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. Risk Management

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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<u>Agenda</u>

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.