continue this procedure. Now that ALT is almost complete, we plan to reorganize our assignments to focus on OFT and begin in aeronautics as follows:

FACT-FINDING ASSIGNMENTS

Member	Shuttle Fact-Finding Responsibility
C. A. Syvertson	Mission Operations and TPS
W. M. Hawkins	Orbiter
S. C. Himmel	Propulsion
H. E. Grier	Avionics
F. C. Di Luzio	Hazard Assessment
C. D. Harrington	Control of Human Error
H. K. Nason	Payload Hazard Assessment
W. D. Johnson*	Launch Preparation and Logistics
J. L. Kuranz	Aeronautics

*Resigned; replaced by Lt. Gen. Leighton I. Davis, USAF, Ret.

Today we will comment on the upcoming tailcone-off flights as we have on the previous ALT flights. An explanatory comment is appropriate. The Panel has traditionally been asked its opinion about the state of readiness of operations as a whole, but we now sense that as a result of our interest in some of the details we may appear to be certifying operational events. This is not our role and can mislead one as to the extent of our certification, no matter how qualified it may be. Our Panel cannot be expected to investigate in detail all the aspects of an operation which are required for a complete certification. This certification is the task of the programmatic organization which we can supplement by knowledgeable, independent assessment, but we cannot supplant the responsibility of the program organization.

It is worth repeating that the ASAP is a group of senior, experienced people who should dig into details only enough to interpret from their experience the shortcomings, if any, of the Management System and to make recommendations for its betterment. We should not attempt to do technical design no matter how appealing the job is to us--that's not our job. Neither should we certify an operation unless we have examined it in depth.

We need a definition of the Management System we are talking about. We would say that it is the NASA organization that identifies tasks, formulates specifications, assigns responsibilities and monitors performance so as to achieve effective and economical solutions to the problems at hand. ASAP has a legitimate concern with this because in the "chips are down" operation which NASA is responsible for, safety in its broadest sense is a result of the proper solution of all the problems. It is also important to spend no more than necessary on a given phase of the problem, to assure that funds are available for other areas that need to be worked on. We will talk about the test program in this context.

In all the Panel's work there is a common thread and that is risk--its identification and assessment. A problem that greatly concerns us, as well as many other people, is what is the aggregate risk? What is the composite result of all the individual risks that one identifies, quantifies and accepts? In any complex undertaking where design is divided into subsystems and done by different groups, it is difficult to coordinate the effect of all the engineering tradeoffs on the total system. In the case of the Shuttle, this process is further complicated by the fact that not only technology, but money and schedule pressures also drive the tradeoffs. In fact, the same problems exist in individual subsystems where design efforts and external influences have been traded off over a long period of time. The Shuttle is such a complex system that judgment alone may be inadequate as an assessment tool.

It is suggested that there should be a formal effort within the program to quantify the aggregate risk to the project of the total system concept and the changes that have occurred in the design and test program.

There are many methods of identifying a risk, but it can only be quantified as the result of a test program and hence the importance of the test programs that NASA so stresses. In a program as large as Shuttle the amount of testing can be so great that it must be reviewed to make sure of its pertinency and necessity in order that all risks inherent in the mission environment are accounted for within a test program that can be accomplished within the time and funds available.

In an evaluation of the adequacy of the test program for risk assessment the tendency is to propose an outside entity to take a "fresh" look. This is difficult for two reasons. First, the people making such an assessment must have been involved virtually from "day one" so that they know the entire history and modus operandi and, second, this should not be an ad hoc effort, but a continuing part of the Management System. We believe the capability and funds to do this are within NASA, but it should be a discrete responsibility. It cannot be done by the engineering organization as a part-time effort. The Technical Assessment Group at JSC would seem to be a good model for the aggregate risk assessment task and perhaps could be involved in the task via a restructuring and the addition of some personnel. In order to place the aggregate risk assessment in the proper perspective and yet involve it adequately, it should probably be a programmatic staff function, but in any event should not have an engineering design function of any type.

This year it seems appropriate to involve the Panel in NASA's aeronautic as opposed to manned space activities. The charter establishing the Panel directs priority to manned space flight, but makes provision for review of the other NASA programs. The organization and character of the manned space flight activities are different from the other programs, and the first step the Panel should take is an identification of its appropriate relationship to these, new to it, activities. To this end we have assigned a prime responsibility to one of our members to the role of the Panel in this area. In doing this we intend to solicit program input and to submit our plans for concurrence before proceeding.

The continued and broad overview of the Management System does not rule out the Panel's applying its expertise on an ad hoc basis to a specific problem for the Administrator. A good example is the Panel's consideration of the threaded fastener problem where a public charge was made that NASA was procuring inadequate fasteners for its programs. The Panel's investigation and opinion helped NASA refute that charge.

In summary, the Aerospace Safety Advisory Panel is a senior, experienced group with continuity, whose task is to review the programs of NASA and identify for the Administrator undue risks that may have escaped the notice of the program managers as a result of their close involvement with daily problems. It is also to assess the potential or aggregate risk as a result of the acceptance of many individual risks, each one of which was validly accepted.

MISSION OPERATIONS

The outstanding success of the ALT programs is of itself a better report on the mission operations than the Safety Panel could present. As the program has progressed there have been some schedule problems, some equipment problems and some procedural problems. In toto, however, these have been minimal alongside the fact that the technical objectives of the flight series have been met and the specific answers have, in almost all cases, been positive from the program point of view. For us to dwell on these points would be repetitive and unnecessary. There are two points, however, that the Panel feels bear emphasis.

First, the Panel is impressed by the indications from ALT that the modeling and analytical procedures used in the Orbiter design have been relatively closely validated. This gives a substantial degree of confidence in the theoretical and model work involved in the upcoming OFT activities, while the problems in the orbital and entry phases are different than in the subsonic regime. It is a milestone to document a good general concurrence between theory and practice in the early phases of the flight test programs leading to orbital flight.

The second point that we should like to stress is the dedication and competence of the entire flight test organization under Deke Slayton. These people represent a somewhat different culture than the more theoretical and scientific design people in the program, and the burden of bridging the gap is on them. They must understand and make work the product of the program. They did this magnificently, and successfully demonstrated what, up to the present, has turned out to be a superior product.

ORBITER READINESS FOR ORBITAL FLIGHT TESTS

Introduction

Before discussing the current status of the Orbiter and its system, it should be emphasized that the operation of the ASAP and its individual members would not be possible without the open doors of the NASA Centers and the contractors to the requests, questions and visits of the Panel. I, for one, want to express my gratitude for this universal attitude.

NASA, since the start of the Shuttle program, has been constrained by budgetary pressures and originally estimated schedules that define a substantially different program environment than NASA has been exposed to before. This has constrained changes when the original concepts were found to be less than optimum, and it has caused the program to be planned as a completely successful venture. The inevitable difficulties have caused test programs and decisions to be postponed with the result that many tasks are left to be done close to first orbital flight.

A second factor that has impacted the program is that the NASA Centers and the chosen contractors have accumulated their experience in space or military aircraft programs and there is little awareness of the growth and sophistication of the technologies implied by aircraft designed to "fail-operationally." These technologies are most apparent in agencies, government and commercial, involved in transport aircraft for the military and the airlines.

In spite of these problems, the program has made remarkable advances as demonstrated by the latest tailcone-off ALT experiment.

Orbiter Status, General

The ALT flights, now including the first tailcone-off experiment, have demonstrated the aerodynamic, the control system, the computer, and the operational concept of horizontal landing in an impressive way. Based on this success, the ASAP suggests that the remaining tailcone-off flights should include an experiment, even if very short, in which the blind landing system flies the aircraft on approach.

Still to go, however, is a thorough evaluation of the boosters, the external tank, the launch system, and the abort planning. The ASAP will spend the remainder of this year and next in expanding its attention to these system elements and operations plans.

Flight Control Systems

Very early in the deliberations of the ASAP we questioned the concept of the flight control system and its vulnerability to single point failures. The state of the art in transport aircraft, both military and commercial, has progressed substantially since the Shuttle control system was conceived, and it would be profitable for the future operations of the Shuttle to incorporate as many of the new concepts of how to design fail-safe and fail-operational systems into the Shuttle.

An example of one such Shuttle control system is the rudder speed brake actuation subsystem. There are several critical points; for instance, the gear boxes which if they fail completely will jam the entire system, in spite of the fact that the system is fed by three completely independent hydraulic power sources. Since there are two of these gear boxes in series and since the gear loadings are higher than is standard practice on helicopters, it is essential that test programs for certification be strenuous and thorough. Similar single point failure potentially exists in the two drive shafts and eight actuators, any one of which, if completely jammed, eliminates that side of the rudder speed brake system. Here, too, test programs are essential to confirm that these elements are sufficiently reliable and that they do not constitute a hazard to the Shuttle flight's success.

A somewhat different single point failure problem appeared in the elevon servoactuator system. Three hydraulic power sources are again available, but the system comes together in a single switching valve system, power spool and single ram actuator. NASA responded to initial criticisms of this system and has redesigned the actuator eliminating many single point failure elements. There are now only 11 such elements per actuator and these have been designed in such a way that a leak is prevented even though a seal fails by means of a backup close fitting metallic seal with a controlled leak rate sufficiently low that the hydraulic capacity is not exceeded for any one mission. There are four such actuators on the Orbiter and they, too, must be subjected to an extremely critical testing program to confirm their adequacy. In a review of all the systems on the Orbiter there are a number that are shown to have similar characteristics. The body flap is similar to the speed brake and the main engine vector control pistons are similar to the Fortress piston. There is a rather different potential problem concerning the main engine fuel control which relies on hydraulic power for operation. In this case the hydraulic control is a single string and depends upon an APU for power. There is no backup hydraulic power. Thus, if the hydraulic power fails, that fuel control is locked in whatever position it was operating at. It is not known how long the control will stay in the locked position. If it drifts or is in a position which would cause the engine to reach any safety temperature or pressure limit, the engine will shut down, causing the Orbiter to enter some kind of abort mode. It is suggested that testing of the main engine should include a simulated failure of this kind. If the likelihood of the engine continuing to run is high, this may not be critical. However, the Panel could find no confirmation of this likelihood and thereby suggests that accumulators or backup hydraulic systems be considered to prevent this failure. The APU is the source of all hydraulic power and has been a continuing problem during development. Although there are three APUs driving the three separate hydraulic systems, the likelihood of one or more APU failure in the early Orbiter's flights would seem to be perceptible. It is suggested that the program review installation of backup accumulators or a fourth system for early flights. In any case, those early flights should be loaded such that the center of gravity is in a position where reentry and landing might be possible with only one hydraulic system operating. Similarly, flight modes should be selected that provide the highest chance of return with jammed dive brakes or body flaps.

Testing Program

As a result of early pressures on the budget and on the concepts of the various system elements, many of which have changed, the testing programs have become compressed and some are scheduled quite close to the first orbital flight.

From the schedule for delivery and test of the Fortress pistons for the elevon actuators it is noted that the qual testing of two units is completed just 45 days prior to the scheduled first orbital flight. The Panel urges that subsequent rescheduling not reduce any of this qual testing and that the orbital flight be delayed, if necessary, until the units are qualified. A series of tests is then planned, entitled Fortress-Plus Testing. This is not completed until the Spring of 1980, substantially beyond the first orbital flight. Since this is the kind of testing designed to confirm how many reuses can be made of the system rather than to confirm that the system is adequate for its function, it is normal that the test span would come after the first orbital flight. The Panel is not concerned by this overlap.

A similar problem that has not yet been fully defined exists with the Orbiter's reaction control subsystem. Due to the fact that the configuration of this system was changed late in the design process, the implications for testing the elements have not been fully evaluated.

We note that there are a number of configurations of reaction control rockets. Although there are only two types of combustion chamber and throat, the skirt configurations are numerous and different. Since these rocket nozzles are exposed to external heat loads, the reentry end must be designed so that the radiant heat output within the installation fairing is controlled. The implication is strong that the test program will be complex. This will be one of the Panel's evaluation subjects through the end of 1977 and all of 1978.

Summary Assessment

It would appear that the multiple system concepts of the Shuttle do not represent the known state of the art in design for "failing-operationally." The NASA laboratories have responded by making substantial changes and augmenting the test program to validate those elements of the system which could be construed as single point failures. It is suggested by the Panel that many of these systems should be reviewed in the event that added shuttles are purchased. The Aerospace Safety Advisory Panel will review in detail the redundancy concepts in the cabin and environmental system, the reaction control system (as previously noted), the APU (its water boiler, lube system, control valves and operation in the main engine environment), and also the boost and main engine vector controls. The Panel will reconsider the abort concepts to determine if additional changes to the Shuttle could be made in order to avoid some of the most hazardous.

The Use of Safety Panel and Other Outside Reviewers

It would appear from the ASAP experience that many of our current concerns might have been avoided had the Panel been involved in the early concept of the system. This suggests that similar evaluation groups should be brought in whenever possible while the system concepts are being formed. It is worth noting that the McDonnell-Douglas review of the current flight control system is to be completed only nine months before the first orbital flight. It is obvious that any output from such a review will be too late to affect the configuration of the Shuttle before first launch unless the change implied is quite simple. In view of the complexity of this system, the McDonnell-Douglas review should continue, but if major problems are uncovered the first flight schedule is bound to be delayed.

It is the Panel's opinion that NASA has responded completely to all of the Panel's suggestions and has outlined test programs which, when completed, should confirm that the present Orbiter will fulfill its mission safely.

This past year has seen both significant progress and some serious technical problems in the Main Engine program. Problems were, perhaps, to have been expected as the engine represents a venture into new areas of technology. As a result of the problems the program is behind schedule, and work-around plans to support key milestones have had to be devised.

Problems

As has been the case for the past year, the turbomachinery is the principal focus of the technical troubles of the engine development program. A series of major problems, two involving hardware failure and fire, have kept the program behind schedule.

At the beginning of the year the High Pressure Fuel Turbopump (HPFTP) exhibited subsynchronous whirl and turbine bearing problems that precluded operating at RPL. After intensive efforts, stiffening of the HPFTP shaft and modification to the turbine bearing coolant flow brought the problems under control. These changes permitted the achievement of engine operation at RPL early this spring.

Shortly thereafter a High Pressure Oxygen Turbopump failed during an engine test at NSTL. The failure was accompanied by a fire and, in addition to destruction of the pump, major damage was done to the engine. The test stand suffered only minor damage. It took quite a while to determine the cause of the failure. The origin was found to be in the seal assembly that serves to isolate the turbine from the pump. To permit the resumption of engine testing, an interim fix was devised. The lift-off face seal that had served as the primary LOX seal was replaced with a three-step labyrinth seal and the helium purge flow rate in the intermediate seal was increased substantially. Ultimately the entire seal assembly must be revised. The character of the revision is well defined and development testing at the seal level is in process.

With the interim seal modification, many successful, long-duration runs were achieved from late July through August. About 4,000 seconds of running were accumulated in this relatively short interval. The average thrust levels for these runs increased as the test program proceeded. During this period a 301-second duration run at RPL was achieved. Then, on September 8, another failure occurred. This also involved a LOX fire and resulted in the loss of most of a HPOTP, a LPOTP and the interconnecting duct. Again, test stand damage was minor.

The investigation is still going on. It appears that the failure originated within the HPOTP. To date the HPOTP seals have been exonerated. There are indications that there was a bearing overload. Whether this is cause or effect is yet to be determined.

Of concern is that the failure may have resulted from a subtle marginality in detail mechanical design. Two other pumps of the same configuration have been run for considerable time without failure, albeit one of them showed some evidence of bearing distress. Another possibility is that some phenomenon associated with long running at high power levels may be manifesting itself. In the highly mechanically-interactive system of a high speed, high pressure turbopump it would not be surprising for load distribution to change significantly as power level changes. Such a shift could, for instance, easily change an acceptable bearing load to an unacceptable one. Possibilities such as this one are being examined by the investigating teams that have been established. Testing has recently been resumed with added instrumentation. Hopefully, the data will help in finding the culprit.

This most recent problem has impacted the Main Propulsion Test (MPT) program that had been scheduled for December. It would obviously be imprudent to risk damage to a set of three engines in the MPTA prior to establishing and implementing corrective action for this last failure.

Progress

All is not bleak in the program, however. On the positive side of the ledger, the engine has been operated at rated power level (RPL) a number of times including the 301-second duration run noted earlier. The 75:1 area ratio nozzle has been run successfully. The combustion systems have proven to be stable and, with trimming type modifications to injector flow patters, should provide the desired life characteristics. Much of the auxiliary equipment has completed design verification testing satisfactorily and the remaining tests are on schedule. The controller has performed very well in the field. It has proven to be a great asset to the program by permitting changes in sequencing and valve rates to be made via software rather than hardware. This provides for rapid development of start sequences and desired system dynamics--previously a slow process.

The thermodynamic performance of the turbomachinery has been established experimentally. The design modifications required to correct performance deficiencies have been defined and sufficient experimental verification has been obtained to warrant confidence that desired thrust and efficiency can be achieved. Fabrication of modified hardware is in process. It is estimated that these "fixes" will all be incorporated into the development hardware by early next year.

Assessment

By way of summary and assessment, much progress has been achieved in the program. Identifying the fixes for the mechanical problems of the HPOTP and proving them out is the major immediate challenge. Once that is accomplished, accumulating engine running time over the power spectrum to demonstrate sufficient durability for commitment to MPT is a key requirement.

For the longer term, consistency in performance both run-to-run and engine-to-engine must be demonstrated to provide confidence in the design. Preferably such demonstrations should be accomplished if at all practicable with engines that incorporate all the performance fixes referred to earlier. Such demonstrations will, of course, be a part of the test program required to establish confidence in the durability of the engine for operational use.

As noted earlier, the MPT schedule has been impacted. Without intending to be pessimistic, it must be noted that the possibility of an impact on the OFT schedule is present. The demonstrated ability to accumulate much running time in a short period offers the possibility that an impact can be avoided if the fixes are successful and no new problems surface. In any event, it would seem prudent to consider contingency plans for meeting the established testing goals for engine flight certification for OFT. It would also be appropriate to examine whether any alternate approaches to achieving flight certification might be advisable. Of course, any such changes in plans should be the subject of thorough management review. It is this aspect of the program and the testing itself that will be the focus of Panel attention on the Main Engine for the coming year.

It is difficult to make a specific critique of the Shuttle Avionics system because the problem really is the determination of the level of confidence in its proper operation as a result of testing of the complex system that has so far in the ALT program demonstrated its success.

The system is divided into two parts and their testing: hardware, software, and the necessary integration or systems testing.

Hardware has not been an undue problem, and the problems that have surfaced have been resolved in a timely manner with very few "ghosts" left to plague our confidence. The Panel and the program both are concerned about the number of recent computer problems, but a new computer will be used for the orbital flight, and the redundant management of the present computers is satisfactory for the current operations. The Panel believes that the Management System can and will effectively cope with any unexpected "black box" problems.

People tend to feel suspicious of software because, unlike hardware, you can't "kick the tires." Early on, the Shuttle software was plagued with escalating and changing requirements, but as that problem was controlled and laboratory system testing was emphasized, the software has straightened out and seems to be in good shape. Continued testing in the laboratories will enhance the degree of confidence that we now feel in the vital software area. We believe that successful ALT flights to date reflect a maturity of the Avionics system that is remarkable, considering the few times that the Orbiter has "played" together.

The Panel's concern about the Avionics system for OFT centers around the new computer and the expanded mission as compared to ALT. Every effort must be made to structure and program it so that the test time and results already accumulated can be directly applied to the new computer. In the OFT configuration the enlarged memory and the new computer should in large part supply margins of safety, not open the door to unrestrained changes and additions to the computer's tasks.

The Avionics system of the Orbiter is akin to the nervous system of a human being. Both are extremely complicated and have many of the same functions, sensory and physical inputs, signal conditioning and transmission, prioritizing, computation, command, feedback, updating and monitoring of performance. In such a complicated system the number of permutations and combinations is so large that the major system problem is to be aware of the results of any possible combination of inputs. Man formally spends about a quarter of his life trying to learn the limitations of his system in response to the environment and the characteristics of his personal components. In the Shuttle we do not have this long to learn our system, and thus this illustrates the major problem facing Orbiter Avionics. It is the understanding and correlation of the integrated elements in the time available so that we can predict the response of the system to any possible real set of inputs.

For some parts of the system this can be done by analysis, for some by component test and, in the case of that indispensable component software, by running on the computers against all conceivable conditions. This assurance of component quality is very important and must be done, but just as a man must learn to use his own real set of components working together, so must the Shuttle be run in final and real configurations sufficiently to demonstrate that its responses to real life are those designed for and expected of it.

In the Panel's view, if there is an Avionics problem for OFT it is simply the time necessary for all-up configuration tests of sufficient depth to give management the confidence it needs for the first OFT. SAIL and ADL are needed for systems development tests, but to the extent that they are not physically identical to the Orbiter, time must be available for sufficient Orbiter 102 testing, either at Palmdale-DFRC or at Kennedy.

The Panel's activities in Avionics for OFT will be centered around the new computer and the testing of the new software that must cope with an entire mission, including ascent and abort modes, not just the last subsonic portion as in the case of ALT. The performances and successes of all the people involved in the Avionics system to date would lead us to believe that there are not insurmountable obstacles for OFT, but that the degree of confidence in the system will be a function of discipline of requirements and the specification and performance of an adequate test program.

THERMAL PROTECTION SYSTEM

The Shuttle Thermal Protection System (TPS) remains a major concern in the preparations for Orbital Flight Tests (OFT). One source of concern is the problem of obtaining adequate production rates for the RSI tiles. With this problem there is a potential desire to relax dimensional tolerances for the tiles. In addition, delays in obtaining certain specific sets of tiles are making it necessary to install the tiles out of sequence. Larger tolerances and out-of-sequence installation could both result in larger steps and gaps between tiles. At the same time, concern over temperatures in the Orbiter basic structure has led to a reshaping of the entry trajectory to reduce the total heat load experienced during entry. The changes in trajectory result in lower heat load being traded for higher heating rates. As a rule of thumb, a 25-degree reduction in structural temperatures results in a 100-degree increase in peak surface temperatures. Peak surface temperatures have thus increased from 2500 degrees to 2600 degrees Fahrenheit. A combination of higher peak heating rates and larger gaps and steps results in significantly increased gap and step heating and raises the question of whether or not the current material can withstand this higher heating.

There are several problems associated with obtaining the required test data on the TPS. First, ground test conditions are not likely to result in the proper transition Reynolds number. It is probably true that the transition Reynolds number won't be known accurately until after the first entry flight. Knowledge of the transition Reynolds number is doubly important; not only are heating rates much higher for a turbulent boundary layer, but also steps between tiles will have a larger effect on heating in a turbulent boundary layer than a laminar one. Second, our arc jet facility capabilities are such that it is very difficult to provide the higher required test temperatures, especially with the proper boundary layers. Normally under ground test conditions boundary layers are, relatively speaking, thinner than they would be in flight and this tends to magnify the effects of gaps and steps. Finally, the overall capacity of arc jet facilities at Ames, Johnson and Langely is such that 100 percent success will be required to meet the present schedule of tests. There is little excess capacity for added tests in certain facilities if such would be required; and to make the situation even more difficult, arc jets are not the most reliable of ground test facilities, and facility failures are not uncommon. Any major failure could complicate scheduling problems.

Future ASAP activities related to the TPS should include the careful tracking of any trajectory changes as they affect the trades between structure temperatures and surface temperatures. In addition, we should keep close watch on the TPS testing program because it is very critical to the qualification of materials. Consideration is being given to gap fillers in order to reduce the effects of the gaps on both heating and boundary layer transition; but much remains to be done in the development of an acceptable gap filler pad. Finally, continued attention will be required in the RSI tile manufacture area because of the numerous difficulties that have been experienced in this area.

HAZARD ASSESSMENT

For the past several months the Panel has been reviewing and participating in each step of the management of Safety, Reliability and Quality Assurance functions. Particular attention has been paid to the specific responsibility of the Johnson Space Center as the lead Center, and its role in risk assessments.

The ALT successful flights to date verify the general adequacies of the Orbiter design in subsonic flight.

During the past year improvements have been made in the manner safety consideration and evaluations were handled. There was a greater and highly visible interest by NASA Headquarters in suggesting improvements to the Safety, Reliability and Quality Assurance System, and in examining and questioning the findings. Efficient use of special task forces was made with good results. The Aerospace Safety Advisory Panel also concentrated on working much closer with Safety, Reliability and Quality Assurance organizations at the several centers involved. The increased attention resulted in a more aggressive approach to risk assessments.

The imposition of several changes to the methods applied to the identification and evaluation of risks, particularly "single point" has strengthened the process. The four important changes are:

1. adding an engineering representative to the Major Safety Concerns Screening Board, whose functions are:
    a. ensure periodic review of all identified safety concerns;
    b. review major candidate safety concerns in-depth;
    c. select major safety concerns for program management visibility; and
    d. document major safety concern status and closure rationale.
2. adding representatives of program/project management as observers to the Major Safety Screening Board;
3. the requirement placed on Johnson Space Center and already under implementation to conduct a critical functions assessment is being made by the systems engineering group at the Johnson Space Center;
4. develop a method to evaluate the aggregate risk involved.

Several additional and somewhat independent reviews are being proposed, i.e., an independent analysis of critical Shuttle Avionics systems and a Shuttle system integrated functions assessment.

Some of the questions the review of the Avionics system should answer are:

1. What are the functions controlled by software which could cause loss of Orbiter and/or crew if a single command is, or is not, initiated because of a single software fault?

2. What safety-critical commands, if inadvertently initiated in error, cannot be overriden by the crew?

3. What safety-critical commands inadvertently initiated by the crew do not have software controls to inhibit action?

4. What is the plan for software prioritization of the safety-critical functions to assure that they are not buried in low priority functions?

5. What are the safety-critical functions during planned single computer on-orbit operations?

6. What is the complete software verification program in ADL, SDL and SAIL, and how does it verify the critical functions involving nominal/off-nominal contingency events? What are the limitations of this program and resulting inadequacies?

As NASA must use its resources judiciously, an in-depth review of the need for and the extent of these new approaches should be made. Perhaps the same end results can be obtained through other arrangements such as using existing personnel and organizations.

The need for an aggregate risk assessment has generated several approaches to developing the needed information in the right format.

The process of making a critical functions assessment by mission phase/events will provide much of the additional needed data.

If implemented, the independent analysis of critical Shuttle Avionics systems will also provide useful data and increase the confidence in the aggregate risk assessment. The Panel will work with and monitor this effort at the Johnson Space Center.

The Panel believes that the present Safety, Reliability and Quality Assurance System strengthened as indicated can perform a creditable function in OFT 1 risk assessment.

HUMAN ERROR

The Panel has studied in some depth and over a long period of time the various management paperwork systems used to control design and execution of design. These systems appear to assure that design features and design changes will be well thought out, and to assure the closing of the loop in the case of required changes. However, these paperwork systems are all dependent on the accuracy of performance of work or of observation on inspection so that the input information to the paperwork or computer systems corresponds to the real world of the hardware. This has been referred to as the man-material interface as opposed to the various interfaces of paperwork systems. The Panel is now in the process of investigating the basis of confidence in this aspect of control. Visits to Downey and Palmdale have been made to determine how this is handled by RI and its subcontractors. Also a preliminary visit has been made to KSC.

The control system starts with documents which establish inspection points and procedures for major subcontractors as well as for RI. These are so selected as to assure that the quality and conformance of the work to this point can be verified.

The Manufacturing Verification system (MV) permits manufacturing personnel to inspect work in process. These inspection points are spelled out in the manufacturing operations record. MV stamps are issued only to qualified manufacturing personnel and will be withdrawn if the individual is careless in certifying to work which is not in conformance. The right to have an MV stamp is being developed to be a matter of pride to the individual so as to reduce the likelihood of work so stamped to fail in subsequent QA inspection. A similar process being established at KSC is called Designated Verification (DV).

The contractor quality assurance personnel are responsible for final in-process verification. In general, this QA signoff will include a determination that the previous MV stamped steps are correct. Only items which are previously determined to be non-critical are permitted to be passed by the MV procedure if they cannot be later picked up by the QA inspection.

Suitable Government agencies are used for final acceptance of the work. These are the Defense Contract Administration Services for RI and the majority of subcontractors, and Navy, Air Force or FAA in specific instances. From manufacturing flow plans and problem reports mandatory inspection points are set. NASA establishes controls, tests, and inspection, metrology and reporting systems.

The system is highly dependent on the use of personnel with a previous track record of experience and/or detailed extensive training. Common inspection requirements for manufacture, assembly, and pre- and post-flight aid in the human factor. Use of streamers (red flags) on non-flight hardware with numbered records of their addition and removal decreases the likelihood of leaving such articles on during flight. Detailed test and checkout procedures are used to assure correct positioning of valves, switches and so forth.

The basis of confidence in the system may be summarized as follows:

1. audits show no significant deficiency in the system;

2. surveillance inspections correct any physical discrepancies on the spot;

3. systems are progressively improved;

4. fewer problems are found on each flight; and

5. statistics show that most discrepancies are found before final inspection, a better average than industry in general.

There remain concerns which must be continuously watched. People will fail to follow instructions, especially if not clearly written, or written without concern for the human element. Changes can confuse people. Over-familiarity with the system may cause some people to bypass procedures.

The need for continual updating of inspection checklists, modifications, and temporary installations give particular trouble because of lack of experience with these. Procedures for handling unexpected conditions, such as spills, must be reviewed and continually updated.

Implementation of the system defined herein has reduced human errors. Continued monitoring is required to assure that all disciplines and controls are maintained. Corrective action must consider the contribution of human errors to all discrepant situations.

NEW PROJECTS

Thus far today the speakers have concerned themselves with the Panel's traditional role in the Space Shuttle program where we have been concerned with the safety of man in space--our Number One Priority. It now seems appropriate to extend a portion of the interest and activities of the Panel to NASA's aeronautic and non-manned space activities. In order to introduce the Panel to this area we have met earlier today with Dr. James J. Kramer, NASA's Associate Administrator for Aeronautics and Space Technology, for a briefing on the general activities, and we intend to follow up with in-depth discussions with the appropriate programmatic people. In this endeavor we are fortunate to have on the Panel Drs. Himmel and Syvertson who are both involved in these NASA activities.

It is the Panel's intent to develop a schedule of its activities in NASA's areas other than manned space flight and to submit such a schedule for Headquarters' concurrence before we proceed. Suffice it to say that the Panel is very interested in these, new to it, activities, and will expect to make an effective contribution to these programs.

RETROSPECT

I joined the NASA Aerospace Safety Advisory Panel four years ago. During most of the time I have served with the Panel I was also on active duty as an Air Force Lieutenant General, serving as the Director of the Defense Nuclear Agency here in Washington. I have submitted my resignation from the Panel because of the demands of the position I accepted in industry when I retired from the military. I was most reluctant to leave the Aerospace Safety Advisory Panel, having found a great amount of satisfaction in the close association with the NASA staff, the industries which work with NASA, and with the very dedicated members of the Panel.

It also has been very exciting and rewarding dealing with some of the problems which have come to the attention of the Panel during this period. I believe the Panel has contributed valuably and hope that I had some small part in that contribution.

I must admit that initially I was somewhat reluctant to challenge or criticize anything NASA was doing. Frankly, NASA's successes had been so stupendous that I was almost overawed. I found, however, that even NASA was occasionally guilty of complacency, possibly because of those past successes. Occasionally I noted someone who was afflicted by the old syndrome of: "But we've always done it that way." So, soon I found myself playing the role of a hero worshiper who has realized that even his hero can occasionally be human. Perhaps even more important I found that the hero (NASA) was receptive to challenges. I found that NASA management at every level was highly aware of the need for criticism. I also found they were patient when we asked what often appeared to be silly questions. If indeed NASA was human, NASA was also eager to listen and quick to react. It certainly seems to me that NASA has responded promptly and thoroughly to the sometimes cynical input from the Aerospace Safety Advisory Panel.

I mentioned and must re-emphasize my reluctance to relinquish my association with the Panel. I really hate to give it up. It gets me right under this NASA badge. However, I must admit that my leaving is probably healthy for the Panel. I believe it is good to have some turnover in the membership of the Panel. A new critic is better than an old critic. Some new thoughts are good for the Panel, just as they are for NASA. Thus, I am sure that whoever replaces me on the Panel will enhance its value to NASA and to the Congress.

Perhaps I may offer a few suggestions. First, I believe that it may have been valuable to have had on the Panel an individual who had an active role with the Department of Defense. It seems to me that the close interface between NASA and DOD is most important in the development and deployment of the National Space Transportation System. I realize that both NASA and the DOD have exerted major efforts to assure such an interface. Yet I believe that effort can bear even further emphasis because of the fact that this system literally represents the total commitment of the United States for manned space activity and indeed for most of its space activity for the foreseeable future.

I believe it is essential that there be separate roles for NASA and DOD. However, I have seen some evidence of the jealous guarding of traditional roles and prerogatives. Because of the tremendous scope of the Space Shuttle program, because it is so important to the United States and indeed to the world, because it is unique and cannot be bound by tradition, I believe it is essential that both DOD and NASA challenge those roles. They should deliberately examine whether some traditional roles should be changed.

For example, I am aware that they have examined the command and control aspects of the Space Transportation System and that there is a consciousness of the need to avoid costly duplication. I am convinced NASA can perform this role for the DOD without any sacrifice of effectiveness and with due regard to the need for careful adherence to international treaties. I am aware that some of my DOD contemporaries may feel such remarks are heretical, but I believe most would agree. As I indicated, I am aware that this specific role has been discussed, but I urge continued attention.

As noted by Willis Hawkins, the operational mission of the Space Shuttle is really a new role for NASA, since all previous space ventures have been one-time flights. I would hope that NASA will draw heavily upon DOD operational safety, and maintenance experience, since the Space Shuttle clearly must serve as an operational aircraft as it returns to its soft landing and its turnaround operation. Going back to the remarks by Willis Hawkins, perhaps also more emphasis should be placed on the experience of the transport industry. Again, I know NASA and the Air Force are working closely together, probably even more closely since one of NASA's Center Directors is now the Under Secretary of the Air Force and an ex-Air Force Director of Laboratories is the Deputy Administrator of NASA. However, I wonder whether anyone has really set out to challenge those traditional roles. I suggest that the Aerospace Safety Advisory Panel might help to do so. In fact, I'll go even a bit further to recommend that the Panel's charter might be expanded to require it to look over DOD's shoulder as well as NASA's.

Finally, I would like to comment briefly about a role I believe the Panel has fulfilled. Often during the past four years I have noted that the Panel, working quietly with the NASA and industry management teams, has brought about change without fanfare and often without really surfacing the issue. In many cases the detailed conversations and working sessions in which the Panel participated have resulted in decisions which might otherwise have been missed, or at least delayed. In many cases there was no written report, no seeking of credit by either the Panel or the others involved. It has simply been good teamwork, and the personal satisfaction from such actions has been rewarding indeed. I realize that some of the Panel's activities require documentation and I believe the record shows abundant accomplishment. I suspect that those quiet accomplishments that were never written down are at least equally abundant.

Lest I appear bragadoccio, let me hasten to add that my personal contribution has been very small indeed. The Aerospace Safety Advisory Panel as a whole, and very ably led by its Chairman, Howard Nason, has provided some very dedicated and sustained efforts. I believe its individual members have served its charter extremely well and I appreciate having had the opportunity to serve with these fine people and this great organization.

APPENDIX B

STATEMENT TO SENATE SUBCOMMITTEE

on

SCIENCE, TECHNOLOGY AND SPACE

by the

AEROSPACE SAFETY ADVISORY PANEL

February 22, 1978

STATEMENT TO SENATE SUBCOMMITTEE

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SCIENCE, TECHNOLOGY AND SPACE

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AEROSPACE SAFETY ADVISORY PANEL

February 22, 1978

I am Herbert E. Grier, Chairman of the congressionally established Aerospace Safety Advisory Panel of the National Aeronautics and Space Administration. At your request I should like to acquaint you with our Panel, its method of operation, and our assessment of NASA's Shuttle program.

The "housekeeping" for the Panel and its staff of three people is done by NASA Headquarters, but the Panel itself is an independent body that schedules its own investigations and submits its annual reports to Congress and the NASA Administrator. The Panel feels an obligation to be a timely force in the management system, and reviews its findings with the appropriate people in NASA as the investigations are completed. Our relations with the programmatic groups are excellent and their responses to our comments are full and sincere. In fact, we find that we must be careful not to unwittingly trigger an undue response to a minor point.

The majority of the Panel members are from outside NASA and all are experienced in the management of technical expertise. The deliberations are such that each and every member is heard and independently contributes to our reports, which are a consensus, not a compromise.

The members of the Panel are listed below, and I have just recently been chosen to be Chairman. Mr. Howard K. Nason has been our most recent past Chairman, and Dr. Charles D. Harrington was the first Chairman when the Panel was established in 1968.

<u>Members, Aerospace Safety Advisory Panel</u>

Lt. Gen. Leighton I. Davis (USAF, Ret.)
Mr. Frank C. Di Luzio
Mr. Herbert E. Grier
Dr. Charles D. Harrington
Mr. Willis M. Hawkins
Dr. Seymour C. Himmel
Mr. John L. Kuranz
Mr. Howard K. Nason
Mr. Clarence A. Syvertson

Each of the members spend two to four days per month on Panel activities and, as Chairman, I spend from one to two weeks per month on behalf of the Panel.

The Panel's objective, and the limitation on the members' time, indicate that we can be expected to review NASA operations only to the extent necessary to judge the adequacy of the NASA management system to identify risks and to cope with them in a safe, efficient manner.

Before talking about the Shuttle specifically, I should like to make a few observations on the philosophy of management and the changes in that philosophy that we have perceived in NASA over the years.

NASA's early task was to implement a national commitment to space exploration in a specified time frame. In order to do this NASA had to develop not only the technology, but also the capability to solve unknown problems in a timely manner. The results were spectacular and the capability and expenditures massive. With changing priorities, a greater knowledge of space, and the shifting of emphasis from exploration to utilization, NASA experienced pressure to move into a success-oriented program plan for the development of the Shuttle. In such a program one assumes that the basics are known, accepts only the identified contingencies, and plans staff, hardware and facilities on this basis. If all works as planned this is by far the most economical way to accomplish a program. However, when unforeseen events do occur, the schedule must be relaxed and/or more funds made available to solve the unforeseen problems. Phrased another way, planned maximum economy must have some flexibility in budget and schedule. The Panel believes that this is an appropriate mode for Congress to ask NASA to operate in. If all involved understand the process, no undue or increased risks need to be incurred. The principal difficulty with success-oriented planning is the controversy that arises as to whether a contingency should have been or was planned for, and this causes a tendency to overlook the fact that success-oriented planning in a patient and understanding system will be the most economical.

The Panel's observations of the NASA management system have led it to the conclusion that the system is objective and competent, and while there were some initial learning problems in establishing success-oriented programming for a project as large and complex as Shuttle, safety does not seem to have been sacrificed as a result. We have, however, arrived at the conclusion that any restrictions of the test programs directly supporting the upcoming orbital flight tests must be carefully examined and weighed.

In its investigations and deliberations the Panel has obviously formed opinions on the state of the various parts of the projects. These opinions follow, grouped by the Panel's specific categories of fact-finding.

1. Mission Operations

The Panel has been preoccupied with the mission planning for the approach and landing test series. The ALT was pursued in an orderly manner and efficiently executed. This bodes well for the mission planning for the orbital flight tests, although it is completely different in scope and magnitude. The Panel is now reviewing the OFT planning and particularly the provision for the various abort contingencies. It is too early to evaluate this subject completely, but it seems to be off on the right foot with a team that has demonstrated competence in the ALT program.

2. Thermal Protection System

The Thermal Protection System is a problem of a different character. It is a new technology and must be evaluated by plasma arc testing of small samples. The desired thermal characteristics are so difficult to achieve that questions of bonding, fragility and reusability must of necessity take secondary roles during the development. Methods of inspection, refurbishment, replacement of bad tiles and perhaps even continued exposure to humid air at the launch sites must be determined from experience. We are continuing to monitor this program, but at present do not believe that the safety of the crew on the initial flight is at stake and feel that some of the other concerns must simply await full-scale testing. At this moment we feel that the economics of a conventional aluminum air frame are somewhat offset, but not overbalanced by what might be problems of reusability of the TPS tile.

3. Orbiter

We have deliberatley assigned the consideration of the Orbiter as a vehicle to our Panel member with the most experience in transport aircraft. The Orbiter in its intended use is a transport and should take advantage of the lessons learned in that industry. There are differences between the Shuttle and a transport, for instance, in the matter of certain mechanical system redundancies. We have brought this matter to the attention of the program and it has been thoroughly considered. We acknowledge the difficulty of making the Shuttle adhere to all the constraints of design of transport aircraft, particularly since it is now an experimental vehicle. However, the Panel feels that the routinely operated and maintained operational Shuttle would benefit from all critical subsystems being redundant.

One of the Orbiter subsystems that has been troublesome in the past is the Auxiliary Power Unit (APU). Initial runs were with less than optimum machines, and current progress seems to be resolving the difficulties. There is one problem, however, that is not yet resolved and that is the problem of hot restart. The catalyst bed is so hot when the machine is stopped that it will not restart properly unless the bed is cooled by being purged with a gas such as nitrogen or helium. The purge system was not considered vital in the early stages of design and was a weight tradeoff. The current mission profiles, particularly abort situations, make hot restart desirable and methods of accomplishing this are being considered. A purge or other cooling system may be necessary.

4. Propulsion

The Shuttle propulsion system consists of the three main engines, the propellant tank, and the two solid rocket boosters and interconnecting plumbing and wiring. Each of these components has its own set of problems and will be discussed in turn.

The Space Shuttle Main Engine (SSME) is perhaps the most obvious place where success-oriented planning may now be a problem. The time necessary to procure and/or modify turbopump hardware is so long that should current problems persist, schedules may have to slip. It is also apparent now that more basic development work at the component level should have been done. The original decisions were made by a number of people, and the fact that in this case the troubles have exceeded the norm should not be viewed as a breakdown of the system. In fact, there are some bright sides to the SSME situation. A high thrust, reusable throttleable engine has been built and has accumulated a significant operating time. The control of this engine by a computer operating in the engine environment has been eminently successful and represents a major breakthrough in engine control technology. The loads and speeds involved in the turbomachinery may, now that we are having difficulty, require some basic support work to the empirical machine design. It is the Panel's understanding that such activity, for instance, in turbine blade structural design, is now being used. The Panel is not comfortable with the current status of the SSME, but this is a matter of caution. We see evidence to indicate that a safe, serviceable engine can be made; however, current problems may impact schedules.

The propellant tank does not seem to have any major technical problems. Fluid flow and POGO phenomena seem to be under control and we feel that the matter of the tank's protuberances shedding ice can be solved. The plumbing, while massive in size, does not involve new technology and should present no critical problems.

The solid rocket boosters represent an increase in size of an established technology that seems to be behaving as predicted. We are monitoring this program, but feel that the issues, if any, are matters of quality control and tailoring rather than any significant new technical problems.

The recent investigation of a failure of a Delta vehicle caused by a strap-on solid booster is being carefully monitored by the Panel to make certain that any lesson learned there is fed into the Shuttle SRB program.

A fourth element of the propulsion system is the orbital maneuvering engine and small reaction control rockets. In the Shuttle picture these components have a lower priority than, for instance, the main engine. The Panel has just begun to look at these areas and has not formed conclusive opinions or judgments at this time.

5. Avionics

The Avionics for the approach and landing test series uncovered a few problem areas in computer management, but did not prevent a successful series of tests. The performance was in fact good. The Avionics task for the orbital flight tests, however, is much more complicated and extensive in that ascent, orbit and descent all have to be accomplished. The new computers with the double-density memories are a help, but current demands are crowding this new capability. This software load must be closely monitored. The Panel feels that the Avionics system will present no unmanageable problems, although the redundancy management of the computers themselves must be thoroughly explored for failure modes that might shut down all computers.

6. Hazard Assessment

The subject of hazard assessment is not one of the Shuttle subsystems, but is vital to the understanding of the risks associated with the Shuttle operations. The Panel has been interested in this area for some time and has played a role in getting a more complete involvement of the various program groups in the evaluation of hazards, both individually and cumulatively. The Panel has been investigating the need for an independent audit or review of the Avionics system. We are concerned with the rapidity with which the double-density memory capability was used up, and feel that rigorous controls must be established.

7. Control of Human Error

The Panel has been concerned that the massive effort on the Shuttle program could be compromised by a relatively insignificant failure on the part of a person who had either not been properly trained or who had not been given due consideration in the man-machine interface. The solution to this problem takes the form of training, checklists, and people-oriented design. The Panel is concerned that this problem may be overlooked in the press of the severe technical challenges that exist in many parts of the program. When the "chips are down" these pedestrian problems can be crucial and frustrating.

Another aspect of human error is the control of processes where specifications are incomplete or, of necessity, imprecise. The resulting personal interpretation or inadvertent deviation can be of major importance. The Panel is investigating the control of this factor to evaluate its importance.

8. Payload Hazard Assessment

An area of concern to the Panel and one it is now pursuing is that of the compatabilty from a risk point of view of the Shuttle with its intended payloads. In any payload/Shuttle interface the same rigorous design, test, and inspection procedures must be observed, and crew training, including simulation, must be accomplished. It is important that the combination of Shuttle and payload be safe, but in addition, effective.

9. Launch Preparation

A review of the orbital tests is incomplete without mention of launch preparation and logistics. However, the Panel's attention has to date been on the Shuttle itself rather than on the launch operations. This has been an appropriate emphasis, and the Panel is beginning to study the launch operation.

In summary, the Panel views the Shuttle program more philosophically than the program personnel; hence, when asked "What are the major safety problems in the Shuttle?" we tend to answer in a framework that is different than that of a person or group involved in specific technical problems and their solutions. At the present time we feel that one of the important safety considerations is the effect of the schedule driving technical people to make "fixes" rather than to engineer the solution to a problem.

Secondly, we are concerned that further cutbacks in testing may jeopardize the verification of the capability of subsystems to meet the demands placed upon them. This is particularly true of non-redundant systems and software where extensive testing is the only way to explore all the variations of input that might produce an improper output. Allied to this is the concern that the computer and its new memory do not have the capacity margin that was envisioned when the double-density memory was designed.

We also are concerned with the criteria for development of new technology which requires both performance and long life in the initial product. The normal stages of a development are to attain the performance and then, from experience, make the modifications to attain the required life. In areas of new technology such as the main engine it is difficult to achieve both final life and initial performance in one step.

The Panel views its role as bringing these questions to management's attention rather than submitting specific solutions to a current technical problem. We monitor these problems as indicators of the state of the development, and we feel that the program has responded appropriately. This procedure will produce a safe and effective Shuttle whose life will be verified by the flight test program, but whose schedule may be impacted if current problems do not respond in a timely manner.

We should emphasize that in the presentation to NASA of our comments and independent point of view we are more than satisfied with the programmatic response and attention that senior NASA management gives our opinions. The Panel's audit does contribute to a safe and effective NASA program.

APPENDIX C

1977

PANEL MEETINGS

and

FACT-FINDING MEETINGS

1977 PANEL MEETINGS

January 14 — Status of Preparations for ALT Program - JSC

Mission Operations

Mission rules and contingency plans, including provisions for emergency separation and jettison. Handling of anomalies in terms of their proper resolution and assessment of impact on subsequent flights.

Shuttle Carrier Aircraft

Remaining open items which when closed complete certification of the aircraft for the ALT program.

Mated aerodynamics, performance and flight controls as to their effect on structure and pilot control.

Orbiter

Potential impact of modifications deferred from Palmdale to DFRC on the flight schedule for inert Orbiter flights.

Results of CARR and remaining certification work for the first all-up systems manned Orbiter flight. Differences between doing integrated tests at DFRC and Palmdale.

April 13 — Status of Preparations for Manned Active Flights in ALT - DFRC

Overview of inert captive flight test results. This covered dynamics, performance, loads, stability and control and separation. The purpose was to assess whether results were as predicted and to evaluate any anomalies.

Manufacturing and test status of the Orbiter. This covered the remaining manufacturing and retest activities and the scope of the Delta integrated checkout to assure the vehicle would be ready for flight. Particular attention was given to the APU.

Review of the flight test program with the active Orbiter to review the current objectives and the associated mission and contingency planning.

April 14 — Review of Detailed Inspection of Following Areas — Rockwell/Downey

The method by which systems certification for the entire Orbiter is accomplished prior to flight. This included APUs, hydraulic systems, control system, main computers, backup computer and control system, cockpit equipment, etc.

Exceptions to spec performance. This focused on the significance of these exceptions as constraints on a safe mission.

Changes made to the Orbiter since it left Palmdale and the contractor's visibility and control over the checkout process by which the newly installed equipment had been certified before it was assembled.

July 18, 19 — Review of Results of Captive/Active Flights and Work Remaining before FAL - JSC

The objective as in the other inspections was to assess the developing basis of confidence for proceeding with the next series of flights, the major risk involved and problems remaining to be resolved. The agenda included the following.

Certification of the Orbiter for the aerodynamic load envelope based on captive/active flights and analyses.

Orbiter subsystems, covering the performance and anomalies of the APU and hydraulic system, Avionics hardware and software and flight control system during captive/active flights. In addition, a review of the anomalies on the remaining systems was conducted.

Remaining work on Orbiter subsystems, covering modifications to bring the vehicle into configuration for the first free approach and landing test, and a summary of certification status.

Major risks accepted for this series of flights, including control of such hazards as the APU hydrazine leak into the Orbiter as on the first captive/active flight 1-A.

October 11 — Review of Program Director's Policy and Plans for Orbital Flight Test Program — Washington, D.C.

Given the Panel's preoccupation with ALT the review of the Program Director's policy and plans for the orbital flight test program provided the Panel a status report on changes since their last review. In addition, the Panel received an assessment of aeronautics planning from the Associate Administrator for Aeronautics and Space Technology.

October 12 — Annual Meeting — Washington, D. C.

This is described in the body of the annual report and consisted of a presentation by each Panel member on his assessment of his area of responsibility.

December 14-15 — Assessment of the Adequacy of the Overall Test Program for OV 102 for Orbital Flight Test Program — Rockwell/Downey

This review was also to assess the acceptability of the plans to use the Structural Test Article as the orbital vehicle. Particular attention was given to the program changes since 1974 and the rationale for their acceptability. The review, therefore, covered the following:

Overview of certification-verification plan for the Orbiter.

Combined element verification plan.

Structures development and qualification testing.

Major ground test program covering the description, objectives and rationale for any changes in the main propulsion test program, the mated vehicle ground vibration test and one-quarter scale tests, flight control hydraulics, laboratory tests and the Avionics tests in the ADL and SAIL laboratories. Attention also was given to the OMS and RCS tests at White Sands as well as the vibro-acoustics tests.

Rationale for the use of the Structural Test Article as OV-99 orbital flight vehicle.

Simulated flight test plan on the integrated flight vehicle and software.

1977 FACT-FINDING MEETINGS
by
Individual Panel Members

January 21	Held meeting concerning flight control systems and APU.	Rockwell/Downey
February 2	Held meeting with Mr. John F. Yardley, Associate Administrator for Office of Space Flight regarding Shuttle program.	Washington, D.C.
February 3	Attended Flight Readiness Review of ALT flight.	DFRC
February 22	Conducted review of Space Shuttle Main Engine "Review Item Discrepancy"(RID) status resulting from SSME Critical Design Review conducted in October 1976.	MSFC
February 23-25	Participated in Space Shuttle Level II Hazards Screening Board as contributing member.	JSC
March 2	Witnessed captive ALT flight.	DFRC
March 25	Participated in Center Management SSME Quarterly Review, obtaining updated engine status and NASA/Contractor activities.	MSFC
May 2-4	Participated in Hazards Screening Board to examine Orbiter 101 regarding upcoming ALT program. Reviewed subsystems and particularly single point failure concerns.	JSC
May 18	Attended ALT Flight Readiness Review.	DFRC
June 1	Attended meeting with Rockwell personnel concerning the APU, the hydraulic system and status of Avionics.	Rockwell/Downey
June 14	Attended Mission Readiness Review.	DFRC
June 21	Attended meeting with NASA administration personnel.	Washington, D.C.
June 28	Witnessed ALT flight.	DFRC
July 7	Attended meeting with NASA Administrator and Deputy Administrator, Drs. Frosch and Lovelace.	Washington, D. C.

July 14	Attended administrative meeting at NASA Headquarters.	Washington, D. C.
July 17-18	Attended meeting for fact-finding on Thermal Protection System.	ARC
July 18	Held review of specific concerns associated with SSME turbomachinery and the engine test program.	Rocketdyne
July 27	Attended Mission Control conduct of an ALT flight.	JSC
July 29	Held administrative meeting with NASA Administrator and Deputy Administrator, Drs. Frosch and Lovelace.	Lockheed
August 2	Attended meeting investigating hydrazine leak during captive flight.	Rockwell/Downey
August 2	Participated in Center Management Quarterly Review, obtaining updated engine status and NASA/Contractor activities.	MSFC
August 8	Attended Flight Readiness and Technical Readiness Reviews for active Space Shuttle Orbiter.	DFRC
August 24	Held discussions concerning methods used to control and check upon human error. Modified inspection systems were described, including Designated Verification.	KSC
August 26	Held meeting with General Accounting Office personnel concerning Shuttle's critical elements.	Lockheed
August 30	Witnessed conduct of ALT flight.	DFRC
August 31	Held administrative meeting with Assistant Administrator for DOD and Interagency Affairs and Panel staff.	Washington, D. C.
September 9	Attended Entry Working Group meeting to review status of Shuttle aerodynamics characteristics with emphasis on flight test results versus wind tunnel tests and analysis based on ALT data.	JSC
September 13	Attended Mission Readiness Review and observed second manned free flight.	DFRC

September 13	Held meeting concerning APU.	Sunstrand
September 26	Held discussions regarding Shuttle problems.	Rockwell
October 4-6	Examined the approach and methodology used by NASA and its Contractors in their risk assessment activities and definition of aggregate risk for a Shuttle mission.	JSC
October 5	Held administrative meeting with NASA Headquarters personnel.	Washington, D.C.
October 5-7	Held discussions concerning Manufacturing Verification as applied by Rockwell International and direct subcontractors to control of human error. Application to sub-tier contractors is dependent upon paperwork control at this time.	Palmdale, Rockwell
October 25	Attended review of results of ALT flights.	Rockwell/Downey
November 14	Attended review of ALT ferry considerations.	DFRC
November 29-30	Participated in SSME Quarterly Review and conducted status review of Shuttle External Tank and Solid Rocket Booster programs.	MSFC
November 30	Attended meeting of investigative board concerning Atlas Centaur failure.	General Dynamics Convair
December 2	Attended investigative meeting concerning payloads.	ARC
December 8-9	Attended administrative meetings; fact-finding on payloads, Spacelab, aircraft programs and Shuttle.	Washington, D.C.
December 16	Attended meeting concerning payloads.	ARC
December 20	Held administrative meetings with NASA Administrator.	Washington, D.C.