ANNUAL REPORT

to

DR. ROBERT A. FROSCH, NASA ADMINISTRATOR

by the

AEROSPACE SAFETY ADVISORY PANEL

Calendar Year 1979

AEROSPACE SAFETY ADVISORY PANEL

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SUMMARY

The Space Shuttle is nearing its first flight and, as a result, it is attracting more attention and review from the lay and technical communities. Each review, this close to first flight, demands an estimate of readiness and risk which, to be useful, must be expressed in consistent terms. In order to facilitate this, the Panel believes that basic definitions should be stated:

Risk: The measure of probability of failure.

Safety: The judgment of acceptability of risk.

It will be seen from these definitions that the world of risk and safety is not precisely defined and, in fact, the validity of a judgment of risk is directly proportional to the knowledge or involvement of the persons making the judgment. This very fact has led to the social acceptance of different degrees of safety, depending upon whether failures affect only direct participants, or include non-participants--"the public." For instance, we accept a different degree of safety for a race car driver than we do for a spectator at the race track. The judgmental problem of assessing risk to arrive at a measure of safety is more difficult as a project becomes more complex. The Shuttle, for instance, has dual solid rocket boosters, state-of-the-art cyrogenic liquid fuel reusable engines, monopropellant auxiliary devices, is equipped to exist in space, and then reenters the atmosphere as a computer-controlled fly-by-wire airplane which lands conventionally and is expected to be reusable in a matter of weeks. The number of individually critical elements in this complex machine are such that a valid judgment of risk and safety requires an intimate knowledge of the system and its interdependencies. In the face of this complexity the Safety Panel has taken the approach of assuring itself that the project organization is structured and staffed so as to insure that the many factors affecting an acceptable level of risk are considered, and that a reasonable population of knowledgeable people participate in the assessment to avoid, unknowingly, a biased view.

In its fact-finding and deliberation the Panel recognizes its responsibility to take into account the interests of the public as well as the participants. In addition, national interests and cost must be considered as well.

During the past year the Panel has been concentrating on the readiness of the Space Shuttle for its first flight and has assigned a lower priority to the questions of reusability. This should not imply serious doubts about the ability to achieve reusability, but only emphasizes that the total functional performance must first be developed and demonstrated. Perhaps the largest unknown in potential reusability is the fragility of the thermal protection tile. This unknown is being resolved as the method of attachment is being improved. This progress suggests that the problems are a matter more of experience than of inherent design deficiency.

The Safety Panel's position today is that the Shuttle has no major problems that should prevent a safe flight. The time of the flight should be determined by the satisfactory conclusion of the required test program as defined now, and as they may be changed to confirm adequacy. Much work remains to be done, but it is being accomplished in an expeditious and predictable manner. We feel that the certification reviews now underway are essential, but we do not feel that they will turn up any glaring deficiencies in either the test programs or the hardware design and manufacture for the experimental flight configuration.

Recent criticism of the management of the entire Shuttle project from a point of view of budget and schedule have caused the Panel to go back over our fact-finding experiences to see if we can see any real deficiency in design or manufacture. The Panel concludes that the design team has been conscientious and competent. There have been hardware shortages, notably in the main engine, that may have contributed to schedule slippage, but the quality and the safety of the project concepts have not suffered.

The members of the Panel, while scrutinizing detail looking for signs of trouble, find it useful to occasionally revisit the entire project. Few people realize the amount of pioneering that has been done and the quality of the work that has been accomplished. This work has been done by uniquely creative scientists and engineers.

Once the early flight operations demonstrate adequate functional integrity the Shuttle team can then focus on the necessary improvements to assure routine operation. The Panel suggests that there will be specific operational problems that need to be solved by an operationally experienced organization if maximum safety and efficiency are to be achieved. The current NASA organization is being restructured to achieve this, and the Safety Panel is seeking members with similar expertise for the future. It is apparent to the Panel that, as soon as the functional systems have been confirmed by flight test, certain changes will be desirable to facilitate routine use and maintenance. We will document some of these later in the report. They should be regarded as product improvements, not early flight safety items.

CURRENT STATE OF THE SHUTTLE

In the internal operation of the Panel the responsibility for documenting investigations in special areas is assigned to individual members. In the following sections of this report these individual assessments are summarized. The Panel uses these contributions in its deliberations to arrive at a total system evaluation.

1. Propulsion Systems

The several elements of the Shuttle propulsion systems have made notable progress in development during the past year, albeit not without some difficulties. With the exception of the main engine, the major elements of the propulsion systems are well into their qualification programs and should complete the testing required for STS-1 flight certification by mid-1980. Because of the welding wire problem the main engine test program has been delayed. The identification of deficient welds and their reinforcement represent a task of significant magnitude.

External Tank

The baseline qualification program for the External Tank is almost complete. Only two minor components remain to be tested. Three other items have to be retested because of recent changes to environmental specifications.

The functional verification of the External Tank depends on the completion of full-duration firings of the Main Propulsion Test Program (MPT). Successful firings will permit the final testing of the flow and pressurization systems. In this and the other remaining tests no difficulties are anticipated on the basis of the results to date.

To preclude the possibility of ice forming on tank protuberances and then shaking loose and striking TPS tiles during ascent, all brackets and the like are being either equipped with heaters or covered with spray-on foam insulation (SOFI) faired into suitable aerodynamic shapes.

The air loads on the protuberances have been reassessed. Most protuberances had demonstrated structural margins well beyond that required for the originally specified loads. Some retest to higher loads is required and is planned. For the few items not having adequate margin, minor beef-up is planned. To preclude unacceptable aerodynamic loads on the cable trays of the External Tank due to the asymmetric shock impingement and cross flows from the solid rocket booster bodies, an aerodynamic fairing of SOFI is being installed.

For the future, a redesign of the tank with the objective of relocating as many as possible of the feed lines, brackets, etc., to positions inside the tank is being considered. The Panel recommends such a change. The relocation will permit the elimination of much of the specially faired SOFI required by the present design. This will reduce the cost of fabricating the tank and will probably also reduce the weight.

Solid Rocket Booster

The Solid Rocket Booster (SRB) development has proceeded well. At present the first SRB is being stacked at KSC and this should be completed by the publishing date of this report.

All component tests for single mission qualification should be completed by the end of January 1980. No significant problems have been encountered nor are any anticipated in what remains to be completed.

The SRB control voltage interface requirements for STS-1 have been resolved in principle for the early flights. A test of the flight hardware to verify the acceptability of these values is planned at KSC. Under certain extreme conditions (e.g., maximum fuel cell degradation after a number of missions) it may not be possible to satisfy this interface requirement. This does not appear to be critical for STS-1, but a modification may be required to the Orbiter wiring for multimission certification.

The final qualification motor firing is scheduled for February 1980. The achievement of all design case insulation and nozzle ablator factors of safety have been demonstrated in the testing to date. Ascent load testing has been completed satisfactorily and structural factors of safety have been confirmed. Work is progressing on testing for water impact loads. The latter tests are not required for STS-1 certification.

Orbital Maneuvering System

The Orbital Maneuvering System (OMS) has also progressed well and is essentially ready for STS-1.

The OMS engine has successfully completed the "Qual I" test program which established its acceptability for the R&D flights. No substantive problems were encountered.

The remainder of this propulsion system is also in good shape for STS-1. Some tank screen fatigue failures were encountered in vibration testing for multiple missions. Modifications were made and verified by test. These modifications are not critical for STS-1 because the consequence of such type failures would be the transfer of a bubble to the engine. Tests to date would indicate that the engine is tolerant of such bubbles in either the fuel or oxidizer system.

The remaining major test is the vibroacoustic multimission test at the system level. Because of the success of the component level testing only minor problems are anticipated. No major product-improvement type changes are believed necessary for the operational application of the OMS.

Reaction Control System

The Reaction Control System (RCS) is not as far along as the OMS. It is about three-quarters of the way through its development and qualification program.

The main thrusters (870 lbs. thrust) have, in general, performed well. The pilot-operated propellant valves exhibited a tendency to leak at low temperatures. This was obviated by adding heaters to keep the valves at acceptable temperatures. In addition, testing with simulated leaks demonstrated that no problems occurred when a leaking thruster was fired. This was demonstrated for both fuel and oxidizer leaks. Should both leak, very low thrust would result.

The vernier thrusters (25 lbs. thrust) have experienced difficulty in that the leak detectors that are built into the thrusters do not work properly. With a propellant leak under orbital conditions, it is possible to freeze the leaking propellant and plug the thruster throat. A thruster firing with a plugged throat would cause an explosion that could not be tolerated. Without the warning of a leak provided by a leak detector, a firing with a plugged throat could be attempted. A solution to the problem is being sought. As the vernier thrusters are meant for precision maneuvers on orbit for purposes such as spacecraft retrieval and are not required for STS-1, it is planned to inhibit vernier firing for the STS-1.

The RCS tankage is satisfactory except for a concern about a possible screen dry-out that would permit pressurant gas to reach a thruster. This poses no physical problem to the thruster but would, however, reduce its thrust. Low thrust could be interpreted as a thruster malfunction by the flight control software and result in a cutoff of the thruster group served by that manifold, thus eliminating a redundant set. Work on a fix is in process.

It is expected that all testing needed for STS-1 will be completed by mid-1980.

Space Shuttle Main Engine

This past year has seen considerable progress in the development of the SSME towards its Preliminary Flight Certification (PFC) coupled with frustrating failures. These failures have impacted test schedules and taxed the ingenuity of the project staff both technically and with respect to devising means to work around impediments caused by the failures.

The ability of the SSME to provide the performance level needed for RPL flights has been demonstrated satisfactorily including the Return to Launch Site abort duration of 820 seconds. Cumulative test time to demonstrate maturity has grown, albeit not at the rate planned.

Firm standards for the achievement of PFC have been established and two engines have been designated as the certification specimens. Progress on these PFC tests was halted by the failure of the nozzle steerhorn during the Main Propulsion Test (MPT) run attempt in November. Hardware had to be reallocated and testing was deferred until the cause of the failure was established.

The Main Oxidizer Valve problem was resolved early in the year and design changes have been incorporated and proven. The POGO system performance deficiencies have been overcome by redesign and await resumption of MPT testing to provide final verification of the adequacy of the modifications. The High Pressure Fuel Turbopump (HPFTP) turbine blades still exhibit a limited life, but a stringent inspection program coupled with well-defined criteria for blade replacement should make this situation acceptable for STS-1. Work is continuing on both blade material changes, and ignition sequence and coolant flow modification to reduce the thermal shock and transient thermal loads that contribute to blade cracking.

A redesign of the nozzle coolant duct (steerhorn) to reduce the dynamic stresses it experiences during engine starts and stops is being implemented. This should increase significantly the allowable cycle life of this component.

Corrective action in the form of a detail design change and clearer process control has been implemented to overcome the Main Fuel Valve housing failure that caused a serious interruption of the MPT program in mid-year. There is, however, a lingering concern that the basic mechanism leading to the housing failure has not been identified. A test program to resolve this is planned. In the interim, stringent proof testing is being used to verify the adequacy of the housing.

The High Pressure Oxidizer Turbopump (HPOTP) secondary ring seal material is being changed to carbon and a sleeve that is part of this assembly is being thickened to provide for a more dynamically stable assembly. This change should help alleviate the problems of this seal until the planned redesign of the entire seal assembly can be incorporated.

By far the most serious aspect of the failures experienced this year was the discovery, during the investigation of the November failure of the steerhorn, that the welding wire used in manufacture of the SSME contained mixed lengths of both the correct alloy and an incorrect alloy. This occurred despite the fact that the supplier had certified that all the wire was of a single, correct alloy. As a consequence, almost all welds on all engines manufactured in the 1976-1978 period must be considered suspect. The welds have to be inspected and, where improper weld material is found, corrective action taken. This is a very large task and the impact on overall schedule is still being assessed.

This is the third time this year that a material problem of this general character has occurred in the aerospace industry. The other two were: the Reynolds aluminum plate problem (caused by non-uniform quenching) and B-nut sleeves of incorrect alloy on an Atlas that caused a launch slip. This series of unassociated problems causes concern about how widespread is this industry shortcoming.

Looking to the future, the design changes believed necessary to achieve full power level (FPL) thrust in the SSME have been identified and a program to achieve this level of performance has been planned. Implementation of this activity is, of course, contingent on progress towards PFC for STS-1.

At this writing an MPT run for full duration has just been accomplished. For this run the nonflight stub nozzles were used while the steerhorn welds were being reworked on the flight-type nozzles. Much testing remains to be accomplished to achieve confidence for first flight, but there are no apparent reasons why this cannot be done. It must be emphasized that the pressure to achieve a predicted flight schedule must not be permitted to truncate any of these planned "maturity" tests.

2. Auxiliary Power Unit

During the past year the nature of the thermal soak-back problem which has plagued the Auxiliary Power Unit has been understood and resolved. The solution has involved the addition of water cooling jets directed at critical locations. Testing on modified units incorporating the effects of altitude and temperature has demonstrated that the hot restart problem is now under control, and one would not expect the qualification testing to produce any surprises.

The pulse modulation system used to control the flow of hydrazine has in the past resulted in many problems for this machine, each of which has been solved by detail changes in the hardware or system. The latest such problem has been the failure of the seal in a hydrazine fuel isolation valve, presumably as the result of fuel pressure surges or "hammer." This is indicative of a problem that has normally been solvable and should not delay progress. Cracking of the modulation valve seats has resulted in a redesign of the seat. Until this is proven, frequent replacement of the original design is a satisfactory solution to the problem for the early flights.

3. Avionics

The Avionics System related to the Orbiter itself is in good shape, with a minimum of serious black box problems and the designation of the current software as the flight software. The existing configuration control and continued testing should assure that the system is ready for flight when needed.

The software related to the launch processing system is not as mature in that it has not been in existence as long. The current integrated testing at Cape Kennedy should tell how this system will react as a whole. We don't expect major problems, but small troubles should be expected and also should be reasonably easy to correct. Here again, flight schedule pressures must not be permitted to shortcut adequate verification of the compatability and reliability of the launch and flight systems.

The validation of software and crew training involves simulators and functional math models that of themselves utilize software. It is extremely important that this subsidiary software be rigorously controlled in order to be certain that the test programs are in fact valid. This is important, for instance, in the crew's evaluation of the flight characteristics of the Shuttle.

4. Thermal Protection System

Installation - The Panel continues to be deeply concerned with the quality of the Thermal Protection System. This system is new and has not been tested in space, is complex in its installation, and has been undergoing a continual development program as it is being installed. The catastrophic result of a serious loss of critical tiles on ascent or descent is obviously of great concern. It has been recommended in the past that one individual should be concerned full time with all aspects of improvement, testing, and actual installation of tiles. It is understood that this has been done. The effectiveness of this individual, however, will be directly proportional to the support he receives from all elements of NASA and the contractors.

The use of special study groups on the TPS has been helpful and the recommendations of these groups should improve the quality of the tiles as installed on the flight vehicle.

It is obvious that some of the tile work done in the past has not been satisfactory. Some tiles have pulled off at less than the required tension, and in some instances examination has shown that the bonding polymer has not wet an appreciable portion of the tile. The fitting and bonding of these tiles is very much a "man-material interface" type of process where the skill of the workman with his hands is of utmost importance. This means that supervision and subsequent testing are of utmost importance.

The Panel concurs with the recommendation that all tiles be pull-tested. This is being implemented for all tiles that are of a configuration that can be tested. It is suggested that special added procedures be instituted for the certification of those tiles which cannot be pull-tested.

The continuation of acoustic emission testing should also increase installation quality and produce a body of data to validate this new method of testing.

The Ashley Study Group has strongly endorsed the continuation of the study of possible means for inspection and repair of tiles in orbit. It is understood that this is continuing. Comment on the advisability of utilizing this cannot be made until the system has been developed and its practicability evaluated.

Since the Thermal Protection System installation and testing remains as an on-going program, the Panel will continue to follow it in subsequent months. If all of the recommendations and current programs are carried out, it appears that the TPS will be a reliable system for the first flight. Its reusability can best be evaluated after examination upon return from orbit.

New Developments - The problems encountered during the installation and certification of the TPS on STS-1 suggest that major effort should be directed toward future improvements in system concept and materials. The Panel will follow the planning of such new programs to assure that any new system retains or improves the capability of the present system and achieves a substantial improvement in reusability, and resistance to damage.

5. Wheels, Tires and Axles

Recent analysis of loads, coupled with experience in the subsonic flight tests and static ground tests, suggest that the main landing gear has inadequate margins for future operational reliability.

Design changes appear to be available to improve tire, wheel and axle strength. These changes should be pursued with the intent to incorporate them at the earliest possible time. The Panel now understands that plans for changing these elements for STS-1 will be carried out for first flight so as to not introduce a potential risk that could result in serious damage or destruction of the Orbiter after an otherwise successful flight. The Panel intends to review gear strength improvement changes and the potential schedule for test and incorporation of such improvements into the flight test orbiters.

6. Flight Stability

The Panel is cognizant of the critical nature of the control of the Orbiter during the supersonic regime experienced in reentry. Adequate knowledge of the aerodynamic characteristics of the Orbiter and its control surfaces throughout this regime is the basis for design of the control system itself, the performance requirements for the propulsion elements of the control system, the operational demands on the crew, and the software system that properly couples the crew and the auto flight system into an integrated useful Orbiter. Participation by Langley, Dryden and Ames in this effort is recognized. Such high-level technical review of the efforts of the JSC/Rockwell design effort is essential and should be formalized as an element of the certification process. Thorough testing of the final configuration, including the potential emergency modes, by high-fidelity simulation--and training of the astronauts--are mandatory to safeguard against control loss on reentry. This flight regime dictates the center of gravity limits imposed on future operational flights. Present limits must be expanded if the Shuttle is to fulfill its operational role; therefore, maximum effort must be expended during early flight tests to determine real safety limits.

7. Materials

The standard methods of industry for assuring the composition and properties of materials have presumably been accepted with little change by NASA. These methods generally involve paperwork which accompanies such materials and purports to identify heat and analysis for metals and alloys, physical test properties for fabricated sheet and other parts, composition for welding wire and so forth.

Experience has shown that this paperwork does not always correctly represent the material as actually incorporated in the vehicle. For example, test samples from corners of metal sheets may not represent the composition, heat treating, and physical properties of the center of the sheet. The composition of an entire reel of welding wire for an automatic welding machine may not be represented by the analyses of end pieces (reels are sometimes made up of two or more separate runs of wire).

In addition to these problems where the samples tested do not accurately reflect the properties of the material being used, it is always possible that mixups may occur so that the material received and incorporated in the vehicle is not the same as that purportedly represented by the accompanying paperwork. A classic example in all metal working industry which occurs repeatedly is the use by workmen of incorrect welding rods (despite many attempts such as color coding, individual job issuance by supervisors, etc., to avoid this).

Many instances of inadequate materials, improperly identified, have been experienced in the Shuttle system manufacturing and testing program.

There is probably little that can be done at this stage for the first vehicle except for specific inspection of critical areas. However, for future hardware programs NASA should join with other Government agencies so that the correct materials can be procured and their identification depended upon. Where single-point failures can be of catastrophic importance the present quality control methods of industry are not sufficient. An example of improved control which has been used in the past is the use of an on-the-job spectroscope for identification of alloys and welding wire on a piece-by-piece basis by the workman (or supervisor) just before use. Such compact instruments are commercially available and are used for sorting scrap metal. Many non-destructive test devices are also available for shop use on a piece-by-piece basis as actually used. It is strongly recommended that such point-of-use quality identification methods be developed until such a time that national programs reestablish the validity of normal material procurement methods.

EVALUATION PROGRAMS

The Panel has noted a growing dependence on formal review procedures throughout the NASA organization to evaluate progress on the Shuttle development. This kind of monitoring is useful and frequently essential to be certain that all supporting test work is completed and that an adequate time span for system element maturity and certification is protected. A word of caution is in order, however. Multiple reviews, particularly in a large, decoupled project, can tend to remove the feeling of responsibility from the programmatic worker. This must be guarded against and the role of the review teams be emphasized as one of critique, not of problem solution.

The review system does not guarantee that the proper design judgments have been reached or that the adequacy of the plans themselves have been critically reviewed on a continuing basis.

It is suggested that NASA, through its certification process, introduce formal "outside" critical assessments of the Shuttle system elements. Major contributions have already been made by such reviews in the Thermal Protection System (Ames, et al.) and the beginning efforts by Langley, Dryden and Ames to assess control adequacy during reentry. NASA, in its certification process, should be certain that judgmental, critical, experienced outside assessments of the concepts of design and the procedures to achieve Shuttle performance and to guarantee adequate safety margins are obtained.

NASA's Chief Engineer currently has such a verification/certification assessment effort underway for the first shuttle test flight (STS-1).

PAYLOADS

Evaluation of safety matters related to payloads was accomplished through NASA personnel at Headquarters, Ames, Johnson, Marshall and Huntsville centers, and with ESA at Noordwijk, Bremen, Cologne and Paris.

In general, payload safety is being pursued conscientiously and competently. Policies, requirements and procedures are in an advanced stage of development and appear to be appropriate and adequate. ESA is working to the same requirements as NASA. Their awareness of safety is good and their personnel are both informed and diligent. NASA work with ESA includes constant surveillance of safety-related problems. These are known and are being controlled. European Spacelab is behind schedule, but safety inspections are planned both at Bremen and after delivery to KSC. Ultimate responsibility for verification before launch rests with NASA and will be handled by planned and fully prescribed procedures.

Problems currently being worked by NASA personnel, and which will be followed by the Panel, include the following:

Inhibits

Requirements are specific regarding the number of inhibits and their verification, both on the pad and in flight, for all hazardous functions. This causes problems with some payloads, including Intelsat and some DOD items, for which observability of inhibits from the flight deck may not be possible. It may be necessary to employ waivers with suitable controls in some cases. The problem is receiving appropriate attention.

Structural Verification

Requirements for testing of materials and structures are well defined, and rules for verification by test, or in some cases by analysis, are established. Controls appear to be adequate.

Off-Gassing

Requirements to insure protection against fire, odors or toxicity resulting from off-gassing are established for both materials and components. The extensive experience gained on previous space flights is being utilized.

Integration and Mission Management

The Panel previously has recommended that particular attention be paid to insure utilization of the extensive experience with high altitude payload flights at Ames. This includes the use of specific mission managers for each flight, with overall surveillance, control and responsibility for integration of payloads. This sort of responsibility for Shuttle, except for DOD payloads, is assigned to JSC, where the individuals to handle safety-related matters, including integration, have been designated. Whether the concept of an overall mission manager is to be employed is not yet clear to the Panel, and this will be pursued further.

Radioactive Materials

Rigid rules for payloads incorporating radioactive materials, including Presidential review prior to each launch, have been in effect for years. These rules and procedures will be followed scrupulously for all Shuttle operations, as they have been for all other NASA missions. Procedures which are in place to insure compliance appear to be adequate.

DOD Payloads

For DOD payloads a joint working group has been established, with NASA representatives designated from Headquarters, Johnson Space Center, Kennedy Space Center and Marshall Space Flight Center, and USAF representatives from the Space Division and the 6495th Shuttle Test Group. The charter provides for the necessary liaison and responsibilities.

As we enter 1980 the Panel will intensify its surveillance of payload safety procedures to assure the Administration that proper control is maintained and that no added payload-related hazard is introduced without its knowledge. The Panel will also give attention to the upper stages being developed for specific missions. Interest in this is one of compatability with the basic Shuttle systems, and the evaluation of any increase in risk that is introduced.

OPERATIONS AND RANGE SAFETY

1. Astronaut Training

Slippage in launch dates has increased the time available for training. This time has been put to good use in training on high performance and specially modified aircraft. Terminal Area Energy Management of the flight path to flare and touchdown appears to be under control. The PIO problem on flare and touchdown has been alleviated by increasing the rate of the computer in processing data, tightening up on the control delays, and increasing elevon response rates. The Panel deems touchdown control to be adequate for FMOF.

Slippage in the availability of the moving base simulator has delayed training on the most critical phase of the Shuttle mission--reentry. The software is dependent on valid aerodynamic data, and depends on the operation of the simulator itself in the nominal and off-nominal reentry paths to tailor the control response coefficients, and to select trajectories that will ensure safe margins from thermal, structural stress, and stability boundaries. A danger exists in that excessive use of RCS fuel overcoming disturbing forces, such as an anomalous CG location, or an oscillation due to an incorrect gain setting in a servo control loop, could deplete the fuel available.

It is obvious that all the data necessary for design of a precise reentry trajectory and the necessary control coefficients will not be verified until after several Shuttle flights. It is also obvious that this data must be adequate, within rather narrow margins, before the first flight. Off-design point and emergency procedures must be emphasized in all of the training remaining.

2. Pilot Error

The presence of two pilots in the cockpit backed up by ground monitoring of critical operations, reduces the chance of pilot error. For redundancy, it would be ideal if each pilot could see and operate every control separately, but that is not possible due to the number of switches and circuit breakers and controls and displays in the cockpit. In addition, some switches have to be operated in a correct sequence. With the intent of reducing the chance of pilot error, the Panel would advise a thorough review of the cockpit design for subsequent operational vehicles, but does not suggest any major changes before initial flight experience.

3. Shuttle Pitch Control on Landing (Pilot-Induced Oscillations)

The Panel has followed with interest the progress of NASA engineers in investigating and improving the pitch control characteristics of the Shuttle on landing. Control has improved with reduction of computational cycle time, reduction in servo response times and an increase in elevon pitch rates.

The control problem is basic: A compromise between stability and responsiveness. It is related to pitch moment to moment of inertia of the Shuttle in pitch. In addition, the "camber effect," i.e., the inverse effect on lift as the elevons deflect, serves to introduce what amounts to a 180-degree delay in altitude response.

The recent trial of a "non-linear" filter, aimed at suppressing frequencies associated with PIO, is predictably disappointing, because it limits bandwidth in the region where anticipation or "lead" is necessary for stability. Decreasing gain in a region of aerodynamic delays may satisfy a criteria (mathematically) for stability, but it leaves the pilot with a sluggish control system that endangers his ability to recover from upsets due to gusts or turbulence

It is recommended that attention be directed to giving the pilots visual indications that will improve resolution of pitch information and improve their ability to introduce "lead" into their contribution to the control of the vehicle.

The progress to date on solving the PIO problem suggests that it can be handled by the current crop of astronauts for the first orbital flight. For later operational systems, improvements should be pursued.

4. Range Safety

The Panel has reviewed the Range Safety Destruct System and feels that it is well designed and reliable, and will not add any unnecessary hazard to Shuttle developmental flights. JSC and KSC officials are working cooperatively with ETR management to establish criteria for guidance to the Range Safety Officers. These "ground rules" for range safety action are expected to be submitted to NASA and USAF Headquarters for review not less than 60 days before the first manned orbital flight.

The results of the Wiggins study should be viewed in the light of the purpose expressed in the contract, i.e., evaluation of the need for a Range Safety System, and as guidance in establishing criteria for Range Safety action, such as destruct lines. The failure rates estimated should not be judged to represent a valid determination of the reliability of the Space Shuttle System.

The matter of if, and when, the destruct system should be removed should be determined by experience developed in the early tests. In the Panel's opinion this should not be coupled with the time for decision to remove the ejection seats.

SYSTEM SAFETY IMPROVEMENTS FOR THE SHUTTLE OPERATIONAL MODE

1. Uprating of the Main Engine

The operation of the main engines at 109 percent of rated thrust is a specification requirement, but in the Panel's opinion will entail a substantial amount of work on various engine elements and, as such, warrants being identified as an improvement effort. Achievement of this performance, reliably, is essential to operational safety.

2. New Concept Auxiliary Power Unit

The present Auxiliary Power Unit (APU) is a complex assembly embodying many "shop fixes" to its various elements. It is also underrated for the current power loads required to maintain acceptable redundancy in emergency situations. Its fuel--hydrazine--while having many advantages, is a toxic hazard, the procurement of which may become more difficult with time. It does not have complete containment for a bursting wheel, and its pulse-modulated fuel flow system is responsible for a large share of recurring problems. The Panel feels that a new start should be made on a different, simpler, more reliable APU. In light of current and expected demands, a review of the design rating of a new APU should be held before initiating a development program. The Panel has said for some time and still believes that this is a high priority item.

3. Wider Flight Stability Margins

The currently predicted flight characteristics of the Orbiter and its center of gravity tolerance are tight. This may be the result of unnecessarily conservative assumptions or too cautious interpretation of past experience, but if such limits are valid the potential for unforgiving responses to off-nominal situations certainly exists, the Panel does not think that this is critical for the first few flights, but it may well inhibit the future utility of the Shuttle. Every effort must be made to get pertinent flight data and to further study the control and emergency systems so as to determine the real flight CG "envelope."

4. Improved Thermal Protection System

The Panel feels that the thermal design of the tile is conservative and that every effort must be made to determine the true environment from the first flights. Such data will allow a redesign of the system to, hopefully, reduce weight and reduce the fragility and/or number of the tiles. It is also clear that current work on better, stronger materials must be continued.

5. Ground Control in Emergencies

Routine operation of the Shuttle must include provision for ground control of an acceptable reentry of the Orbiter in the event of incapacitation of the crew.

The Panel feels that this problem is largely one of methodology and psychology and believes that most or all of the elements necessary exist in the present system. It should be borne in mind that we are talking of an acceptable or emergency reentry, not a nominal one.

6. Reexamination of Black Boxes

A review of the black boxes, principally in the Avionics and GNC systems, should be made. In the years since the Shuttle electronics designs were completed there have been many strides made in the size, weight, and reliability of electronic units. In the future it would be impractical to manufacture duplicates for at least some of the Shuttle systems, and it will be advantageous for reasons of reliability and safety, if for no other reasons, to adapt newer designs to the Shuttle.

7. Reexamination of Redundant System Philosophy

The concepts incorporated in Shuttle systems reflect the state of the art in design of redundant elements for safety which were current when initial Shuttle concepts were evaluated. Many new concepts have emerged in both military and commercial aircraft systems since that time, and most have been proven and accepted in operations.

It is essential, for maximum operational safety and reliability, that all Shuttle systems be reviewed in parallel with the early flight tests to determine what systems might advantageously be redesigned for retrofit into the fleet, both for safety and for eventual reduction of operating costs through improved reliability. Design suggestions have been made in the past which should be included in such a review. These include:

a. Tandem or parallel hydraulic control surface cylinders;

b. Electro-mechanical control push rods (could be used to eliminate torque tube and gear box single failure points in rudder-drive brake system).

c. Programmed or fixed solid rocket nozzles (eliminating APUs in solids).

d. Augmentation of alternate power sources beyond triple APUs.

e. Potential recovery of Orbiter with crew incapacitated.

This list does not include many other system improvement concepts that have been suggested, but the proposed concepts are illustrative of the improvement potentials that should be systematically sought during the development phase of the program.

RECOMMENDATIONS

1. It is important to set a realistic schedule that will allow the orderly completion of the work to prepare the STS-1 for flight. For instance, all manufacturing should be completed before stacking, and it is imperative that all testing be finished with adequate time for analysis and evaluation before flight.

2. Start the necessary main engine design for 109 percent rated operations.

3. Start an alternate APU design and plan for early replacement of present APUs.

4. Continue thermal protection material development and system design looking to simplification and elimination of present fragility.

5. Investigate the assertion of ground control of reentry in an emergency.

6. Investigate the widening of flight control and center of gravity margins.

7. Review the redundancy philosophy for major systems, particularly in light of first flight experience.

8. Review black box inventory for state of the art improvements that should be utilized.

9. NASA should take the lead in getting high reliability users of materials to solve the problem of the inadequacy of industrial material supplies.

10. NASA should formalize an improvement program similar to that followed by transport manufacturers following introduction of a new model transport airplane. Elements of such a program have been suggested throughout this report. Recommendations 2, 3, 4, 7 and 8 contain such improvement candidates, and comments under System Safety Improvements for the Shuttle Operational Mode contain similar proposals.

The creation of an official improvement program would justify new budget elements and serve to focus NASA efforts on the configuration of the final operational Shuttle system. This program, coupled with the incorporation of experimental flight results into system improvements will accelerate the availability of a truly operational system.

AERONAUTIC RESEARCH

The aero-research programs are, in general, small as compared to the Shuttle and done at various test centers. The risk management systems vary with the NASA elements involved and tend to be simple, but adequate. Able people and flexible systems make for an efficient management of each program.

1. Highly Maneuverable Advanced Technology Aircraft

This remotely piloted research vehicle is advanced technically, and is important to the exploration of the limitations and capabilities of high performance aircraft. Initially it was plauged with delays and costs not entirely of its own making and the first two aircrafts were delivered for completion by DFRC. The extent of this work was underestimated, but it has now been completed and flight testing is now underway.

Flight #1 went well enough on July 27, 1979. During readiness for Flight #2, component failures were detected, but these are now corrected. Flight #2 was planned for December 21, 1979. Flight #3 will be completed by mid-January and Flight #4 should be in March. All of these first four flights will be conducted with the aircraft in a benign configuration, with the CG well forward. After Flight #4 the test programs become more critical, as the center of gravity will be moved aft, closer to the design configuration. In this unstable mode, the uplink, the downlink, software, and all systems must perform as designed. If an uplink, downlink, or software delay exceeding 80 milliseconds occurs, the vehicle can experience an unrecover able loss of control. The major risk is property (vehicle and real estate, principally Government facilities). As reported before, HIMAT will need improvements in the remote pilot cockpit to accomplish all flight limits and will need F15 or F16 chase planes to follow maximum maneuvering flights, since the F104 is not sufficiently maneuverable.

2. Tilt Rotor Research Aircraft

The NASA/Army Tilt Rotor Research Aircraft (XV-15) program is now in active flight status. Since April more than 30 flights have been accomplished, including several complete conversions from helicopter to aircraft mode. In preparation for the flight program the aircraft was extensively tested including tests of the flight vehicle in the Ames 40- by 80-foot wind tunnel. Ground testing revealed two problems. First, the wind tunnel tests indicated that tail vibration loads were in excess of fatigue allowables for the empennage. This problem was solved by addition of steel reinforcements to the horizontal tail spar caps and by strengthening the joint between the horizontal and vertical tails. In addition, fatigue tests indicated a problem with the engine coupling gear box from which the engines are supported in cantilever fashion. A support strut was added which reduced vibration loads both by providing added support for the engine and by changing the natural frequency of the assembly. Data obtained during flight tests indicated that the tail and engine load problems were solved by these changes.

One fundamental safety feature of the Tilt Rotor design has been proven in flight. During the climb-out phase of Flight #32, an incident occurred which began by the chase aircraft crew observing excessive smoke coming from engine number 2. The Tilt Rotor aircraft began a return to base, but enroute the smoking engine quit, abruptly. The aircraft continued on one engine and made a roll-on landing without further incident. The equipment, particularly the cross-coupling system, the flight crews, and the ground crews, all performed in exemplary fashion. Cause of engine failure is under investigation.

3. Rotor Systems Research Aircraft

This aircraft is now in the very early stages of flight testing and no large problems are apparent that have safety implications.

PUBLIC LAW 91-596

Public Law 91-596 "Occupational Safety and Health Act of 1970" applies to NASA to the same extent that it applies to other entities doing work that affects the health and safety of employees. The Panel feels that a periodic monitoring of NASA's compliance with this, and other pertinent law, is in order.

During Calendar Year 1979 the Panel visited several centers and made reviews of center compliance with the referenced OSHA laws. After a rather slow start in earlier years, and aided by NASA Headquarters' assistance and specific directions, the Occupational Safety and Health programs improved tremendously. NASA's experiences with the implementation of OSHA laws and executive directives follows the experience of other Federal departments. Centralizing and directing the annual surveys by NASA Headquarters and the Department of Labor required by OSHA and strengthening top NASA management oversight role has resulted in very impressive improvements since 1975 in center compliance.

The role of the NASA Headquarters designee as Director, Safety and Environmental Health for all routine and normal contacts concerning NASA safety and health programs, assigning the general responsibility for the overall OSHA compliance program to the Associate Administrator for Center Operations, and the high visibility, performance and interest of NASA's Chief Engineer, all contributed to an improved OSHA program performance.

The Panel also examined the NASA Safety and Health policies contained in NASA Policy Directive NPD 1701.1B, Marsh 26, 1974, NASA Safety Manual NHB 1700.1 (UI), July 1969, NMI 1800.1A NASA Occupational Medicine Program, January 12, 1976, and several other implementing documents.

A review of the above documents and the several annual survey reports, including those done by the Department of Labor, along with center visits and detailed discussions with responsible personnel, provided the basis for the Panel evaluation of OSHA program performance. In our opinion, NASA has in place acceptable, competent staffing, both in Headquarters and its centers to adequately perform and monitor OSHA compliance.

In addition to the application of OSHA laws and the Executive Order 11807 to NASA activities, there are several states in which NASA centers are located that have statutory laws which apply to worker and general public health and safety. Several states also enforce and administer the Federal health and safety regulations. It would take a special effort to research and evaluate NASA conformance with state laws, rules and regulations, but there is no obvious evidence of substantial non-compliance.

Continued attention by NASA Headquarters staff responsible for operations must be maintained if further improvements are to be made.

FUTURE PLANS OF THE AEROSPACE SAFETY ADVISORY PANEL

In order to fulfill the responsibilities of the Aerospace Safety Advisory Panel to the Administrator of NASA an analysis of the membership has been undertaken. This assessment suggests that new members should be added to bring the following talents to bear on future safety evaluations.

1. Experience in the engineering problems inherent in operations of a complex technical system.

2. Current experience in systems engineering, particularly those systems required to control modern military and commercial aircraft.

3. Recent experience in managing the development and adequate support of operations for modern aircraft and space systems.

4. Creative organizational management of formal safety and safety assessment functions.

These talents will be sought to fit into the membership at the termination of present member terms. Where necessary, individuals will be added as consultants to augment the current Panel membership. In the area of management of development support, the Panel will be augmented in the spring of 1980 by Ira Grant Hedrick, Senior Vice President of Technology and Development of the Grumman Aerospace Corporation.

During 1980 the Panel will continue to follow the progress of Shuttle and aeronautical development programs concentrating primarily on the progress of NASA's certification of the Shuttle systems, the currently scheduled test programs, the training of crews, the verification of adequate maturity of critical systems and the time available within official schedules to assure this maturity. A partial list of activities include:

1. Follow

   a) TPS
   b) SSME
   c) APU
   d) Stability and flight control
   e) Range safety procedures and limits
   f) Crew training
   g) Payloads

2. Monitor certification process
3. Structural margins of safety and attendant instrumentation
4. Mission rules and control center operation
5. Launch processing system
6. Participation in major readiness reviews

APPENDIX A

1979

PANEL SESSIONS

and

FACT-FINDING MEETINGS

1979 PANEL SESSIONS

February 22	Testimony before the Senate Subcommittee on Science, Technology and Space.	U. S. Senate
April 3-4	Space Shuttle review of Main Engine, Solid Rocket Booster, External Tank. Review of Spacelab and Payloads.	Marshall Space Flight Center
July 24-25	NASA's Research Aircraft Programs and Space Shuttle Orbiter Thermal Protection System.	Ames Research Center
August 28-29	Space Shuttle subsystems review, e.g., APU/Hydraulics, Orbiter doors, TPS, and technical management, e.g., configuration management and STS-1 mission rules.	Johnson Space Center
September 20-21	KSC launch preparation and launch procedures, Orbiter manufacturing and test/checkout status, Range Safety system, KSC risk assurance activities.	Kennedy Space Center
October 31-November 1	Space Shuttle STS-1 mission, e.g., entry flight control stability, protocol for ground control inhibit, flight/ground crew training and simulations, critical systems review.	Johnson Space Center
December 6	Discussions with NASA Chief Engineer concerning Space Shuttle issues and their resolution.	Washington, D.C.

1979 FACT-FINDING MEETINGS by INDIVIDUAL PANEL MEMBERS

January 3	Shuttle System Hazard/Risk Activities	Rockwell International, Downey, CA
February 8	Range Safety, Orbiter Flight Characteristics	NASA Headquarters
April 10-11	Orbiter Flight Crew Training and SAIL Avionics Testing and Simulation Activities	Johnson Space Center
April 25-26	Range Safety Discussions with Eastern Test Range (USAF) and NASA	Kennedy Space Center
April 25-26	Participation in Hazard Screening Board Activities	Johnson Space Center
April 30 thru May 2	HIMAT Flight Readiness Review	Dryden Flight Research Center
May 9-11	Shuttle Program Discussions with NASA Management	NASA Headquarters
May 21-23	Recommendations on Solution to Orbiter Pilot-Induced Oscillations Characteristics	NASA Headquarters
May 29	Skylab Reentry Review and Analysis	NASA Headquarters
May 30-31	Critical Items and Hazards on the Space Shuttle-SSME, SRMs, External Tank	Marshall Space Flight Center
May 28 thru June 1	Participation in SRB, ET, SSME, Hazard Analysis and Critical Item Review	Marshall Space Flight Center
June 18-19	Certification and Verification of Avionics Components of the STS System	Johnson Space Center
June 18-19	Space Shuttle Avionics, APU and other Critical Hardware	Johnson Space Center
June 20-22	KSC Operations, Shuttle Schedule/ Manufacturing Assessments	Kennedy Space Center

July 25-26	Space Shuttle Main Engine	Rocketdyne Canoga Park, CA
August 23-24	Shuttle Subsystem Discussions, including APU, Hydraulics, etc.	Rockwell International, Downey, CA
August 24	Inspection of Shuttle Training Aircraft	White Sands, NM
September 4-5	Space Shuttle Discussions with NASA Management	NASA Headquarters
September 5	Sub-Orbital Flight Test and Orbiter TPS Review	NASA Headquarters
September 12-13	Space Shuttle Main Engine Discussion	NASA Headquarters
October 16	Shuttle Range Safety Discussions	Kennedy Space Center
October 16	Shuttle Subsystem Status	Rockwell International, Downey, CA
November 8	Shuttle Range Safety Review	NASA Headquarters
November 15-16	Shuttle Range Safety Review	NASA Headquarters
December 3-5	HIMAT and Use of High Performance Aircraft to Test Shuttle Orbiter TPS Tiles	Dryden Flight Research Center
December 12-13	Developing Simulator Software and Testing of Shuttle Reentry	Johnson Space Center
December 18-20	Shuttle Orbiter TPS Review	Rockwell International, Downey, CA

APPENDIX B

INVENTORY OF PANEL ISSUES AND CONCERNS

PANEL ISSUES AND CONCERNS

ISSUE/CONCERN		STATUS
Orbiter TPS	Tile installation, inspection, aerodynamic cleanliness, external particles impacting TPS, manufacturing, critical tile map, on-orbit inspection/repair, and subsystem/integration management.	Open
Orbiter Umbilical Doors	Unsteady turbulent flow between the Orbiter and External Tank causing difficulty with TPS tiles and door closure.	Open
Mission Simulation & Training	Assure both adequate simulations and training time for both ground and flight personnel.	Open
Orbiter APU	APU fuel isolation valve seal breakage, performance capability, hot restart and reliability for STS-1.	Closed
Orbiter APU	APU performance, reliability and operational missions.	Open
Orbiter Door Closure	Umbilical doors' and payload bay doors' "door closed and locked" signal source to assure they are truly closed and in a locked condition.	Closed
Orbiter Landing Gear	Adequacy of tires, axles, struts, bearings, to take STS-1 loads.	Closed
Orbiter Lateral CG and Stability Qualities	The stability and handling characteristics of the Orbiter during entry (Mach 5 to 1).	Open
Space Shuttle Main Engine	Demonstration of maturity, adequacy of the hydraulic "lock-up" system, development of 109 percent Rated Power Level capacity, achievement of reliability and long-life hardware.	Closed
Orbiter Hydraulic System	Hydraulic system redundancy re maintaining SSME lock-up or last commanded position.	Closed

ISSUE/CONCERN		STATUS
Shuttle Software	STS-1 flight and ground software program adequacy/validation and configuration management.	Closed
Mission Operation	Uncontrolled (as opposed to planned contingencies) reentry of the Orbiter. Ability of the ground stations to enter the on-board control system without the aid of the flight crew.	Closed
Shuttle Configuration Management	Currently "good and appropriate," but as launch date approaches for STS-1 there must be equal or more rigor.	Closed
Range Safety	Assurance that range safety matters are under careful scrutiny and resolution by NASA and DOD.	Closed
Sub-Orbital Flight Test	The Sub-Orbital Flight Test Mission (SOFT) should not be made. Decision was made by NASA to drop this mission.	Closed
SRB Electric Requirements Supplied by Orbiter	Electrical capacity available for control of Solid Rocket Booster appears marginal under certain mission conditions.	Closed