NASA
National Aeronautics and Space Administration
Washington, D.C.
20546

ANNUAL REPORT

BY THE

AEROSPACE SAFETY ADVISORY PANEL

(NASA-TM-84094) REPORT BY THE AEROSPACE SAFETY ADVISORY PANEL Annual Report, 1981 (National Aeronautics and Space Administration) 37 p HC A03/MF A01 CSCL 22A
N82-16142
Unclas
G3/16 07577

FOR THE

CALENDAR YEAR 1981

TABLE OF CONTENTS

SECTION	PAGE
I. Executive Summary	1
II. STS-1 and STS-2 Turnaround Process and Base Operations	5
A. Readiness Review Process	7
B. Technical Audit Process	8
C. Orbiter Performance and Control Margins	9
III. New Function Emphasis for Transport System	10
A. Subcontract Services Required by "Space Transportation" from R&D Organizations	11
B. Space Transportation Ser ices Provided to R&D Elements of NASA	12
C. A Framework for Successful Routine Operations	13
D. Prime Functions of Transport Operations	14
IV. Continuing Activities of the Aerospace Safety Advisory Panel	16
A. Panel Membership	16
B. Informal Subgroup Activities	17
C. Plans for 1982	18
V. System Assessment and Hardware Concepts to Improve Operating Safety and Performance	23
A. Redundancy Review	24
B. Specific Systems	25
VI. Conclusions	31
APPENDIX - The Panel Membership	35

1981 ACTIVITY REPORT
AEROSPACE SAFETY ADVISORY PANEL

I. Executive Summary

In 1981, the first two Shuttle flights were accomplished and the Aerospace Safety Advisory Panel (ASAP) logically concentrated on the process of preparation for flight and the gathering of information from these flights to confirm the concept and performance of the major elements of the Space Transportation System. In this year's activities it became obvious to the Panel that the safety of the Shuttle operation would be increasingly dependent on (1) the procedures for turnaround, (2) the ability to quickly assess system performance from flight experience, (3) the developing judgment concerning what needed to be rechecked for each operation, and (4) the astute creation of truly "operational" procedures which would be simple enough to realize cost saving and thorough enough to maintain safe and reliable operations. Following this line of reasoning, the ASAP has reviewed its membership, has revised it to amplify operational know-how, and has turned its attention to the operational plans that NASA is developing and the organization concepts that will be used in fulfilling those plans.

In the current budget environment, it is recognized that many of the significant system changes previously suggested by the ASAP and those recommended in this report will not be feasible for retrofit in the present Orbiter production series. As a direct result, a number of the present systems will require more continuing special readiness attention than revised systems designed to be optimum for routine operation. Under these limiting circumstances the ASAP considers that the estimated 24 flights per year with 4 Orbiters will be very difficult to achieve. Having to use the hardware currently available should not prevent planning for an orderly R&D and certification program to create more nearly optimum operational systems. Such systems will then be available for incorporation in future Orbiters or for retrofit in the event that other factors, such as a demand for major performance improvements, dictate an extensive change program.

In reviewing the "incidents" which have occurred during STS-1 and STS-2 flights, it is apparent that the R&D nature of these first efforts, along with the reliance on complex paper systems for documenting the check and balance functions, have nearly obscured the necessity for personal, "on the floor," responsibility of supervision at all levels for safety and success. Many details of doubtful importance are raised to the highest management levels for decision by-passing the judgment of middle management and clouding the truly important issues that should be defined for major management decisions. The Safety Assessment Report, the Accepted Risk Summary, and the Critical Issues procedures as made available to the ASAP are examples of systems that should be reexamined for simplification and reorientation to identify the issues that truly need top management attention. In this process simplified turnaround procedures should emerge, along with tighter discipline to assure properly scheduled events and avoid last minute improvizations which can introduce hidden hazards.

The concept of the transportation system itself, including the essential subsystems, should also be reviewed for operational simplicity along with the management and procedures. The ASAP has attempted to review the basic architecture of the essential subsystems and recognizes that, in a number of cases, the state-of-the-art in modern transports and military aircraft offers opportunities for improving the safety and reliability of Shuttle systems based on mature concepts that have been operationally proven. Specifically, the ASAP recommends a major audit of the concept of redundant systems as applied to the essential elements of the Shuttle. The Panel believes that a more consistent approach to redundancy throughout all systems will simplify the elements and reduce costs while enhancing safety. The Panel recognizes that changes of any kind must await schedule and budget "windows" but suggests that an orderly subsystem improvement program can reduce ultimate costs and improve turnaround time.

Previous advice to NASA on turnaround procedures implied changes in organizational functions within NASA. The ASAP has suggested that a purely operational organization should be created that would function like an airline or a military mission command as compared to an engineering and development organization. Such an operational entity would relieve the R&D organization of responsibilities it is ill-equipped to handle and would improve the R&D function itself by stabilizing the performance requirements and by developing future customers to justify continuing development programs. The operational organization, it is suggested, should purchase services and hardware from the development part of NASA much as an airline purchases its transport aircraft, spares, technical support, and early training from the aircraft manufacturer.

II. STS-1 and STS-2 Turnaround Process and Base Operations

As could be expected, the turnaround of STS-1 and STS-2 had to be modified to accommodate the performance of major subsystems and the condition of these systems. As the Panel has reviewed these activities it is obvious that the preparation, and the basic design, produced a near miracle in functional success. The systems representing the most ambitious penetration of the state-of-the-art, the main engines and the thermal protection system, performed almost perfectly. Similarly the control and attitude, primary instrumentation, and boost propulsion units all functioned as required. This remarkable performance must not be forgotten in reviewing potential improvements in the turnaround process -- it suggests that a number of present subsystems will readily demonstrate "operational status" and permits relaxation of "every flight" test and check requirements.

The Panel's annual report for 1980, in the section on NASA Review System, discussed the Panel's generally positive conclusions regarding the commitment of top management to achieve an acceptable level of risk prior to authorizing the first manned Orbital flight of the Space Shuttle. We can reaffirm these conclusions in the present annual report. Panel members participated in all major program and flight readiness reviews prior to STS-1 and STS-2. Concerns reported by the Panel to top management, such as Orbiter entry stability and control, Orbiter seat eject system, SRB overpressure, timely recovery of the crew after landing, STS-2 launch schedule, and flight control analysis of off-nominal conditions, were carefully examined and documented reports were made to the Panel. The new NASA management team, from the Administrator on down, reaffirmed their predecessors' commitment to achieving an acceptable level of risk prior to the flight of STS-2.

Apparent in the preparation and turnaround was the predominant control of the process by the development practitioners of NASA and the understandable lack of patterns and experiments to reduce turnaround time and cost. Of particular concern to the ASAP was the apparent lack of "floor responsibility" at KSC. The Panel believes that the hypergolic propellant spill incidents demonstrate poor local supervision of specific procedures and a vague line of authority for essential tasks. Other evidence of poor discipline were instances of Shuttle damage by ground gear not clear of moving surfaces and ineffective access control of Shuttle areas not habitable due to the suspected presence of gases. The Panel recognizes the complexity of controlling a mix of personnel from other centers, many contractors, and base personnel, not to mention multiple advisors. The Panel also recognizes that written procedures by themselves can never substitute for capable "on the floor" supervision adhering to such procedures. Operations management must be in charge to make the total process successful. NASA organization responsibilities clear to the top need to be re-identified before simplification of the turnaround is achieved.

Of particular concern to the Panel from a design and system standpoint is the practice of major reprogramming between flights. For normal transport operations the essential content of the airborne and ground support computer memories should remain untouched from flight to flight, limiting reprogramming to that necessitated by the particulr cargo being carried. Even this reprogramming should be approached on the basis that there will be common functions for all payloads that can be accommodated without mission to mission reprogramming except for constants or I-Loads.

A. <u>Readiness Review Process</u>

The ASAP believes that the readiness process needs to be reconstituted before it is effective for operations.

To the Panel it appears that:

1. Reliability, safety, and quality organizations should be more clearly in the decision loops and the documentation process appears to be used more for post operation justification of actions than for deciding on readiness.
2. The documentation used for summarizing risk and evaluation of readiness as represented by the safety assessment report, the accepted risk summary, and the critical issues summary all appear to be dedicated to listing every possible concern so that retrospective examination will find no basis for criticizing thoroughness. These procedural activities did not appear to represent a management level by level evaluation of risks and a summary of judgmental total risk truly suitable for use by higher management.
3. The inherent assurance of having a separate operations team independently assess readiness,

as is the case with established transportation systems may not function adequately with NASA's present structure to assure an independent readiness opinion. Historically, management of the Space Transportation System has developed a pattern whereby Headquarters balances input from the "program," the centers, and the test community. Thus, no one organization within NASA has full responsibility for operations decisions. This must be modified before a routine and reliable operations function can achieve success.

B. Technical Audit Process

Among the many successes of STS-1 and STS-2 was a technical audit initiated at Houston to review and supplement the more routine sneak circuit analyses. This ad hoc function did not use "independent" evaluators or professional safety or quality assurance practitioners. It utilized the design team members who were responsible for major elements of the Shuttle systems and therefore had familiarity with the fundamentals of the systems and their limitations. They were also familiar with the test successes and failures and the interface functions among the elements.

The success of the ad hoc technical audit suggests that the process should be expanded in support of future Shuttle concept changes and improvement programs. It should also be considered by any new operations organization to assess routine processes and procedures and suggest new approaches which could save costs without increasing hazards. The ASAP believes that the success of such ad hoc teams stems from the currency of their technical or operational experience, their total familiarity with the system and their lack of dedication to any routine reporting or documentation discipline.

C. Orbiter Performance and Control Margins

The R&D program of four flights may be adequate to assess the safe operation of the system, but routine efficient operations require knowledge of the boundaries of performance that may not be fully established within the planned R&D effort. A plan needs to be established for continued performance envelope expansion to improve operational utility. Examples of the limitations include, e.g. limits for re-entry control, launch tower clearance for broad weather variables, and a myriad of redline limits which must be cleared before launch.

The Panel is particularly concerned with the demonstrated ambivalence to "redline" limitations. Redline limits should be set, and presumably have been, by combining accumulated experience of both design and safety engineers. To override such judgment in the readiness and launch environment potentially introduces unevaluated risks. This should be avoided in any cas and must be for any operational mode. The Panel conclusion from this experience is that "redlines" should be reassessed -- this may be a task for an ad hoc technical audit team. This could remove unjustified conservatism and could provide a rational basis for the rigid "redline" discipline which must be achieved.

III. New Function Emphasis for Transport Systems

The development of the Shuttle was a massive research and development task done by or under the direction of NASA's development-oriented centers. This was appropriate and successful. The task after the remaining development flights is to operate the present system in as economic and routine a manner as is possible. In addition, it is necessary to gain information that will create requirements for progressive improvements or needs that will become the basis for future new systems.

To achieve routine operation, the Panel believes that the Shuttle must be operated by a separate organization, with facilities dedicated to transportation services alone. Much like an airline or a military operational base, this organization should have no research and development charter nor capability but should be staffed by an experienced cadre of operational people. Although there are many capable "test" people in NASA the ultimate success of the transport system probably depends on NASA's ability to attract new people both in house and via contract. A clearly separate operations organization will be helpful in recruiting such talent.

Properly constituted and manned, such a transport organization would have the capability to:

- Assess hardware performance on the basis of operational reliability, reusability and low cost.
- Emphasize logistics planning, including spares.

- Assess changes on a cost and reliability basis rather than on performance improvement alone and control these changes.
- Base operations planning only on payload need thereby producing reliable schedules, and an operations budget plan that reflects cost savings due to learning.
- Create requirements for future performance improvements based on "market" needs -- for NASA itself as a customer, commercial programs, and the military.
- Stabilize the rate of technical change, simplify procedures, and reduce the traffic of decision demand upon Headquarters.
- Develop future customers.

A. <u>Subcontract Services Required by "Space Transportation" from the R&D Organizations</u>

It would be naive to think that the Shuttle and its operation would not require substantial continuing research and development as experience generates either new demands or desirable improvements from a cost or safety point of view. To accomplish this the operational organization must have a formal channel, and be required, to call upon NASA's research and development elements for the necessary work on essentially a subcontract basis. This will assure that the proper people do the work and that an appropriate framework for financial control is maintained and monitored. A few examples of the activities or functions that the operational organization should obtain from the research and development elements of NASA are:

1. The creation of any new Shuttle transportation elements, the requirements for which should be defined by the operations organization based on transportation customer needs.

2. The engineering required for changes to improve reliability, safety, cost or performance, the requirements for which are similarly originated and defined by the operational organization.

3. System and component testing services, including the certification of new or changed components or systems.

4. The advisory support of development specialists on a consulting basis.

5. The establishment of a formal program for the continuing performance audit of flight and ground systems, including tracking, communications and data systems.

B. Space Transportation Services Provided to R&D Elements of NASA

The Panel suggestion that the operational Space Transportation System look to the scientists and engineers elsewhere in NASA for research and development is coupled with a similar recommendation that the R&D community of NASA look to the transportation service organization for the performance of transportation and operations tasks for all of NASA. This on a "subcontract" basis in order to implement a framework for monitoring functional, financial, and schedule performance. A few examples of these services are found in the operation of OSTS (Office of Space Transportation Systems) today and include further:

1. The transport, or orbital placement, of payloads.

2. The orbital repair or retrieval of payloads.

3. The eventual maintenance of orbital facilities for manned or unmanned experiments.

4. Data delivery from orbital experiments for analysis by those responsible for the experiments.

5. Launch services and appropriate support for non-Shuttle systems.

C. A Framework for Successful Routine Operations

Last year's report by the ASAP commented upon the need for expanding its attention to the entire subject of logistics, payloads, and operations. These subjects, until the completion of two successful launches, have been transcended by the pressures of the research and development demands. With the production lead-times characteristic of small-batch highly specialized products a study which will lead to investment ranging from space engines and airframe components to the multitudinous system and accessary components is probably already overdue. The Panel is directing its attention to this operational phase and can be pected to require access to activities and developing programs in which its experience and expertise should be of value. The Panel looks forward to full cooperation from cognizant organization.

Maintenance and overhaul plans must first be developed in detail for KSC and VAFB and then, using these, such logistics elements as supply, manning, training, publications, and vehicle standardization can more logically fall into place. A range of turnaround rates should be considered from the most optimistic to the pessimistic, the latter considering the possible grounding of one vehicle due to accidental damage or modification. The ground support equipment and requirements have no parallel in previous practice and matters affecting overhaul and in-service life arising from repeated launch degradation are in need of special study now. Until this most comprehensive planning is undertaken it will be difficult to maintain budgetary control in a program which has now to be very cost-conscious. Schedule reliability is the sine qua non to attract commercial and even military payloads and, in the view of some Panel members, is more likely to be affected around 1983-85 by parts shortages than by equipment or design failures.

In attempting to assess its own capabilities to review future Space Transportation Operations the ASAP produced a broad outline of functions that must somehow be fulfilled by a truly operational organization. Although many of these needs have no direct impact on safety they do have an impact on the routine nature of any transport system, and therefore a secondary but important impact on the recognition of hazards. At the rates of the orbital missions now planned, it will be absolutely essential that procedures stay consistent, changes be reduced to near zero, and that the launch teams be experienced, well trained, and have qualified spares at hand.

D. Prime Functions of Transport Operations

1. Planning and marketing

a. Planning for present market

b. Future payload and orbit needs (commerce, government, military)
c. Total traffic projection
d. Service cost projection
e. Service pricing policy recommendations
f. Selling of services

2. Engineering and operations
   a. Definition of product improvement needs
   b. Facility Planning
   c. Logistics plans and operations
   d. Support and procurement (spares, fluids, services)
   e. Scheduling
   f. Overhaul and maintenance
   g. Base operations (launch and landing) support
   h. Quality assurance
   i. Cost control of transport system services
   j. Payload services to customers
   k. Training

3. Tracking, communications and data services
   a. Routine support of operations
   b. Payload communications and customer data service
   c. System and data base, modernization requirements
   d. Cost control of track, communication, data services
   e. Training

IV. Continuing Activities of the Aerospace Safety Advisory Panel

A. Panel Membership

As noted in the executive summary, Panel membership to provide operational experience has been augmented by members:

John F. McDonald, Vice President Technical Services of TigerAir, Inc., the parent corporation for Flying Tigers. John F. McDonald served for a number of years as Vice President of Maintenance and Engineering, and as a director for the Flying Tiger Line. Previous to that, he directed all commercial customer support activities for the Lockheed California Company. He was educated as a mechanical engineer in England and served British Overseas Airways Corporation before coming to America.

Norman R. Parmet, recently retired Vice President of Engineering and Quality Assurance for TransWorld Airlines. Norm Parmet has served TWA since 1947 in a number of roles including power plant development and as Vice President for New Equipment Development as well as Logistics Management. He was graduated as a mechanical engineer from Drexel Institute of Technology.

Plans for 1982 include a replacement for Dr. Seymour C. Himmel, whose term of appointment as a member was completed in 1981, and has been retained as a consultant for one year. It is hoped that his replacement will bring to the Panel similar expertise in the power plant field, particularly in hypergolic systems which now appear to require concentrated attention. During the year, it is also hoped that the Panel can be augmented by experience in the architecture of modern control systems.

B. Informal Subgroup Activities

It is expected that informal subgroups of the Panel will be formed to follow certain specific activities. In the view of ASAP the following appear to be particularly important:

1. An assessent of any continuing technical audit function instituted by the R&D program management. Such concentrated technical assessment was responsible for uncovering sneak circuit hazards prior to STS-2, and should be continued seeking improvements in safety and reliability for the electrical, electronic, and computational systems.
2. Suggested in this report is an audit of the systems redundancy concepts for the many Shuttle subsystems. The Panel believes that major simplification is possible which could benefit cost, performance, and safety. If alternative concepts cannot be accommodated within budget and schedule constraints, they can be incorporated in subsequent block buys of improved transportation systems and should be initiated now.
3. If NASA reorganizes to include an independent "operations" entity, a safety audit team should review the transition of procedures from R&D to operations. The criticality of this transition and

the obvious need for massive procedures simplification suggest that a continuing audit will be required. The ASAP will assess this activity or its equivalent.

C. <u>Plans for 1982</u>

The Panel has operated in the mode of fact finding by individual members or small informal groups visiting the appropriate centers and contractors. During the year the Panel compares notes and communicates with top NASA management. It is the Panel's intention to continue in this fashion, probably with an increased number of times when the entire Panel participates in the readiness activities prior to STS-3,-4,-5, and -6. It is planned to follow Orbiter 099 and particularly note the impact on operational procedures with two Orbiters being readied for launch in parallel.

The actual dates and locations of Panel fact-findings are to be keyed to the Shuttle major milestones recognizing the increased activity planned for Shuttle payloads with accompanying hardware and software impacts. Payloads include OSSA-1, Spacelab, Tracking & Data Relay Satellite System (TDRSS), and the probable incorporation of the Manned Maneuvering Unit (MMU). In addition to such payloads it is expected that the Panel will review concepts for upper stage propulsion systems and any early proposal for basic Shuttle performance improvements such as light weight SRB's or a light weight Expendable Tank.

KSC intends to have a self-sufficient Shuttle Processing Contractor when the Space Shuttle becomes operational. It is of interest to the Panel that such a transition take place without any loss of emphasis on ground and flight safety.

Although the Panel's efforts directed at programs other than the Space Transportation System require less concentrated attention they are equally important from the viewpoint of NASA's public accountability regarding their safety. In creating the Panel, Congress clearly envisioned this broader responsibility. These areas include aeronautics programs (manned and unmanned), unmanned space vehicles, and tracking and data acquisition as it affects safe mission operation. In times of great budget stringency, such as the present, it is especially important that safety considerations not be permitted to erode as program managers stretch their highly-constrained program resources to achieve desired objectives.

The following is a sample of those areas that are of continuing concern to the Panel:

1. Other Flight Operations: The concentration on the early Shuttle flights has diverted the Panel's attention from flight operations at Ames, Dryden, and Langley. Past Panel experience has shown that NASA controls the safety of test operations most carefully at these centers and the record shows good performance. Several accidents involving flight in aircraft not operating under strict NASA test control suggest that reviews should be made of procedures

whereby NASA personnel are exposed to hazard in less than controlled test conditions. The Panel plans to assess policies at these centers and review the control of such activities.

2. Pressure System Recertification: It has been suggested that the ASAP review how NASA certifies the pressure vessels and systems at its many facilities and how it maintains such certification. The Panel believes that its primary purpose is to concentrate on the safety aspects of manned flight and on the safety implications of operating unmanned systems rather than on what is normally called industrial safety. It is the Panel's assumption that industrial safety is a center function which has been successfully fulfilled through the years and will not address this important subject unless instructed to do so by the Administrator.

3. Contracting Out: Budget pressures and the efforts to provide more flexibility in manpower levels as operational efficiencies are achieved suggest that many more program operations be placed under contract. This does not relieve NASA of the supervisory responsibility. The inadequate compensation schedule of the Federal Government for top level managers makes it increasingly difficult to maintain a management team of highest technical and managerial competence. The exodus of key NASA

personnel during the past year provides striking confirmation of this grave problem. Although the Administration and Congress recently collaborated in achieving a small increase in the Federal pay cap, the problem is still unresolved and likely to remain so under present extreme budgetary pressures. The Panel believes it is essential to point out that loyalty and dedication to NASA -- a hallmark of the Nation's space program to date -- can only go so far in substituting for a pay schedule that is truly competitive with private industry. In this environment it is essential that contractors be chosen who can bring the maximum experience to the program.

4. Hydrogen Safety Standard: The Panel suggestion of a future hydrogen-oxygen auxiliary power system and the use of this fuel combination for on-Orbit reaction control systems imply different safety standards than are currently used for the fuel cells. In addition, the possible use of the Centaur as an upper stage in the Orbiter and the emerging potential of LH_2 as an aircraft fuel all indicate that the Panel should review existing safety standards for handling hydrogen in flight vehicles and in ground facilities for storage and service. The Panel will initiate such a review.

5. NASA-Air Force Coordination: ASAP activities have not included any reviews of Air Force launch facilities or simulation activities. Much could be learned from new approaches and it is assumed that NASA is fully familiar with Air Force activities. The ASAP will rely on instructions from the Administrator before making any requests to the Air Force for information.

V. System Assessment and Hardware Concepts to Improve Operating Safety and Performance

The two successful flights of the Columbia have demonstrated that the Shuttle can perform as a space launch vehicle and that the Orbiter can be reused -- an outstanding technological achievement. Even the most enthusiastic proponent of the Shuttle would not, however, claim that its present design can achieve the level of operational reliability (and hence safety) required for economical and "routine" transportation to and from space. There are Shuttle subsystems and components that, although acceptable for use during a flight test program and early transiton to operations, are not optimum for routine operational use. Even though the flight test program has just begun, it is optimistically planned to be nearly complete with only two more flights. It is not too soon to begin the process of study, analysis, design, and planning to improve the operating safety, cost, and performance of the Shuttle by reassessing it essential elements.

A two-part effort is required to achieve the improvements desired. The first part is a systems-engineering effort -- a reexamination of the consistency with which systems design principles have been used. The second part will necessarily address new designs or design modifications of specific hardware to achieve simplification, improved safety, and enhanced performance.

A. Redundancy Review

The Shuttle employs redundancy in its systems to achieve high reliability and thus safety. The degree of redundancy employed, however, varies from subsystem to subsystem. For example, in the flight control system the main computers are quadruple-redundant with a backup computer (and software) and a spare computer that the crew can install. The hydraulic system that provides the power to move the Orbiter flight control surfaces is triple-redundant in pumps and hydrazine-fueled turbines, is not redundant for each main engine control and it is double-redundant for each Solid Rocket Booster. The hydraulic actuators that move the surfaces are simplex with duplex servo-valves. The main engine thrust controllers have dual computers and a "lock-up" feature in the propellant valve system designed to retain thrust level in the event of a total controller failure.

Similar diversity in the use of redundancy exists in other vehicle systems. This raises the question of whether safety concepts have been employed in a consistent manner in the Shuttle systems design.

It would be advisable, therefore, to establish an "audit" team of experienced R&D systems-engineers to review the design of Shuttle systems to ascertain whether consistent safety/reliability concepts and criteria have been employed in the design. Where such consistency does not exist, the team should recommend design changes to provide such uniformity. At a minimum, this team should review the following:

- o Hydraulic power systems
- o Flight control system architecture
- o Main engine thrust control system
- o Main and backup computer systems (including programming)
- o Electric power system (including fuel cells)
- o Communication and data systems

B. Specific Systems

There are a number of systems which can be improved by redesign or design modification. The Panel believes that the following systems deserve attention in approximately the order listed.

1. Landing gear: At present the margin of safety of the gear for the originally-established design conditions is low. In addition, the design is such that should a tire fail, its mate (almost certainly) would also fail -- a potential hazard. Redesign of the gear incorporating a larger number of wheels than the current configuration would improve both the load-carrying capacity and enhance the operational safety of the system. Experience has shown that debris from the wheel ground interface has damaged the thermally-protected Shuttle surface. In any redesign, an effort should be made to divert such debris away from contact with the Shuttle -- spray ribs on the tires might be helpful.

2. <u>Solid Rocket Boosters</u>: At present, the gimballed SRB nozzles provide part of the control authority during ascent. Each SRB is equipped with a pair of hydraulic power units for the gimbal actuators. These hydrazine-fueled turbopump systems are complex and heavy. It was prudent to provide this control capacity for the early flights as it is not possible to predict with suitaole accuracy the control moments required during ascent in the absence of flight data for the unique configuration of the Shuttle. Now that flight data are becoming available, this system should be examined carefully to determine whether all the control authority provided is necessary or whether the SSMEs alone can provide all that is needed. In the latter event, the SRB auxiliary power units could be eliminated and relatively slow-acting electric actuators substituted to provide a programmed pitch profile during boost as the center of gravity changes. The savings in weight, complexity, and safety should be significant.

Additional performance improvement might be obtained by employing a composite material for the SRM case instead of the metal now used. This possibility should be studied thoroughly. Finally, the booster recovery system should be reexamined to see if it cannot be made substantially more simp than it is now.

3. <u>Cockpit and Crew Station Design:</u> The crew has myriad duties to perform in the cockpit. The workload can, at times, approach the saturation point. During STS-2, the crew workload, aggravated by sensor anomalies and the fuel cell problem, became so heavy that the crew fell a couple of hours behind in the "Crew Activity Schedule." The many sensor and transducer indications of "redline" approach or penetration, thermostat malfunctions, etc., raise the question of whether the qualification and certification for such instrumentaton is adequate. A thorough scrubdown of the cockpit displays, controls & switches, and the reliability of the sensors furnishing the information is indicated. In addition to assuring that the crew is furnished needed and valid data it is probable that a combination of automation and simplification would make Shuttle flight an easier task for the crew and thus safer.

During discussions with the flight crew of STS-1 concern was noted over the design of the emergency egress systems after flight STS-4 when the ejection seats are scheduled to be removed. The entire Panel did inspect the mockups available at JSC and concurs with the crew comments that an important safety concern exists. Of particular import is crew egress after ditching. The Panel heard an outline for future study at JSC and reviewed what was known of previous tests. It appeared to the Panel that substantially more effort to determine likely scenarios and their consequences is in order. Although ditching may be extremely remote this does not relieve NASA of the responsibility to provide the crew with as great a chance to survive as possible.

4. SIP Material Improvement: One of the problems of the Orbiter thermal protection system is the hysteresis in the stress-strain relationship in the strain isolation pad (SIP) material. A new version of the material with organized fiber orientation and consistent adhesion to the structure and the tile, rather than the random orientation of fibers in the present material, offers the promise of substantially reduced, if not eliminated, hysteresis. This development should be pursued actively.

5. Flight Control: At present, each control surface of the Orbiter is a single structure driven by a single actuator. Such simplex configurations are undesirable and are avoided in modern transport and military aircraft. Two alternative configurations have been employed in transport aircraft. The first is to employ a set of smaller independent control surfaces and actuators in place of a single large surface and actuator. The second is to use multiple actuators in parallel or in tandem on a single surface. Either approach enhances operational reliability and safety and these should be studied for possible incorporation in the operational Shuttle design. The Orbiter shares the problem of directional instability at high mach numbers with most

modern supersonic fighters due to the vertical tail being blanked by the shock waves eminating on the forward surfaces of the vehicle. This has resulted in changes in the computer handling of the reentry maneuvers and the use of yaw thrusters nearly down to Mach 1. Since a more direct reference system has already been designed and qualified it would seem prudent to utilize this Shuttle Entry Air Data System (SEADS) to determine whether such a reference would help to produce more stable reentries and reduce the demand on use of yaw jets at low mach number.

6. Common Non-Hypergolic Propellants: Other than for the main propulsion and booster systems, the Shuttle employs hypergolic propellants for auxiliary propulsion and power generation. Hydrazine and Nitrogen-Tetroxide are the propellants employed for these purposes. Both are toxic, incompatible with many Orbiter materials with which they may come into contact inadvertently, and are difficult to handle. None of these attributes are conducive to "routine" use and continuing problems involving safety and schedule can be expected. During both STS-1 and STS-2 preparation and turnaround, the presence of such materials limited access to the Shuttle, and during preparations for STS-2 there were two incidents involving spills of these propellants. Both these incidents and the lack of access impacted the preparation schedule for the Orbiter.

It would be advantageous if the use of these propellants could be avoided. The propellants for the SSMEs, hydrogen and oxygen, albeit cryogenics, could be used for the Orbital Maneuvering System (OMS), Reaction Control System (RCS), and APU systems without many of the operational problems of the hypergolics. There have been significant advances in the technology of hydrogen and oxygen for ancillary systems applications since the decisions were made to use hypergolics in the Orbiter a decade ago. A serious review of the possible use of H_2 and O_2 should be made.

The recommended studies and redesigns should be established as an overall program for the improvement of the Shuttle and its further development as an operational transportation system. The Panel fully recognizes the budget and schedule pressures that inhibit incorporation of changes even if many advantages accrue. The Panel also recognizes the hazard of change itself and its impact on procedures and the performance of even well-trained personnel and supervision. Thus, the concepts suggested are only for the purpose of indicating areas of attention for any planned improvement program or for defining the configuration for a future block purchase of an advanced transportation system.

VI. Conclusions

The Aerospace Safety Advisory Panel commends and congratulates all of NASA and its contractors for the historic flights STS-1 and STS-2. A task that verged on the impossible has been accomplished with the world privileged to watch every step. The success of these missions tempers any suggestions for improvement but, impressive as the development has been, the aim of the program is routine operation. In this spirit the ASAP offers these suggestions based on its evaluation through 1981.

A. To achieve true operating safety, regularity, and minimum practical cost, the organization of efforts between the R&D community and any transportation service organization should be clearly separated. The transportation service organization should assume responsibilities analagous to commercial airline managements. This includes marketing of its services to government agencies, and to commercial as well as international entities needing space transportation. Implied in "operations" is the planning and acquisition of prime hardware and spares, maintenance, certification of procedures, training, creation of requirements for future development including performance improvement and the responsibility to determine readiness for all missions and the fulfillment of these missions safely.

B. The Panel suggests a technical audit of the application of redundancy concepts to Shuttle systems. From design reviews the ASAP believes that many systems can be simplified with both safety and cost benefits while other systems should be backed up further for operational safety. ASAP candidates for such a review are:

1. Total hydraulic power system -- both for solid rocket and Shuttle control -- including the use, numbers, configuration and location of auxiliary power plants.
2. Basic control system architecture for aerodynamic controls, main engines, SRBs, and Orbiter control motors.
3. Control of main engine thrust.
4. Computer logic in normal and backup modes with a special effort to standardize programming for operations to prevent flight-to-flight and particularly last minute reprogramming.
5. Electric power systems
6. Avionics and communication

C. The current development state of the space transportation hardware suggests that a number of concept changes may improve operational safety, reliability and costs. In priority, the ASAP suggest:

1. Investigating a main landing gear with more than two wheels per side and devices to avoid gravel "spray" which damages thermal protection tiles.
2. Reviewing the need for control of SRB nozzles to maneuver the total Shuttle vehicle. As performance

of the control system evolves, it may be possible to revert to a programmed "trim" system on SRBs. In addition, when investigating lighter cases (composites) the separation and recovery systems should be reanalyzed to simplify.

3. The automation and simplification of cockpit and routine crew duties, along with improved reliability of sensors.
4. Review of the hysteresis of SIP. Repeated missions will require SIP that is less susceptible to dimension changes with steady and vibratory loads.
5. Reassessment of flight controls concepts. It is suggested that multiple control surfaces or drives be considered.
6. Investigate non-hypergolic fuel and oxidizer for orbital boost, on orbit control motors, and APUs.

D. For the remaining R&D flights, it is suggested that a "redline" audit be made of limits that should not be exceeded for "ready to launch." It is poor practice to set conservative limits and then bypass them at last minute launch readiness conferences.

For 1982 the ASAP plans to follow the developing operational transportation program to review hardware changes, procedural changes, and the progress in clarifying the duties and responsibilities of any new operational organization. The review of 1982 scheduled flights, their readiness and performance, will be a primary ASAP activity.

In addition, the ASAP plans to revisit non-Shuttle flight activities at NASA centers both support and test. Finally, in 1982 the ASAP plans to review concepts and hardware for Shuttle payloads and upper stages since many of the unique mission equipment items introduce potential operational hazards to both individual crew members and the Shuttle itself.

APPENDIX I

Name and Affiliation	Appointment Ends
Willis M. Hawkins Senior Advisor Lockheed Corporation Burbank, CA 91520	September 1, 1988
Richard H. Battin Charles Stark Draper Lab. Cambridge, MA 02139	April 7, 1986
Lt. Gen. Leighton I. Davis USAF (Ret.) Albuquerque, NM 87123	December 19, 1983
Herbert E. Grier Consultant La Jolla, CA 92037	January 18, 1985
Ira Grant Hedrick Presidential Assistant for Corporate Technology Grumman Aerospace Corporation Bethpage, NY 11714	November 17, 1985
Seymour C. Himmel Consultant Lakewood, OH 44107	December 23, 1981 (Consultant status through 12/82)
John F. McDonald Vice President-Technical Services TigerAir, Inc. Burbank, CA 91505	June 15, 1986
Norman R. Parmet Consultant Fairway, KS 66205	1988 (in process)
John G. Stewart Manager, Office of Planning and Budget Tennessee Valley Authority Knoxville, TN 37902	April 14, 1986
Walter C. Williams NASA Chief Engineer Washington, D.C. 20546	Ex-Officio Member
Gilbert L. Roth NASA Headquarters Washington, DC 20546	Staff Director
Susan Webster NASA Headquarters Washington, DC 20546	Advisory Committee Assistant