NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

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Reply to Attn of: LB-4

TO: A/Administrator
AD/Deputy Administrator

THRU: L/Associate Administrator for
External Relations

FROM: LB-4/Special Assistant, Aerospace
Safety Advisory Panel

SUBJECT: Annual Report of the Aerospace Safety
Advisory Panel

On behalf of the Panel and with the Panel Chairman's concurrence, I am submitting the Panel's annual report to the Administrator covering the Calendar Year 1978.

The activities of the Panel were reported to you at the public meeting on November 30, 1978. During this meeting each of the members reported on his area of investigation. The first twelve (12) pages of this report summarize their findings, conclusions, and recommendations. Individual reports are attached as Appendix A, and the record of Panel activities is outlined in Appendix B.

John Yardley and his people have reviewed the final draft and Herb Grier and John discussed the report on January 25. The Panel is scheduled to testify before Senator Stevenson's subcommittee on February 22, and it is our understanding that the Hill staffs have requested copies of the annual report be supplied prior to that date.

With your approval, we will provide copies of the annual report to Legislative Affairs for their distribution and will also make our normal distribution within NASA and to the Library of Congress.

Gil Roth

Gilbert L. Roth

ANNUAL REPORT

to

DR. ROBERT A. FROSCH, NASA ADMINISTRATOR

by the

AEROSPACE SAFETY ADVISORY PANEL

Calendar Year 1978

ANNUAL REPORT
to
Dr. Robert A. Frosch, NASA Administrator
by the
Aerospace Safety Advisory Panel

Calendar Year 1978

The activities of the Aerospace Safety Advisory Panel during Calendar Year 1978 were reported to Dr. Robert A. Frosch, NASA Administrator, at a public meeting in Washington, D. C., on November 30, 1978. During this meeting each of the Panel members reported on his area of investigation during the year. These individual reports are attached as Appendix A, and the record of Panel meetings and other activities is outlined in Appendix B. The 1978 schedule was similar to that of 1977 in that formal meetings were held approximately bi-monthly and the interim activity was fact-finding by the individual Panel members in their particular assigned activities. The 1978 assignments were:

1. Aeronautical Programs - Mr. J. L. Kuranz
2. Avionics - Mr. H. E. Grier
3. Operations and Training - Mr. L. I. Davis
4. Orbiter - Mr. W. M. Hawkins
5. Payloads - Mr. H. K. Nason
6. Product Assurance - Dr. C. D. Harrington
7. Propulsion - Dr. S. C. Himmel
8. Risk Management - Mr. F. C. Di Luzio
9. Thermal Protection System - Mr. C. A. Syvertson

During the past year the major emphasis of the Panel's work has been on the Shuttle, its payloads, and the preparations for the upcoming first manned orbital flight, although one of our members has been looking at NASA's aeronautical programs. The thrust of our 1978 investigations thus is the state of preparations for the safe manned orbital flight as we perceive it.

We believe the Shuttle and its components as now configured are satisfactory for the first manned orbital flight. There are many problems still to be solved, but few to be resolved if we may draw a distinction between known problems that simply require man-hours and problems that are not fully understood. There are as many opinions on the various elements of the Shuttle as there are people who have looked at them, but our considered opinion is that the machine will fly well, but the schedule (9-79) will depend on individual problems that may crop up. However, at the present we do not foresee long delays in the current schedule (9-79). Later in this report we are going to recommend that studies be initiated to reaffirm the philosophy and implementation of certain aspects of the Shuttle in the light of its use as an operational vehicle and in the light of the state of the art today. These recommendations are not reservations on the Panel's part as to the readiness for the first manned orbital flight.

During 1978 there was a plan to use the second Shuttle mission as an opportunity to either re-boost or de-boost the Skylab in order to reduce any possible dangers from its return from orbit to earth. Several of the Panel members looked at this in the course of their individual fact-finding, and the Panel concluded that this was possible, but that great care should be taken to make sure that the mission parameters and equipment utilized would be thoroughly tested both on the ground and on the first flight. Such a program, coupled with the uncertainty of Skylab's return from orbit, led the Panel to conclude that the exercise might well not be completed in time, when considering the uncertainty of the actual date of the first flight of the Shuttle. This point is now moot, because during the writing of this report the decision was made not to attempt the exercise.

The scheduled date of the first flight of the Shuttle at the time that this report closes, December 31, 1978, was September 1979. In order to prevent confusion with various schedule dates where it is important, we have indicated this date in the text of the report.

In the following paragraphs we will summarize the salient points of our investigation during 1978 of the various areas that the Panel has considered. This will be followed by conclusions.

1. Aeronautical Programs

The Panel's activity in NASA's aeronautical programs has been to acquaint ourselves with the various programs and the cognizant center for each, and then to discover the means that each center uses to assure that safety is adequately considered in the broad sense. As one might expect, not all centers use the same procedures and documentation, but we perceive a satisfactory awareness and implementation of safety in the various developments. This work to date would lead us to believe that there is no need to impose a uniform system. Our efforts next year will concern themselves with the substance of the programs and the safety consciousness of the contractors now that we have observed that there are satisfactory safety procedures and awareness at the various involved centers. In this investigation of NASA's "non-Shuttle" activities we are giving our attention to developmental projects wherein equipment is produced and tested in a mode that presents either a NASA or a public risk.

2. Avionics

The Avionics system has matured during 1978. The new computer has taken the pressure off the software system, has itself been overloaded, but is now scrubbed to a comfortable margin. The software is progressing satisfactorily in light of the external constraints, i.e., the new computer and its changing utilization, but the software users see late deliveries and hence little time for their own testing. The entire system verification must be done and the schedule (9-79) could be impacted. A major step forward has been the involvement of system and sub-system designers in the specification, conduct, and analysis of the verification testing. The result is a true end-to-end exercise of a given system within its appropriate limits. This real system testing of coupled hardware and software gives the Panel confidence that Avionics will not be a technical constraint on the first flight. Its effect on schedule (9-79) is not as clear, but we do not see any substantial danger to meeting the schedule (9-79). During the year an on-going independent assessment of the software program was established and is functioning. No major problems have surfaced, but the confirmation is important because of the extreme importance of the software to all aspects of the Shuttle.

3. Operations

The earlier approach and landing tests were simple exercises compared to the operations involved in the first orbital mission. In 1978 the operations task consisted of developing the ground support system and training the personnel, as well as verifying the readiness of all the parts. In order to verify the entire system, a unit of the launch processing system is included in the Avionics integration facility.

The launch facility at Kennedy Space Center is the end of the line, and there is a tendency to pass along work from other parts of the program that have not been able to make their schedule. This is a perfectly reasonable procedure unless it compromises the activities that should be pursued related to Kennedy Space Center's own responsibility for launch preparations.

Delayed delivery of final software for the flight simulators may affect the schedule of pilot training and contributes to our caution that final schedules must allow for all testing to complete training and verification.

The problem of pilot-induced oscillation that appeared during the last flight of the approach and landing test series has been receiving much attention. Now that the pilots are aware of this problem the Panel does not think that it is a constraint at this time, but must eventually be resolved.

4. Orbiter

The Panel believes that the Orbiter and its attendant systems will be satisfactory for the initial orbital flight series. However, the space transportation system may well impose a different set of problems of a routine operational nature that may require some modification of the Shuttle and certain of its systems. Studies should be undertaken to identify such problem areas and to specify needed changes, if any.

In the past the Panel has suggested that commercial air transport experience should be considered in review of the Orbiter design for operational use. This tends to be a broad comment difficult to define. In 1979 the Panel intends to identify areas wherein it feels that the commercial experience will be most applicable.

It is important that any assessment of the Orbiter and its systems be started early so that the proper information can be gathered on the early orbital flights. The Panel should restate its conviction that the current Shuttle development is not only appropriate, but brilliant. Once established and proven as a reliable vehicle, the Shuttle will be affected by the requirements of a routine common carrier.

5. Payloads

During 1978 the Panel began an investigation of the payloads to be flown on the Shuttle with initial emphasis on the European Spacelab. The European Space Agency is at a disadvantage in that it does not have the wealth of programmatic experience that NASA has and, as NASA, is under budgetary constraints. In spite of this, work is progressing and the main problem will be to insure effective integrations of the Space Lab into the Shuttle and the NASA system.

Where applicable the Space Lab should be subject to the same rigorous verification testing as the Shuttle and its elements. The integration effort might be helped if NASA would conduct a "walk through" of the Space Lab. Not only would NASA become more familiar with the Space Lab, but the Europeans would get a little more insight into NASA and its requirements.

6. Product Assurance - Control of Human Error

In past years the Panel has emphasized the importance of systems and procedures in the area of quality assurance. These systems are in place, and recently we have been monitoring the effectiveness of the systems as used by the contractors in producing qualified hardware. In 1978 we concerned ourselves primarily with the prime contractors, and in 1979 expect to assess the quality assurance activities of subcontractors. To date we have found adequate systems in place and a strong desire on the part of the individual workers to make quality hardware and to implement the systems. The resultant performance seems to be satisfactory.

7. Propulsion

The propulsion system has been a source of concern for many people, but the Panel feels that the serious, underlying problems have been corrected and that the feasibility of the main engine has been demonstrated. We would not be surprised if other troubles show up, but we believe they will not be critical from a technical sense, but may impact schedule (9-79) due to the hardware shortage.

The solid rockets seem to be performing well, and problems that have arisen have been solved. The external tank is in much the same position. We would expect it to support the scheduled mission (9-79). Priorities have caused the Panel to delay its scrutiny of the orbital maneuvering engines and the reaction control system. We have followed their reported progress and expect to look at them in more detail in 1979.

8. <u>Risk Management</u>

The area of risk management is, like product assurance, another case of making sure that quality is not being sacrificed in the current push. We do not believe that it is, and as a matter of fact, believe that although we do not know how to simply quantify aggregate risk, the risk management system is better understood and operating this year than it was last year. We think that this is a significant statement because the awareness and control of risk in a big project is not a thing easily implemented. Many people throughout the entire system have conscientiously contributed. They should be congratulated. The more the Panel sees of the risk management problem and process the more it realizes that it is not "black and white," but is judgmental in nature. In this circumstance one can neither be safely right nor completely wrong, and hence eternal vigilance is the only way to minimize risks that will be perceived differently from different points of view and by different people.

9. Thermal Protection System

The Thermal Protection System was beyond "state of the art" at the time of its inception. The Panel believes the solution developed will satisfactorily protect the crew and vehicle on the first flight. We don't believe that we will really know about life of the tiles until after the first few flights. The remaining problems are simply manufacture and installation, and this could well be the pacing schedule (9-79) item. It is interesting to note that in the process of the development, second generation materials have appeared that may make succeeding thermal protection systems simpler and cheaper and, depending on first flight results, perhaps lighter. The life of thermal seals required by moving parts and closures also will not be known with certainty until after the first few flights.

Conclusions

The Panel has concluded that the Shuttle, as a development vehicle, will be ready to fly, and probably on the currently scheduled date (9-79). During our investigations we have gradually come to the conclusion that NASA should review certain philosophies, designs, equipment and procedures to make certain that they are what is required for the Shuttle as it becomes an operational vehicle in the space transportation system. There are several good reasons for this. First, we will have had hard data from the initial flights; second, the state of the art in some areas has progressed since the Shuttle specifications were set. Third, the very act of designing and constructing the Shuttle has resulted in the NASA team being in a position to modify the design of the Shuttle from an operational rather than a developmental point of view. For instance, weight reductions become much easier to accomplish after real flight experience indicates the margins in an engineer's original design. The Panel believes that the Shuttle as it is today is appropriate and, in fact, is a marvelous achievement. From our vantage point we now see the emphasis shifting to the problems of reusable operation from those of technical breakthrough, and believe it is not too soon for NASA to review the Shuttle design from this point of view.

While we do not presume to be able at this time to outline the entire review program, we can supply a few illustrations.

First, a review of the redundancy philosophy should be undertaken to make certain that it is optimum; for instance, the backup flight system is loadable in any computer memory. Does this obviate the need for a dedicated fifth computer? There are also some anomalies such as four computers and three hydraulic systems that introduce components that can fail more than one primary string.

Second, the problem of design to commercial aviation philosophies should be reviewed in the light of the operational maintenance and failure experience that commercial aviation has experienced.

Third, we feel that the Auxiliary Power Unit is somewhat ahead of the state of the art and should be reviewed from the point of view of either improving its performance or replacing it.

There just doesn't seem to be that much experience with hydrazine-fired APUs to demonstrate that they can be a prosaic, dependable component that one can consider as an accessory.

Fourth, we feel that the question of the necessity for controlled gimballing of the solid rocket should be reviewed. The weight and cost savings, along with the system simplification, would be attractive.

Fifth, a review of the main engine "red lines" should be made to see if some of the developmental constraints could be widened, eliminated, or combined with other engine "critical parameters." The obvious goal is to make sure that purely instrumentation factors don't shut down a good engine at a critical time.

Sixth, a review of the pilot-computer workload and its division should be made to make the pilots' task a little less heroic. The hundreds of controls, displays and switches now in use are just too many for a routine operational vehicle and a more formal or better division of work between the two pilots and the automatic system will be a step forward.

Seventh, the matter of range safety needs more study. The Panel would recommend that NASA do an exercise of resolving the problem, assuming that NASA is responsible for range safety as well as the Shuttle. This will insure that a solution will be postulated independently of different agencies having varying responsibilities. Such a solution will be a starting point for negotiating between NASA and the Range Safety Officer.

The identification of the appropriate subjects for review might be hastened if the responsibility for the operation of the space transportation system were organizationally separated from the research and development groups. In any event, in the Panel's opinion, the NASA system, now having created the machine, has the responsibility to review their work in light of the Shuttle performance to make certain that it is, in fact, optimum for its proposed commercial use.

In the past the Panel has urged that for its operational use the Shuttle should make more use of the experience and criteria of commercial transport aircraft. We realize that this comment is too broad in that the Shuttle and a commercial aircraft are two different things. During 1979 the Panel will attempt to identify more precisely those areas in which it feels that commercial criteria should influence future Shuttle designs.

We must repeat: Today's Shuttle for today's mission is appropriate.

APPENDIX A

AEROSPACE SAFETY ADVISORY PANEL

ANNUAL MEETING

before the

NASA ADMINISTRATOR

November 30, 1978

AEROSPACE SAFETY ADVISORY PANEL

ANNUAL MEETING

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Agenda

Introduction................................	H. E. Grier
Aeronautical Programs.....................	J. L. Kuranz
Avionics..................................	H. E. Grier
Operations and Training...................	L. I. Davis
Orbiter Evaluation........................	W. M. Hawkins
Space Transportation System-Payloads......	H. K. Nason
Control of Human Error....................	C. D. Harrington
Propulsion System.........................	S. C. Himmel
Risk Assessment...........................	F. C. Di Luzio
Thermal Protection System.................	C. A. Syvertson

AERONAUTICAL PROGRAMS

J. L. Kuranz

As projected in the Aerospace Safety Advisory Panel's annual report for the calendar year 1977, the Panel has initiated efforts to examine and assess the management system and its implementation by the various NASA centers to assure the highest degree of flight and ground safety for the research aircraft program. The objective of this Panel effort is to provide the Administrator with the results of such assessments, i.e., observations, conclusions and recommendations. For those areas in which we express safety concerns, management's mode of resolution will be noted wherever possible.

The Panel's focus has been on the following programs based on the indicated interest of NASA's senior management:

1. Quiet Short-Haul Research Aircraft
2. Stall/Spin Research Aircraft
3. Highly Maneuverable Aircraft Technology
4. Tilt Rotor Research Aircraft
5. Rotor System Research Aircraft

Information briefings were held with the Office of Aeronautics and Space Technology, Headquarters, prior to fact-finding visits to Ames, Langley and Dryden Research Centers. Additionally, flight safety directives and instructions were obtained from Langely, Dryden, Ames, and Wallops flight centers. Detailed fact-finding was accomplished at Langely on the Rotor System Research Aircraft and Stall/Spin programs; Dryden provided insight on the

Highly Maneuverable Aircraft Technology and other research aircraft testing; Ames and Boeing gave an opportunity to examine the written philosophy and procedures for risk management as well as their real-life implementation. The Panel is appreciative of the candid cooperation of the centers in our fact-findings.

From these early activities the Panel presents the following summary observations.

1. Safety of ground and flight crews, aircraft and the environment are paramount factors in the design, construction, flight planning and test operations. The attitude was consistent in all facilities visited. Although cost and schedule are highly important considerations at all times, safety in all its aspects appears not to have been compromised by either. Confidence in assuring safety and successful programs is further supported by the "free forum" atmosphere that safety is everyone's concern and responsibility, from the top to the bottom. The Panel plans to examine the progress of each of the subject research programs to determine if this remains constant.

2. There exists at each of the centers and the contractors visited management systems and documentation to assess and control both design and operational safety issues. While these methods differ from one another, the emphasis on all clearly puts safety as the dominant criteria. The Panel feels that the differences in systems reflects unique requirements and that all

the centers' systems are adequate to meet program safety needs. The Panel believes that a uniform system/documentation is not required or warranted.

3. Successful management of high technology programs requires able managers utilizing good management systems with the major emphasis on good managers. In the case of contracted programs, this ability should also extend to the contractors who must have special competence in Research and Development.

The Panel studies of the quality assurance program at the Ames Research Center showed that the success achieved was due largely to very capable managers at NASA and Boeing utilizing effective management systems. Boeing facilities and experience in development of special purpose aircraft were valuable in the conduct of the Quiet Short-Haul Research Aircraft development program. The Panel believes that such experience is very important to the effective and safe conduct of aeronautics development programs. This research aircraft will serve to investigate the application of advanced propulsion and high lift systems for transport aircraft.

4. Flight testing of aircraft with unrecoverable spin modes is approached through wind tunnel and dynamically scaled radio-controlled model evaluation prior to manned flight tests. This is in addition to the normal safety reviews that are applied to each aircraft modification. This program has established, at Langely, a flight test facility, procedures and equipment which

provide a sophisticated system for general aviation stall/spin research.

5. Very advanced aerodynamic and structural concepts are being studied under the Highly Maneuverable Aircraft Technology program at Dryden. This sophisticated high performance vehicle is of the remotely piloted type which will utilize new flight testing methods for advanced aircraft systems.

The Highly Maneuverable Aircraft is sized down from full scale and is remotely piloted. It is significant to note that no fewer support personnel are utilized on typical flight tests of remotely piloted vehicles than piloted vehicles. The total program, however, is expected to yield design data for such new aircraft at lower cost and shorter time with less risk. Lower vehicle cost is expected because of aircraft size and the absence of the usual on-board pilot requirements. Shorter test programs can be expected due to fewer flights because more extensive flight envelope expansion can be performed on each flight. Less risk can be expected because abort options need not be considered in the same light as with an on-board pilot.

6. The Tilt Rotor Research Program at Ames with Bell aims to verify the viability of a tilt rotor concept and to verify a solution of rotor aerolastic stability.

7. The Rotor System Research Aircraft at Ames is a flight research aircraft for the study of advanced rotor concepts and the verification of rotor-craft analytical predictions.

Panel activities during the calendar year 1979 will include more extensive review of the foregoing programs through in-house NASA program meetings and fact-finding sessions at appropriate contractors to view their risk management systems at work.

AVIONICS

Herbert E. Grier

The Aerospace Safety Advisory Panel's 1977 report acknowledged the satisfactory performance of the avionics system during the approach and landing tests. It recognized this as a proof of concept and drew the conclusion that the problems to be faced before the first manned orbital flight were those of a new computer, a greatly increased magnitude of task, and the time and patience to verify the adequacy of the software programs. Significantly, the Panel accepted the fact that the hardware was in principle satisfactory and, although we expected "bugs" to show up, we did not expect problems that could not be resolved.

The Panel's monitoring of the avionics system during 1978 has indicated that progress has been made in all the areas of concern, and the Panel today does not expect the avionics system to be a constraint on the proposed launch of the first manned orbital flight next year (9-79). The Panel once again cautions that flexibility of schedule must be planned for if the verification testing is delayed significantly. We should also point up the fact that the backup flight system is operating in a much different mode than it did in the approach and landing tests. As a result, its verification deserves special scrutiny. Included in the Panel's assessment of the avionics system is not only the schedule factor, but we should emphasize that we do not see an undue risk to the flight from the avionics system.

The acquisition of the new computer with the enlarged memory was somewhat like the fat man with a new pair of trousers--shortly they were full--and we found ourselves with the new memory overloaded. The program instituted a series of scrubs and controls that today has resulted in a memory load with an appropriate margin, i.e., 20 to 30 percent. The computer itself has had some bugs that have turned out to be explainable, and fixable, mechanical or electrical problems. We would expect to arrive at the conclusion that the computer is satisfactory as a result of the verification testing.

The avionics hardware has proven itself from a conceptual point of view, and one would not expect failures to show up that diligent effort could not resolve, even though such occurrences could affect schedules (9-79). This is not to say that one can relax, because when either a mechanical or electrical failures occurs, it must be analyzed to make certain that it is an individual, not a generic occurrence. The program is sensitive to this problem and the Panel is comfortable with the extent of the failure analysis being performed and the conclusions being drawn.

There is an incipient hardware, i.e., memory problem on the horizon that is not a constraint to the first flight, but which will bear investigation after the flight. There is evidence that radiation in space can cause a change in state of a very few random individual memory units; that is, a zero can change to a one, or vice versa. At present it is almost impossible to quantify the hazard from this phenomenon and the shuttle redundancy system should protect against it, but it might become a factor in extended missions and should be monitored before and after the early flights.

The development of software is proceeding very satisfactorily, and scheduled deliveries are being made of usable programs to support the project. Early on, the memory units were overloaded and a series of scrubs followed that now leave a comfortable margin in the memory. The system is in place and working to control changes that may unduly erode our margin. It should be pointed out, though, that as we get nearer to flight time, system or hardware problems that arise will almost inevitably be resolved by software changes. This is a fact of life, and we must have sufficient time to verify the acceptability of any such changes.

The Panel's early concept of the backup flight system as a dedicated computer with a simple set of software sitting there ready to save the day was much too simplistic. The application of the backup system to the orbital flight as opposed to the approach and landing tests results in a much more complicated set of software loadable into any one of the computers and requiring extensive verification. The verification is difficult because it is not easy to postulate all the system conditions that may result in a crew decision to activate the backup system.

This brings us to the matter of the verification system for the avionics. In the past the Panel has talked about the verification of the software--which is done in the Software Development Laboratory--but now the program has expanded the avionics verification to include the shuttle system and the subsystem design elements. To do this makes mandatory the use of the Shuttle Avionics Integration Laboratory and the Avionics Development and Hydraulic Laboratories. This end-to-end verification to the satisfaction of and at the specification of the systems design group is ideal, and gives the Panel, and the program, confidence that when this testing is complete the avionics system will not post an unacceptable risk to the first manned orbital flight. The corollary is that the testing must be finished and is currently on a tight schedule that must be accommodated.

A new element that has appeared in the software picture is the software associated with the launch processing system. To the extent that this system is involved in the initialization of the shuttle for launch, it could affect hazards and should be included in any hazard analysis. The fact that the avionics integration facility includes a set of launch processing equipment should include these interactions in the verification process. We must be sure that this point is not slighted.

At the present time there is no avionics problem that we know of that should pace the program, and the avionics risks that we perceive are acceptable.

OPERATIONS AND TRAINING

Leighton I. Davis, Lt. Gen., USAF, Retired

This area of overview by the Aerospace Safety Advisory Panel is so broad and so weighted by the long experience of the officials and astronauts in the operations field that the following observations should be considered only as glimpses into the problems involved.

Selection and Training

The selection process and the extensive ground school and simulator training for astronauts ensure that an unsuitable individual is eliminated, that appropriate individuals and inherent skills are nurtured and expanded. A very important part of this procedure is flight and simulator training. Airplanes are modified in terms of control responses, sensitivities and other aerodynamic factors. The Grumman Shuttle Training aircraft at Ellington Air Force Base and others are examples. In addition, the stable of research aircraft operated by NASA and the USAF are exploited for any contribution that they can make to training, and to understanding the handling characteristics of aircraft that have similarities to the Shuttle.

Simulation

Fixed and moving base computer controlled simulators, with their instruments and displays, serve not only as procedural trainers, but are powerful tools in the design of cockpit arrangements, tailoring of checklists, elimination of unnecessary switches and controls, and in the development of emergency procedures.

Problems

a. The delivery and debugging of software is delaying the final engineering development of the simulators, and consequently the training that they make possible.

b. Simulation indicates that the 900+ switches and controls (over 1500 including circuit breakers and other gadgets) are just too many for a two-man crew to operate and monitor and, in fact, may become a confusing factor in an emergency.

Reentry Profiles

The astronauts feel that the flight profiles designed early in the program are too inflexible, and do not conserve the potential energy of altitude to an optimum degree. The astronauts would rather make a more overhead approach than dissipate energy by "S" turns during an in-plane approach to the runway. It is mentioned here as recognition of the weather problems at Kennedy, and perhaps the need for more flexibility in the approach to landing.

Errors in the Cockpit

Crew procedures and cockpit design and layout stress redundancy. All critical controls and switches, or the effect that they produce, can be seen by both pilots. This duplication increases the workload on each pilot, and consequently the individual error rate, however the redundancy resulting, is recognized as reducing the probability that both would make an undetected error, or overlook a necessary action. Where the increased workload is burdensome procedures are investigated to see if they can be changed to move the action to some other part of the sequence.

Pilot-Induced Oscillations

At the end of a Space Shuttle mission, the Orbiter is brought into a landing by the pilots under conventional aerodynamic control. As the runway approaches, the pilot's perception of errors in attitude, air speed, sink rate, direction, touchdown point, and altitude above the runway become sharpened--even intense. He is in effect closing the loop, trying to reduce the errors to zero and in an inherently unstable system. Data gathered during the ALT program tests using the moving base simulator, and tests configuring the Total In-Flight Simulation system to the Orbiter OFT control characteristics, confirm that pitch control on landing is very difficult.

Approach and landing tests demonstrated that landing can be accomplished safely, and one can say that the risk for the initial orbital flight is acceptable; but, these were and will be piloted by extremely competent pilots, with superb reaction times and years of experience in high performance aircraft. The pilots in the future operational phases of the STS will be a lot better than average; however, they may not have the intensive training and long experience typical of the present pilots. Fatigue, contingencies and weather may well decrease the margin of safety. Therefore, the Panel has investigated the pilot-induced oscillations that occurred on the last of the approach and landing tests. These oscillations are called pilot-induced, because if the pilot will release the control, the oscillation will stop. Such oscillations introduce not only the likely probability of catastrophic damage on landing, but more severe stresses on tires and landing gear. In addition it increases the uncertainty in setting the Orbiter down on the first third of the runway.

In a pitch control loop the so-called inner loop (Computer-Elevon-Airframe-Rategyro) can be made fairly tight and responsive. The pilot "closes" by detecting and taking action to correct a discrepancy between the desired angle of attack and altitude and the indicated values. The speed and force of his response determine the "gain" in his part of the loop; any delay represents a phase lag. If he concentrates on angle of attack, the loop includes a 90-degree phase lag due to the integration delay between pitch rate and pitch angle in addition to the delay that he introduces. Added to this are the delays in the hand controller, the sampling delays, any smoothing delays in the computer, and delays in the servo drive to the elevon. The greater these delays, or representative phase angles, the more difficult it is for the pilot to properly close the loop; hence, an oscillation can result.

If the pilot concentrates on the rate of climb indication, the pertinent loop includes the rather nasty elevon-camber-lift elements. If he concentrates on altitude, he operates a loop that contains another integration, that of rate-of-climb to altitude; therefore, the phase lag around that loop is at least 180 degrees.

During briefings to the Panel at Johnson, we were shown data "Orbiter Response to Step Input." This indicates a momentary reversal of input/output in pitch response to control movement, and a delay element of over a second, and introduces a very difficult element in pitch control dynamics. The Panel believes that the first effect of movement of an elevon is to change the effective camber of the airfoil that is the lifting surface. When the pilot raises the elevon to rotate the Orbiter into a pitch-up attitude, he changes the "camber" to a less efficient airfoil shape, producing an immediate loss of lift. The new elevon position produces a change in pitching moment, followed by an increase in angle of attack, and recovery of the lift that was lost. In moving the elevon from -5° to $+5^{\circ}$, the operating point moves and the Orbiter suffers a loss of lift before rotation can increase the angle of attack and recover the loss. Traversing the path in the other direction, i.e., lowering the nose of the Orbiter by lowering the elevon angle, results in a more highly cambered airfoil, and a definite increase in lift. This seems to explain what happened on the approach and landing test when the pilot pushed the nose down in an attempt to hit a particular spot on the runway; he momentarily "ballooned" and floated well past his intended spot.

The ability of the pilot to choose one or several output quantitites to monitor, and use, as an input to his "closing-the-loop" in addition to his ability to vary the "gain" and introduce anticipation complicate analysis of the control problem. However, basic stability criteria apply and can guide the engineer in making changes to improve the control characteristics. A plot of gain and phase relationships in a feedback amplifier, will remind us that as the frequency of motion is increased and phase lag approaches 180 degrees, gain must be attenuated or there will be a regenerative component fed into the loop.

The DFRC investigation, and especially the pilot's comments, reveal the classic conflict between stability and responsiveness. The phase lags in the components of the loops, plus the elevon-lift transfer function, would seem to force the operating region beyond the 90 degree lag point. The standard technique of the servo engineer is to reduce the bandwidth, i.e., reduce the gain at the higher frequencies. However, the pilots may be expected to object to any changes in control characteristics that reduced the "gain" because they want a responsive system, one that can recover from disturbances introduced by gusts and turbulence.

If one charts the control characteristic there are domains of operation that are stable and will tolerate greater gain than the "reduced bandwidth" solution. Other domains may be improved by introducing lead compensation. Inasmuch as the oscillation frequency to be avoided has a period of about two seconds, pilots, if they have indications that allow them to resolve small changes and sense the correctness of their responses, can anticipate changes in attitude and motion and thereby manually introduce lead compensation. The favorable reaction of the pilots to the control characteristics of the YF12 can be attributed to the long nose ahead of the pilot, which he can use against the horizon to immediately sense attitude changes.

This problem is under high priority study and experiment by Johnson personnel. It appears that a "heads-up" display of pitch attitude, perhaps a reticle pattern focused at infinity that the pilot can compare with the horizon or a runway marker, will give the pilot the ability to retain high gain and still operate in a stable regime.

Range Safety

At Kennedy Space Center all parts of the Shuttle come together. There are hazards associated with transportation, assembly, fueling, checkout, launch and recovery. We discussed these hazards with Kennedy officials and came away with the impression that they were recognized, and that procedures and management attention would reduce the probability of accidents.

The Air Force Eastern Test Range briefing on Range Safety emphasized the magnitude of the explosion if the Shuttle assembly were to fall back to ground without the benefit of range safety action to disperse the propellants. TNT equivalents of 200-400 thousand pounds were estimated. The hazard to the public is under study through a contract with the Wiggins Corporation. In addition, a committee with representation from NASA, DOD and other governmental and industrial experts is considering the problem. A key issue is the amount of focusing of the blast wave under certain meteorological conditions. Criteria, such as applied to the Trident launches to protect Port Canaveral, if applied to Shuttle launches, would result in excessive delays and holds. Additional study and experimental tests would yield data that would decrease the band of uncertainty, and avoid overly conservative launch criteria that would lead to delays and holds.

The decision to eliminate the ejection seats when the crew is augmented seems to be a straightforward program decision. The retention of the Range Safety System seems to arouse a controversy, almost emotional in intensity. Inasmuch as the engineering has been done and about 30 systems are under contract, it appears that it would be wise to defer a decision on eliminating the range safety system until more information is available from the developmental flight tests. Meanwhile, a comprehensive briefing on the details of the system and how it operates, given to NASA personnel, would clear up some misconceptions, and hopefully allay some fears of hasty action. In any event this is not a current constraint.

ORBITER EVALUATION

Willis M. Hawkins

INTRODUCTION

In the evaluation of the current Orbiter design and test status, it appears that current plans are adequate to provide a reasonable assurance of first orbital flight safety. There are, however, a number of risks that have been accepted as reasonable for these initial flight experiments that should be reduced when the Orbiter is considered as a transport vehicle for repeated and prolonged use over the next several decades. It is suggested that some of the kinds of risks which can be accepted for the first few flights of such an advanced system are not the kinds of risks that should continue to be accepted during operational service. This means that the first flights now programmed for the shuttle system have as their prime goal not only the normal assessment of estimated performance, but also the equally important goal of obtaining data not yet available to assess the magnitude of the risks inherent in the current configuration and to obtain the data necessary to permit redesign of selected shuttle sub-systems in order to remove these risks. Finally, NASA should begin immediately to program a major series of improvements using these data, aimed specifically at the reduction of currently accepted risks to the absolute minimum for routine shuttle operation. This system improvement program should start immediately so that data gathering on early shuttle flights will be properly focused to support the design of these system improvements.

PRIME EMPHASIS FOR EARLY SHUTTLE FLIGHTS

1. Of prime importance is the reassessment of the assumed launch environment for the original design of the shuttle system. This includes over-pressures, tower clearance, perturbations that require attitude control such as wind shears, real loads on the interconnections between solids and external tanks and the tank to Orbiter loads. In addition, a special effort should be made to assess ice formations and their effect on the external heat protection system.

2. A re-review should be mounted to assess the instrumentation and any other potential source of information for crew evaluation of all doors, closures, and payload door lock systems from the point of view of the effect of thermal differentials and prolonged symmetrical and unsymmetrical heating on these closure systems. One element of this assessment should be an evaluation of whether or not crew inspection should be planned during orbital flights. This, of course, implies extra-vehicle crew activities.

3. A complete subsystem functional survey must be performed to determine how closely each major essential system is being driven to its design limits. The purpose of this kind of a functional evaluation is not only to confirm that the subsystem performs adequately but also to determine whether or not the original requirements to which the system has been designed have, in fact, been based on realistic requirements.

TESTS TO SUPPORT SYSTEM IMPROVEMENT PROGRAMS

As noted in the introduction, it is suggested that a system improvement program be initiated almost immediately, not only for the purpose of improving the reliability performance of the shuttle system, but also to remove some of the risks that are now acceptable for first orbital flights but which should not be accepted for the eventual operational mode of the shuttle. Included in such design investigations should be:

a. A new concept or substantially improved APU system, including adequate margins of fuel capacity and high confidence of mechanical containment in the event of major failures in the rotating elements.

b. A thorough reevaluation of the necessity for nozzle skirt removal on the solid rocket boosters.

c. A complete reassessment of the necessity of nozzle vector control on the solids. One of the most complex systems with the least impact on the total shuttle performance is the current concept for moving the nozzles on the solid boosters. If a system could be devised that would permit fixed, or simply programmed, nozzles on the solid rocket boosters, a major simplification would have been achieved. Weight saving would be apparent and a substantial reduction in risk would result. Removing the APUs from the solid rockets, removing the vector control system from the rocket nozzles, and removing the necessity for hooking the solid rockets up to the basic control system all would be major improvements. This investigation should include a thorough assessment of the assumptions underlying the requirements for solid nozzle vectoring.

d. Whatever the results of "c" above, it would appear that a parallel or backup program would be desirable aimed at removing the APUs from the solid propellant boosters. The first flights should contain adequate instrumentation to confirm the dynamic characteristics of the total system in sufficient detail so that a redesign is possible utilizing added APUs within the main shuttle vehicle and removing them from the boosters. Even this would be a major simplification and would augment the total APU reliability by putting more than three APUs in the orbiter.

e. Also included in the system improvement program should be a consistent evaluation of all of the systems within the shuttle and the Orbiter to obtain at least "three engine, fail operational" capabilities for all essential systems. Prime efforts should be focused on (1) the APU where "fail operational" safety may require more than three APUs; (2) a new concept of elevon control system (implicit is the suggestion that multiple or tandem pistons are thought to be essential); (3) a completely new approach to the rudder speed brake and trim flap controls to remove from all of these systems any single point total failure elements; (4) a revised concept for main engine nozzle direction control to assure that full thrust to full duration can be achieved even if failure occurs in the nozzle direction control system; (5) a dual or triple source of voltage for solid rocket booster holddown releases; (6) a complete assessment of the interdependence of the backup control system to determine that failures in other parts of the system will not jeopardize the backup; particular attention should be paid to adjacent pin shorts; and (7) whatever is required, the APU should be modified so that shutdown and restart can be done without any time-consuming restraints, and its overall reliability improved so that it is on a par with the mechanisms which it is driving.

CONCLUSION

In planning for the future operational mode of the shuttle system, it should be recognized that the attention and the pilot and support expertise available for the first shuttle flights will not, and should not, be assumed to be present once the system is in its operational mode. Thus, the inherent reliability and invulnerability to failures of the shuttle system and the Orbiter must be substantially enhanced before truly operational status can be achieved. The system modifications just enumerated are only a few of the most obvious. The program management should mount a major assessment program for all systems similar to the evaluation recently done by McDonnell Douglas Corporation for the control system. The attitude of the program management should be one of extreme conservatism for operational safety. Development instrumentation and design investigation should now be concentrated in the risk removal area, even accepting some loss in payload performance to achieve the ultimate operational reliability.

SPACE TRANSPORTATION SYSTEM-PAYLOADS
(Domestic and Foreign)

Howard K. Nason

Payloads are an inherent part of the Space Transportation System and their status has matured to the point where safety issues concerning them could be addressed by the Panel during the past year. (A summary of the sites visited and subject matters discussed is included in Appendix B.) Two major items of interest at this time are the Spacelab with associated pallets and payloads and the Tele-operator Retrieval System (Skylab Mission). Of secondary interest has been the experiment and industrial payloads, both in the United States and those in Europe integrated by the Spacelab payload.

The Skylab reboost/deorbit mission is scheduled to be conducted on the second Shuttle mission some three to four months after the initial manned orbital mission. Our task focused on management's approach to this mission as regards to safety. Two premises have been made: conduct the mission as early as possible to achieve the greatest probability of successfully rendezvousing with the orbiting Skylab; and, if at all possible, attempt to boost the Skylab into a higher orbit to prolong its useful life. Based on our review to date the current program, both hardware and operations, appears to be moving in an orderly manner to meet the September 1979 delivery date. Hazard identification/elimination and reduction are being provided by design, and where this has not been possible, safety and warning devices along with operational constraints are being used. The spring ejection system has been designed and will be tested; stimulation devices for crew training will be in use soon;

the Johnson Space Center Flight Operations Panel is examining what measures can be taken on the first shuttle flight to support the Skylab reboost mission; and Systems Hazard Analyses and the Safety Compliance Data Package are being updated as required to account for a maturing program. Contingency plans should be made so they support the final decision-making which will be made, most likely, after the first shuttle manned orbital flight. In view of the special hazards involved with the relatively large quantities of fuel aboard, this program will be followed especially closely during 1979.

The European Space Agency has made substantial progress during this past year, the first year the Panel has had the opportunity to review this program. We focused on two specific areas of interest: (1) the management of the Spacelab/Pallet/Payload Integration program as it applies to operational safety and product reliability; and (2) the specific implementation of product assurance and safety programs with emphasis on technical aspects of the program. Three questions were in our minds during our participation in Spacelab activities: (1) The degree of "technical conscience" possessed by the program. In other words, do people throughout the organization feel that they have a responsibility to call to management's attention any concerns they may have, and do they believe that their concerns will be heard and acted upon? (2) Are lessons learned from other programs and within the program and are they applied? (3) What attention is being paid to the sum total of all the "accepted risks," and is there a "feed-back" system to assure such technical and management attention?

The program, at all levels, recognizes that time is growing short and to meet the delivery schedules will require continued technical and administrative visibility, timely and orderly exercise of prime contractor control, and enhanced software development and system engineering actions. All of this to conduct integrated tests and qualification testing on both the Engineering Model and Flight Units over the next ten months. Current major technical problems at this stage of the program must be resolved on a "systems basis" in order to minimize their impact on the current hardware, software and operational modes. Examples of this include the resolution of the airlock flange deformation without infringing on experiment volumes, unavailability of freon-21 as a coolant, environmental control and life support system thermal control, completion of the ncessary software programs for both test and operations. The many interfaces between payloads and the Spacelab and pallets need to be strengthened to eliminate conflicts of requirements at a later date. A more pressing need is to complete the technical (design/operational) baseline for the spacelab and pallets to assure that configuration control is maintained now and at the time of delivery of the hardware/software to NASA at Kennedy Space Center.

The European Space Agency and its contractors have put together a dedicated and knowledgeable product assurance organization which appears to receive full support of management. However, resource limitations necessitate prioritizing of product assurance efforts and this has been done well without unduly compromising safety and reliability. It does lead to accomplishment of workload in a serial fashion, and this makes the documentation lag, in some cases, somewhat restrictive.

It is recommended that a "walk-through" of the Spacelab and pallets be made by a highly experienced, non-spacelab group to assure that everything that can be done has been done to achieve a safe system. The walk-through has been an integral part of NASA's manned programs and most of NASA's research aircraft programs. This group might consist of six or seven people (perhaps one each from Johnson Space Center, Marshall Space Flight Center, Kennedy Space Center, Headquarters and several from the European Space Agency.

Within NASA there is a growing organization to handle the Space Transportation System "users," and specific attention has been paid to the safety aspects of such operations. A series of NASA documents from Headquarters and Johnson have been issued to cover policy, requirements and implementation for payload safety. Overall the intent is to minimize requirements to allow for the widest possible space transportation system. A large percentage of the requirements are to be met by the experimenters themselves with support from NASA as required. To fulfill the responsibility for payload integration and safety, the Shuttle Payloads Integration and Development Program Office conducts safety reviews with all organizations involved in the development of designated payloads. The funding to meet such an activity is included within the user's fee paid at the time a flight assignment is given. Additionally, there is a signed DOD/NASA agreement on safety certification of Defense Department payloads, which establishes agency roles and responsibilities. Subsequent agreements will be established covering payload ground and flight operations. It is important that organizational roles and responsibilities be fully defined prior to the first real payload mission, to assure that both operational and safety aspects of the flight have received due attention from the payload organizations. An example of this is the Johnson Space Center Management Instruction #11524, dated August 12, 1977, covering the "Space Transportation System Payload Safety Review Panel."

Ames has a wealth of experience with the management of payloads, as a result of their program of high-altitude experimental flights, and also have conducted simulations of Spacelab missions. It is urged that the entire system take full advantage of this resource.

In summary, the current schedule for the Skylab mission is such that reboost becomes problematical.

The Spacelab program is now into its integration and test phase, with delivery of the Engineering Module to Kennedy scheduled in 1979. This will require dedicated effort over the next months to assure the Spacelab system meets the necessary requirements.

Integration (system engineering) and full vehicle testing are critical at this time to meeting such goals.

The Space Transportation System payload appears to be in good shape with Johnson, Marshall, Goddard and Headquarters working together with Kennedy to assure that, through a standardized approach, safety requirements will be documented, tailored to meet the user's capability and needs, thereby opening the payload opportunities to the greatest number of commercial, governmental, university projects.

CONTROL OF HUMAN ERROR

Dr. Charles D. Harrington

The system for assuring that hardware as manufactured will be in accordance with drawings and specifications has been studied. Concentration has appropriately been at the Space Division of Rockwell International with some emphasis in the way it is applied to major subcontractors. The system of control and inspection remains essentially as it has been for some time and as it has been previously reported by the Aerospace Safety Advisory Panel.

The following factors are useful to management in assessing manufacturing performance.

1. Quality Trends: Assess Production Operations' performance relative to making defect-free hardware.
2. Manufacturing Verify Trend: Assess Production Operations' performance on evaluating the acceptability of their work.
3. Material Review Trends: Assess Production Operations' level of material review actions relative to cause of nonconformance and nature of disposition.
4. Inspection Detection: Assess inspection performance on detecting defects.
5. Corrective Action Trends: Assess status of Open, Initiated, Closed, and duration of Open Corrective Actions.
6. Defense Contracting Audit Service Inspection Trends: Assess nature and number of defects detected by the inspectors.

Items 1 and 2 are perhaps the most important of these in tracking human error.

The information systems have the capacity to detect changes in the level of performance for each of the items measured. The sensitivity of the instrument varies: for the Quality Trend report the lowest level of assessment is the department, whereas for the Manufacturing Verify report the lowest level is the indi-vidiual Production Operation stamp holder. They can also identify by part number, by defect type, and by cause of defect all noncon-formances written on vehicle hardware and GSE at Downey, Palmdale, and all Material Review actions whether at Space Divison or any supplier. All Material Review information is available on-line and the nonconformances within 12 hours, and reports can be made in almost any format desired. The information systems in general cannot identify the individual mechanic who caused or contributed to the defect since many individuals may have worked on a specific part or sub-assembly. It should be pointed out that this refers to the "Assurance Management System" only. Supervisory inspection of individual workmen is used to detect poor performance, and addi-tional training and/or replacement is used when indicated.

Production Quality Performance is presented in graphical and num-erical form to show the performance of the Manufacturing Verification System. The performance is shown in the form of a percentage of defects found out of those which should have been caught by the manufacturing production inspection. This assumes that any defects missed at the inspection are subsequently caught by Quality Assur-ance or by the Defense Contracting Audit Service. This percentage generally runs in the high nineties, with some exceptions where a specific type of problem has caused many defects to go unnoticed at the manufacturing verification level. The dip in the period ending August 12 was caused mainly by the fact that a number of back-shells on electrical connectors were not tightened sufficiently, so that they became loosened and were subsequently detected by Quality Assurance.

The data discussed are for the Space Division of Rockwell International. Similar controls are imposed by Rockwell International on major subcontractors and they in turn are required to extend such controls to their subs as appropriate. It has not yet been possible for the Panel to investigate how well the system has been working at subcontractors, but this will be in the program for the coming year.

The hardware assessment summary is a system which has been put into operation during the current year. Quality Audit teams, in addition to reviewing the compliance with paperwork requirements, are inspecting critical manufacturing steps and hardware to understand better where defects in hardware or processing could occur and to understand the precautions which must be taken to minimize the likelihood of defective parts being produced. Unfortunately, due to lack of funding, this program was interrupted from May to September, but is now back in operation. The subcontractors to be so audited have been identified, but much work remains to be done before the Flight Readiness Review next August.

The Panel was represented at an audit at MOOG and was impressed with the thoroughness of the actual hardware examination.

This hardware assessment appears to be a good advance in the control of human error at the man-material interface.

As a specific example of what can be done to assure that hardware actually is in conformance with specifications, we examined the handling of the Wire Harness problem. This problem is the validation of the wiring after either initial buildup or rework. A team was selected and resulted in a computerized complete continuity test of the harnesses after each rework and included high potential testing. This confirmed the insulation, quality and functional routing of the wires. The physical quality of the work was checked by visual inspection.

The solution of this wire harness problem is an example of what can be done to estabish actual hardware configuration as against the design and prints. In some hardware cases it will be very difficult to establish test procedures which will duplicate all conditions which the hardware may experience in flight.

In summary, the development of primary inspection closer to the work (the Manufacturing Verification System) and the expansion of Hardware Assessment are positive steps toward reducing the likelihood of hardware as actually produced deviating from the drawings and specifications. During the coming year the Panel will follow the progress of these procedures with particular attention to the application throughout the subcontractor system.

PROPULSION SYSTEM

Dr. Seymour C. Himmel

Since our last meeting significant progress has been made in the development of the propulsion system for the shuttle. The SSME, the SRB and the External Tank are showing many of the signs that characterize maturing hardware. This progress was not achieved without problems or difficulty. When problems were encountered, they were attacked both vigorously and competently. Solutions to the difficulties have been devised and, thus far, testing has verified their adequacy.

External Tank

The External Tank is well into its test program and has progressed satisfactorily. It has supported the Main Propulsion Test very well. Changes in thermal loads and ice protection requirements have required extending the area covered with insulation so that now almost all the tank surface is insulated. The resulting weight increase detracts from the shuttle payload capability and this growth will probably have to be counterbalanced by a weight reduction program in the future.

The many manufacturing process controls required for the proper fabrication of the tank have gone through their growing pains. The need for strict adherence to the prescribed procedures is well recognized and steps have been taken to ensure compliance.

There have been two problems of consequence during the testing so far, one in the gaseous hydrogen diffuser and the other in the liquid oxygen tank ogive. The cause of the failure of the hydrogen diffuser has been determined and a design modification enbodying a material change should be sufficient to preclude further difficulty. The oxygen tank ogive buckle problem was corrected by requiring pressurization during servicing.

All told, the tank is doing quite well and should support the shuttle schedule (9-79) well.

Solid Rocket Booster

The Solid Rocket Booster has progressed well this past year. Quick look data from the recent firing of DM-3 looked quite good with ballistic performance, action time and thrust rise rates very close to predictions. The specific impulse from these early data was slightly better than requirement and in line with that achieved in the earlier firings. The case and the remaining insulation looked quite good. The determination of whether or not the modifications made to insulation and inhibitor geometries prior to the test achieved the desired improvements in performance must await detailed physical examination.

Process controls for casting have been improved and the casting equipment has been brought up to standards. The recovery system difficulties have been corrected as have other minor problems in the other subsystems. Handling problems are being brought under control.

The Booster development and qualification program should be able to support the shuttle per plan.

Space Shuttle Main Engine

The SSME development is, of course, the most challenging of the propulsion system programs. The many problems that have beset the development appear to be on their way to resolution. Most of the design changes selected have been incorporated into the test hardware and, for the most part, they have performed well in test.

The turbomachinery, the source of most of the SSME problems, is beginning to show signs of maturity. The high pressure oxygen turbopump bearings are holding up, and the high pressure fuel turbopump turbine blades are showing improved endurance now that the dampers have been improved and the excitation forces reduced. With the operability of the machinery enhanced, more attention can be focused on the performance enhancement of these machines. Progress is being made in this area too.

The combustion system continues to perform well and the fine tuning of the injector pattern appears to have reduced the severity of the local overheating that had been experienced earlier this year. The addition of velocity profile straighteners in the injector gas entrance ducts has apparently reduced or eliminated the injector liquid oxygen post fatigue problem.

The controller has completed, successfully, its grueling vibration qualification test and has performed very well in the engine test program. Software development is on schedule and the programs "fit" the controller.

The engines supported the first phase of the Main Propulsion Test quite well and no significant problems have arisen. Perhaps the more important achievements have been the full duration runs at rated power level, the 5000 plus seconds on engine 0005 and the almost 300 seconds near or at 102 percent rated power level. The heat exchanger operation has been verified in hot firing and fuel flow testing has been initiated. All of these accomplishments attest to the growing maturity of the main engine.

Of major import is the fact that decisions concerning the configuration and performance and test requirements for the main engines for the first manned flight have been made. The hardware currently in test is rapidly approaching the selected configuration. The design and test requirement decisions made are satisfactory for these flights and do not in any way compromise safety.

For operational flights further modifications will have to be incorporated into the engine with changes to provide lifetime and performance predominating. In addition, any consequences of operating at full power level will have to be accommodated.

All told, the main engine program appears to have "turned the corner" and I would anticipate that rapid progress toward achieving preliminary flight certification status will be made. I would expect that from time to time we will experience some hardware failure incidents as we have in the past. I believe that now these will probably not be caused by fundamental design-type problems.

Such incidents will, of course, have schedule implications because of the limited supply of hardware. Nonetheless, barring a major incident or unforeseen problem, the schedule (9-79) should be achievable.

In summary, the propulsion system development programs are in much better shape than they were a year ago. The fixes needed have, for the most part, been incorporated and proven. Much major testing remains to be accomplished and this is the key to Preliminary Flight Certification. All told, I would tend to be optimistic about this system achieving its near term objectives on, or close to, schedule (9-79).

RISK ASSESSMENT

Frank C. Di Luzio

To assure the Aerospace Safety Advisory Panel that the Safety, Reliability and Quality Assurance System mandated by NHB 5300.4 (1D-1) August 1974 - a summary of NHB 1700.1 NASA Safety Manual Vol. 1, NHB 5300.A (1A) and NHB 5300.4 (1B) - was effective and was being adhered to by NASA Centers and their contractors, the Panel conducted a systematic evaluation and review through a series of meetings, briefings, and walk-throughs at Johnson Space Center, Kennedy Space Center, and the Rockwell Safety Support organization (Space Division/Rockwell), Boeing, and TRW on Software Hazard Analysis.

There may appear to be duplication in several of the sub-panel reports or in reports prepared by individual Panel members, concerning areas of their expertise or areas of specific assignments, and this evaluation of the NASA Quality Assurance.

This is primarily due to the fact that quality assurance is an overall function at all levels of the Shuttle operations - as an example, the report on product Quality Assurance and related human factors deals with the Quality Assurance function, the human and/or organizational elements involved, while the risk assessment evaluation concerns itself with measuring the success of risk identification and elimination on the end product. In brief, the first measures performance, coordination, and supervision of people. The second, the effects of this attention on the final products or its elements.

The Panel was interested not only in the question of adherence to the procedures mandated by NASA, but was also interested in the effectiveness, character and climate of the several interfacings between the tier contractors involved. The contractors interface with NASA Centers and between the NASA Centers themselves.

In the opinion of the Panel, this review was necessary due to the great degree of coordination and cooperation needed to insure that no item was lost in the sequential process involved, and that information, evaluation, comments, and concerns flowed freely throughout the total organization, including NASA Headquarters, Centers and Shuttle Program contractor personnel.

The Review was a step-by-step approach starting with Johnson Space Center Quality Assurance operation as the Shuttle Hazard Identification and resolution was administered by Johnson Space Center at level 11 and on the Orbiter at level 111. The Rockwell support activity was then reviewed, and finally, a review of the Kennedy Space Center planning and organizational structure to manage and coordinate the acceptance, movement, assembly checkout and launch of the Shuttle. Kennedy Space Center presented an excellent opportunity to look into the results of all the preceding Quality Assurance programs.

All systems and sub-systems, complete with their Quality Assurance history, flow into the Kennedy Space Center for processing checkout and launch, using the computer-controlled Launch Processing System. Generally, the Kennedy personnel and their supporting contractors have seen, and are familiar with the characteristics of the hardware as they have participated in prior Quality Assurance reviews conducted by the designers and producers of the systems and sub-systems. There is a great deal of inter-play and participation by both NASA and contractor personnel with reviews conducted by lower tier contractors and contractors above, who integrate the components, sub-systems and systems into progressive configurations leading to final assemble.

The second phase of the Panel's Quality Assurance Reviews was to look into the purpose, function, and effectiveness of both formal and informal special reviews by study groups or task forces. These include the formal Senior Safety Review Board, Screening Boards, Orbiter Project Manager, and Space Shuttle Program Manager, formal briefings and the Headquarters-initiated Hawkins Committee, Crew Safety Panel, Safety System Sub-Panel, Operational Readiness Inspection for Sites, internal Rockwell reviews, Yardley formal and informal reviews, and various technical panels considering specific items such as the hydraulic system.

These task forces, panels, or technical reviews are extremely useful, if not overdone, and do not unnecessarily tie up Center personnel nor divert Center Management attention from their internal problems. Such activity appropriately created and staffed with competent knowledgeable people, can focus outside talent and provide a new look at the problem. This activity further concentrates the attention of NASA top Centers and Headquarters personnel on the problems and renews the drive of the total NASA organization for effective Quality Assurance procedures. Repetition and time have a way of dulling the awareness and concerns for a good and effective Quality Assurance function.

The Kennedy Space Center session included a review of the planning for OFT-1 Shuttle Processing Orbiter Landing Facility and the Shuttle Processing Launch Pad, Handling and Stacking, Orbiter Processing Facilities, with particular attention to the handling of toxic and/or inflammable materials such as hydrazine ammonia, etc. A review was also made of the very preliminary draft of the Kennedy Space Center - OFT-1 Space Shuttle First Vertical Flight Assessment dated June 2, 1978.

Many other documents and procedures were reviewed, i.e., Shuttle Element Interface Reliability Desk Instructions, Hazard Analyses Sheets, Kennedy Space Center Safety Review of ground support equipment. Design and Ground Operations and the OFT-1 Ground Operations Review Document prepared for briefing of Deke Slayton on June 15-16, 1978, a very complete and helpful document. Finally, Mission Safety Assessment, Analytical Effort, Critical Events Sequence Selections, Integrated Shuttle Program Risk Management Schedule, and Mission Safety Assessment documents.

As a result of these reviews, the ASAP is of the opinion that the documentation, procedures and internal reviews have been and are effective in identifying, examining and resolving possible hazards and that the free flow of information on evaluation of the safety, reliability, maintainability and quality assurance among Engineering and Design, Manufacturing, Test, and Operational Sites is a significant factor contributing to an effective Quality Assurance process across the total NASA Shuttle System.

NASA Reliability and Quality Assurance publication NHB.5300 (1D-1) August 1974 requires that each contractor maintain a safety activity planned and developed in conjunction with other functions. The purpose is to insure that special emphasis is placed on how to assure identification, elimination and/or control of potential hazards which may lead to injury, loss of personnel and/or damage or loss of flight or ground hardware throughout the program cycle.

In addition, an Industrial Safety/Occupational Health and Safety Plan was to be incorporated or attached to each safety plan. The Panel has predominantly spent its time on the Space Shuttle Transportation System and little time in looking into the normal industrial safety problems. At Kennedy Space Center and at other Centers there are activities such as the handling of heavy loads in the Stacking Operations and the handling of toxic and inflammable materials in the fueling and refurbishing tasks. The Panel will spend some time in reviewing the status of industrial safety, and the application of federal and state laws and regulations to both government and contractor activities.

The last Kennedy Space Center session also concerned itself with the review of Kennedy relationships with both its local contractors and contractors serving other Centers, but who are involved with further processing, testing of hardware shipped to Kennedy Space Center from manufacturers and other Centers. The reason for this concern is that many of the contractors, thus engaged, are under contract to other Centers and perform many other tasks, i.e., manufacturing, design, test and quality evaluations. The implication of these diverse functions and multiple use of contractors, is that they may actually be at work at Kennedy processing, inspecting and testing equipment, sub-systems, and systems provided by their parent organization. This situation can be a plus because of the continuity contractors can provide and their familiarization with hardware design, manufacturing, and prior testing, is very helpful in the final stacking, assembling and testing at the Kennedy Space Center. NASA management awareness of the several roles performed by the contractor organizations and the awareness of the contractors' top management can go a long way to avoid a conflict. It is, however, something that should be monitored.

RECOMMENDATIONS

The ASAP is concerned whether the payloads and, in particular, the Space Laboratory being designed and built in Europe is, in fact, being designed and built in a manner consistent with the operational safety standards of NASA. Both the quality of the Space Laboratory and the coordination between NASA and the European agencies involved should be carefully monitored.

It is very important that European scientists involved be trained and be familiar with the limitations and procedures to be followed in space experiments. The Ames Research Laboratory simulation of flight conditions for experimentors who will use Space Lab is a step in the right direction and should be expanded.

Criteria for payload safety requirements and responsibilities have been drafted, but as payloads change, revisions of standards and procedures will have to be made. From a Quality Assurance point of view, the general philosophy that payload sponsors are responsible for their own payloads' safety and NASA is responsible for payload standards and their interface with the Shuttle and other payloads on the same flight, is sound. NASA should, however, know the contents of each payload to satisfy itself as to its safety in handling and flight, and particularly, in an abort situation.

The Panel suggests that NASA re-evaluate the staffing of the Kennedy Space Center Quality Assurance staff and support personnel. The present staffing may be sufficient to perform the Kennedy Space Center Shuttle Processing, etc., if the program develops no late, unforeseen problems.

If problems develop late in the stacking and preparation process, present staffing may not be enough. The slipping of launch date for OFT-1 obviously helps ease the current workload.

With reference to the NASA decision to use OFT-2 to deliver and attach a small engine to Skylab in order to control and boost Skylab into a safer orbit, it may be prudent to evaluate the results of OFT-1 before final commitment to that course. The problem is that unless the OFT-1 flight is planned to exercise all on-board systems and capability that may be required for the OFT-2 rendezvous and maneuvers to deliver and attach the engine to Skylab, an undue hazardous condition could be needlessly created. Stresses that may be experienced for the first time on the Shuttle during this OFT-2 event should not be a stage for any unknown hazards.

Finally, the Panel is happy with the openness, frankness and efforts of the NASA Centers' and Contractors' personnel during this review of the system-wide Quality Assurance procedures and their effectiveness. Marty Raines, Director, SR & QA Division of Johnson Space Center, and Charles Baker, Product Quality Office, Rockwell, and John Atkins of SR & QA Office, Kennedy Space Center, are due particular thanks for their efforts.

With reference to the NASA request to the Panel to evaluate and recommend a process to achieve a numerical value for an aggregate risk assessment, the Panel has to date been unable to determine any creditable method. We examined the Department of Defense process of risk evaluation, the original Atomic Energy Commission weapons risk evaluation and the current Department of Energy methods. All produce meaningful information, but no one has developed a generally accepted method to set numerical values for aggregate risk.

The very nature of safety determinations and the wide-spread confusion about the nature of safety decision would be dispelled if the very meaning of the term safety were clarified. Many experts will define safety as a judgment of the acceptability of risk, and risk in turn, as a measure of probability and severity of harm to humans, and/or complex costly technical systems. This definition contrasts sharply with simplistic dictionary definitions that have safe meaning "free from risk," because nothing can be absolutely free of risk, nothing can be abolutely safe. There are degrees of risk and, consequently, there are degrees of safety. The NASA Quality Assurance system, in its entirety, can only reasonably insure that the risks involved in the OFT-1 are not caused by human error or because of an oversight.

Note also that the above definition emphasizes the relativity and judgmental nature of the concept of safety. It implies that two very different activities are required for determining how risk-free the Shuttle really is. They are: measuring the risk, an objective but probabilistic pursuit and judging the acceptability of that risk, a matter of personal-political and social value judgment. As most risk acceptance is based on human judgment, it is impossible to place any numerical value to that judgment.

In closing,the ASAP believes that the Quality Assurance system is working well and is effective, particularly, with continued top management interest and support.

THERMAL PROTECTION SYSTEM

C. A. Syvertson

While considerable work remains to be done, the key technical problems associated with the Space Shuttle thermal protection appear to be sufficiently well in hand to permit the first orbital flight to be made with confidence. The remaining work comes in two major areas: one of these is manufacturing. While a significant part of the tiles and other materials have been manufactured and installed on Orbiter 102, some of the most difficult tasks of manufacturing and assembly remain. Most of the tile arrays have been attached to the lower surface of the Shuttle, however, there are a few panels in more complicated areas missing and, more significantly, there are a large number of close-out tiles which must be manufactured and attached individually before installation of the thermal protection system will be completed. Manufacturing output between June and November was only about three-fourths of that planned. In order to support a launch as early as September 28, 1979, an improvement in manufacturing output will be required, although some time might be gained by shipping the Shuttle to KSC without a complete system; limited installation of tiles could be completed at KSC.

The second area where considerable work remains is testing, especially that for certification of the materials. Some key development tests and a comprehensive series of certification tests must be completed before the first orbital flight. The certification tests necessitate a rigor in terms of identification of test specimens, documentation of materials and processes, and R&QA involvement that makes these tests significantly more difficult to complete than development tests. As a result of the rigorous requirements, difficulties are already being experienced in maintaining schedules.

All of the manufacturing, installation, and test activities associated with the thermal protection system must be highly successful in meeting current schedules if the September 28, 1979 launch date is to be met.

Beyond the first few Shuttle flights, emphasis should be placed on reducing the weight and cost of the thermal protection system and on minimizing and improving the ease of refurbishment between flights. In order to achieve these objectives, two things must be done. First, sufficient data must be obtained from the early flights to define accurately both the performance of the system and the environment it experiences during entry. These data are especially important since it is not possible to create the complete entry environment in ground-based tests or to estimate it with desired precision by theoretical analysis. While flight data systems, such as the Developmental Flight Instrumentation and Aerodynamic Coefficient Instrument package, will obtain some of the information required, other activities within the Orbiter Experiments Program, including remote infrared observations of the Shuttle during entry, will provide important added understanding.

Second, new thermal protection materials and systems should be explored with the objective of making the thermal protection system more compatible with the concept of an operational vehicle. Activities in these areas are underway and should continue to be given modest support. Some of the materials being studied are:

1. Fibrous Refractory Composite Insulation is a new form of Reusable Surface Insulation that provides increased strain to failure and strength by factors of two or greater, over current materials. It also has a significantly increased temperature capability. Arc-jet tests to quantify this will be performed in the near future. An additional benefit is that the coating is in compression whereas in the current material it is in tension--an undesirable state of stress for a ceramic in terms of damage resistance. This new material can be directly substituted for that now in use and should provide increased life and lower weight.

2. Advanced Flexible Reusable Surface Insulation is a silica-felt enclosed in glass, silica or AB-312 cloth and stitched in a blanket form. This material was developed as a substitute for low temperature insulation and those regions where the local temperature limits flexible insulation reuse. The advantages of advanced flexibility insulation over low temperature insulation are lower installed material cost by an estimated 2.4 million dollars per Orbiter, lower weight by 100-300 pounds, and significantly enhanced reuse since it is not rigid and brittle.

3. Black AB-312 cloth was developed by the 3-M Company under NASA sponsorship as a direct substitute for the current white AB-312 cloth used for gap fillers and thermal barrier seals. Two advantages of this development are higher thermal emittance

and reduced crystal grain growth. The increased emittance results in reduced temperature and, therefore, greater reuse of both the cloth and adjacent tiles. The inhibited grain growth will result in retaining flexibility at high temperatures and therefore greater reuse.

APPENDIX B

1978

PANEL MEETINGS

and

FACT-FINDING MEETINGS

1978 PANEL MEETINGS

January 17	Shuttle Critical Functions Review, Space Shuttle Main Engine	NASA Headquarters
February 22	Testimony before the Senate Subcommittee on Science, Technology and Space	U. S. Senate
April 13-14	Shuttle Thermal Protection System and Tile Manufacturing	Ames Research Cent Lockheed
June 13-14	Space Shuttle Main Engine	Rocketdyne
August 8-9	Shuttle Acceptance, Transport, Preparation for Launch. Associated Range Safety Operations	Kennedy Space Cent
October 11-12	Avionics, Shuttle Safety and Risk Analysis, Technical Assessments on Shuttle	Johnson Space Cent
November 30	Annual Meeting: Presentation by each Panel Member on his assessment of his area of responsibility	NASA Headquarters

1978 FACT-FINDING MEETINGS
by
Individual Panel Members

January 17	Ames Experience with Payloads and Mission Simulations	Ames Research Cente
January 19-20	Shuttle Crew Operations/Training	Johnson Space Cente
January 30-February 2	Shuttle Payloads, Propulsion Power, SSME	NASA Headquarters, National Academy of Engineering
January 31-February 2	Reliability, Quality Control, Human Errors, APU for Orbiter	Rockwell Internatio
February 2	Spacelab CDR Preparation	Marshall Space Flig Center
February 14-15	Rotor Systems Research Aircraft and Stall Spin Research Aircraft	Langely Research Center
February 23-March 8	Spacelab Critical Design Review, Payloads, Product Assurance	European Space Agen
March 28-30	Quiet Short-Haul Research Aircraft Engineering/Safety Review	ing
April 4-6/10	Spacelab Joint Working Group, STS Payloads Integration, USAF	Kennedy Space Cente Johnson Space Cente Space and Missile Systems Organiza
May 31-June 2	Shuttle Mission Operations, Crew Training and SS-1 Management	Johnson Space Cente
June 9	Auxiliary Power Units (APUs)	Sunstrand
June 15-16	Reliability, Safety and Quality Assurance at Primes and Subs on Orbiter Program	Rockwell Internatio

June 26-30	Hazard Identification, Risk Assessment, Shuttle Hazards Screening Board	Kennedy Space Center, Johnson Space Center
July 13, 1978	Telephone Participation on McDonnell-Douglas Critique of Shuttle Control System	Washington, D. C.
July 12-14	Launch Processing System and Range Safety for Shuttle	Kennedy Space Center Eastern Test Range
August 9	All Shuttle Projects and Payloads, Solid Rocket Booster, SSME and External Tank	Marshall Space Fligh Center
August 13-16	Particpation in Audit of Subcontract Building Critical Hardware (Actuators)	Moog Manufacturing C
August 28-29	Shuttle Hydraulic System Assessment	McDonnell-Douglas Corporation
September 11-12	Shuttle Avionics Software and Hardware	Johnson Space Center
September 27-28	Shuttle Flight Control System and its Validation	Johnson Space Center
October 5-16	Spacelab Product Assurance/Safety	European Space Agenc Spacelab Project Gro
October 30-November 1	"Fly-by-Wire" and Fault Tolerant Multi-Processors used in Aircraft and Orbiter Control Systems	Draper Laboratory
November 3	Spacelab Program	NASA Headquarters
November 27	Range Safety and High Performance Aircraft Control Characteristics Applied to Shuttle Orbiter	Space and Mission Systems Organizat