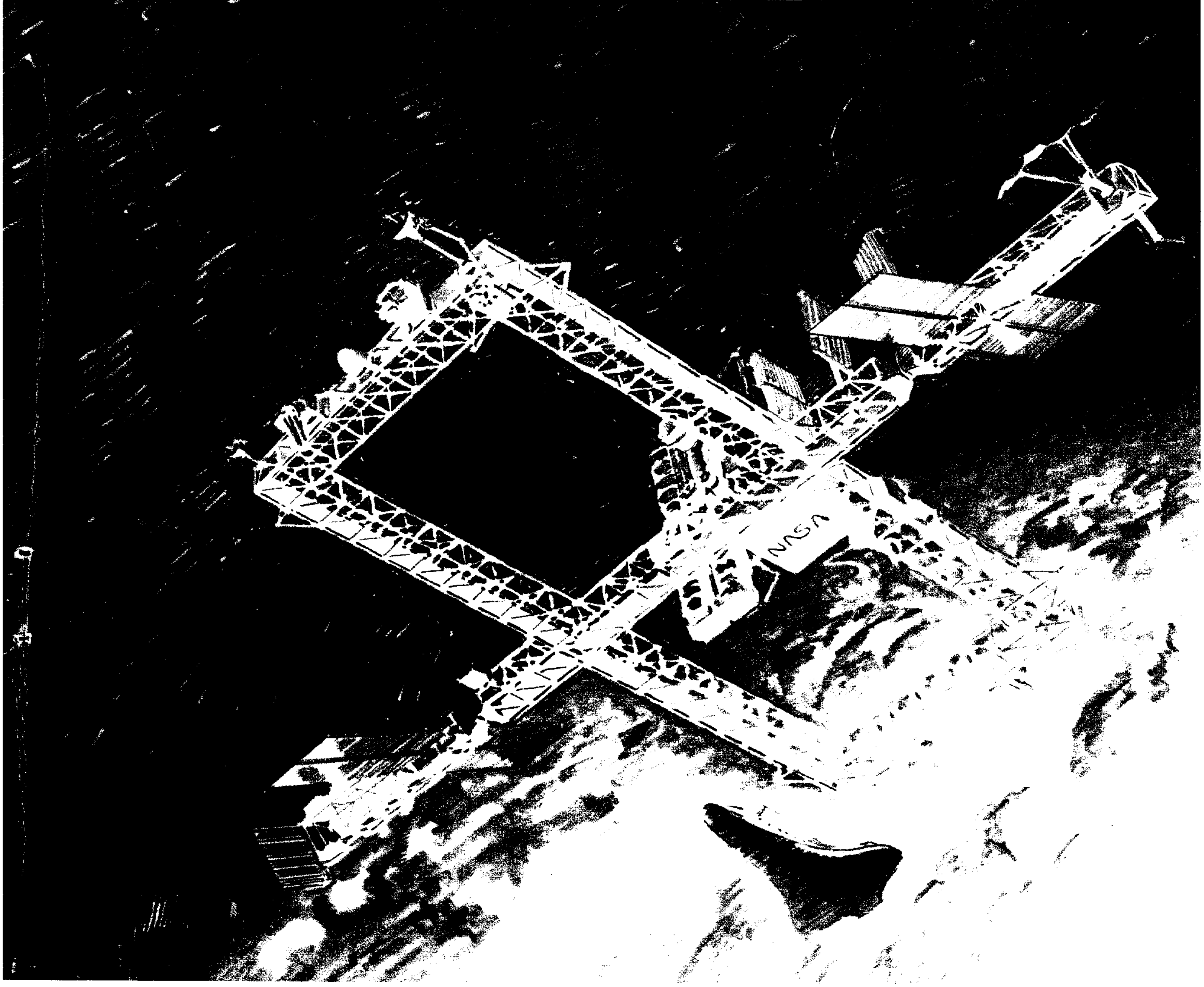
National Aeronautics and
Space Administration

NASA

Aerospace Safety Advisory Panel

Annual Report FOR 1986



AEROSPACE SAFETY ADVISORY PANEL

ANNUAL REPORT

COVERING CALENDAR YEAR 1986

Issued February 1987

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EXECUTIVE SUMMARY

The Challenger accident set in motion a great number of activities directed toward Space Shuttle recovery, the results of which will affect NASA and its contractors for the foreseeable future. The Aerospace Safety Advisory Panel's factfinding and reporting activities were also in support of returning the Space Shuttle to safe flight status in a timely manner.

Given the breadth of Panel findings and recommendations resulting from this year's factfinding work, this report is structured to provide a compact and useable Executive Summary focusing on the most significant areas of interest followed by stand-alone sections covering Space Shuttle management, Shuttle hardware/software systems, Shuttle operations, NASA Safety/Reliability/Quality Assurance, Space Station Program, and aeronautical activities. The majority of the Panel's efforts were directed toward understanding and providing constructive criticism in support of Shuttle Program recovery efforts.

Panel members and consultants were involved in more than 50 individual and group factfinding sessions, congressional hearings, "one-on-one" meetings with NASA senior managers, and were participants in three National Research Council (NRC) independent oversight groups examining the solid rocket motor redesign, flight rate and manifests, and critical items and hazard analyses. Panel information, oral and written, was supplied to the Presidential Commission on the Space Shuttle Challenger Accident and the House Committee on Science and Technology Investigation of the Challenger Accident.

NASA's response to the Panel's last annual report (issued January 1986) is quite detailed. Due to the changes which NASA experienced in 1986, multiple response letters were provided between September 1986 and February 1987 covering first the aeronautical programs, then the Space Station, and last the Space

Shuttle Program. These appear in the Appendices portion of this report along with a status ("open" or "closed") for each specific point covered.

A report summarizing specific and generic lessons learned as a result of the Panel's factfinding activities was issued in November, "Lessons Learned--An Experience Data Base for Space Design, Test and Flight Operations." Copies went to NASA and contractor organizations.

Space Shuttle Management

1. The Panel finds the recent reorganization of Space Shuttle management to be a positive step in recapturing or rebuilding a spirit of mutual respect and trust at all levels. The Panel recommends that: a priority objective of the new management team must be to enforce NASA's management instructions and to define clearly the responsibilities and authority of the NASA centers; a willingness of all NASA centers to pull together, to subordinate parochial interests, and to help each other is absolutely crucial if the Space Shuttle program is to succeed.

2. The Panel finds that NASA and the Congress need to appreciate that the Space Shuttle is a system which remains primarily developmental with some operational characteristics. It is recommended that NASA needs to emphasize the developmental characteristic or it is likely to miss key elements of the Space Transportation System management challenge.

3. The Panel notes that transfer of part of the Space Transportation System (e.g., Orbiter) logistics responsibility from Johnson Space Center (JSC) to Kennedy Space Center (KSC) must be supported with adequate budgets and appropriate authority to: build a sufficient inventory of spare parts, upgrade the Line Replaceable Units (LRU), and develop an effective program to reduce LRU turnaround time.

4. The Panel recommends that those elements of sustaining engineering that are directly related to launch processing should be the responsibility of the launch operations center (KSC) and those elements of sustaining engineering that require detailed knowledge of the design and development history of airborne hardware should remain with the design centers, as NASA now contemplates.

5. The Panel recommends that NASA should achieve consolidation and upgrading of Space Transportation System data/information systems, particularly those related to configuration management and launch procedures.

6. The Panel finds that although top Shuttle Processing Contractor (SPC) and NASA managers are communicating reasonably well, there is a continuing need to communicate even more directly with workers involved in launch processing to assure that there is a clear sense of mission and direction, and to benefit from employee initiatives and suggestions during these crucial months prior to first reflight.

7. The Panel reiterates that NASA and the Shuttle Processing Contractors need to prevent a recurrence of the condition that developed in 1985 where human resources at KSC were excessively stretched due to launch processing workload and schedule pressures (for example, overtime policy).

8. The Panel recommends that NASA top management should address the growing problem of recruiting and retaining talented engineers and managers due to inadequate Federal salaries. This is not just a Space Shuttle problem.

9. The Panel, in an independent review, concurs with the National Research Council (NRC) Panel conclusions on Space Shuttle Flight Rates and Utilization, that is, an upper limit of 8-10 flights per year with a three Orbiter fleet and 11-13 with a

four Orbiter fleet. Further, the Panel recommends that the Space Shuttle be used only where manned missions are deemed mandatory, and expendable launch vehicles should be used for all other missions.

10. NASA and the Congress should no longer expect that "heroic" performance by its workers and its contractors can compensate for funding shortfalls. The sort of heroism that is needed today is the courage to promise no more than can reasonably be expected given the dollars and people available.

Space Shuttle Systems

1. The Panel finds the redesign of the solid rocket booster (SRB) joints is a marked improvement over the original joint design but there may be problems with mating, demating, and reuse. The approach selected entails more risk than one using new forgings that might permit a more sophisticated design but which would delay first Shuttle flight. Since the proof of adequacy of the design depends strongly on satisfactory results from a thorough certification test program, the Panel recommends a truly complete definition of the certification program and that the elements of the certification program must relate to the specific design requirements.

2. The Panel agrees with the decision to test the solid rocket motors in the horizontal position. In line with this a second horizontal-firing test stand is being constructed that will have the capability to apply simulated flight external dynamic loads. Since there is no way to assure that the tests encompass all possible loading conditions and assembly differences, the Panel recommends that the SRBs and the test stand itself be heavily instrumented to assure that flight-type structural and performance data is obtained as part of the certification program.

3. The Panel urges NASA to provide funds to (1) check Orbiter 102 for loads resulting from the latest loads/stress analysis (designated ASKA 6.0), (2) check the other orbiters for ascent and descent loads, (3) update orbiter load indicators and redlines, and (4) prepare appropriate loads/stress summary reports.

4. The Panel urges NASA to have Orbiter 102 undergo a loads test program to calibrate the strain gauges installed so that flight data from these strain gauges may be used with confidence to obtain wing loads in flight.

5. NASA conducted an extensive reexamination of the Space Shuttle Main Engine (SSME) during 1986 to identify any safety issues that might have been overlooked and then to establish and validate an engine configuration for use in the upcoming Shuttle missions. The Panel finds that the changes being made as a rule do not indicate that there will be any significant improvement in "margin to failure." The Panel recommends that the Phase II engines operate at power levels below 104-percent rated thrust, and if possible at no more than 100-percent rated thrust until these engines have accumulated sufficient flight operating time.

6. The Panel recommends that the Space Shuttle Main Engine two-duct Hot Gas Manifold and the large throat combustion chamber be tested and certified as soon as possible.

7. The Panel recommends that NASA and the SSME contractor continue the development of improved methods for actually demonstrating critical operating failure mode margins and the more rigorous risk assessment analytical procedures. It is recommended that, as part of such procedure, the term "failure" be defined as a violation of any of the governing design criteria for a component rather than as an event such as a structural failure or burn-through.

8. <u>Shuttle Orbiter Computers</u>:

a. The Panel findings regarding the use of upgraded computer systems in late 1988 in either the 4/1 (4 new computers plus 1 old computer) or the 5/0 (5 new computers) configuration include the following factors:

(1) The degree of additional safety provided by dissimilar hardware (there already is dissimilar software);

(2) Human factor contributions to risk--part of the safety provided by computer redundancy is achieved through astronaut training and in flight operations and maintenance procedures performed by the astronauts. This risk difference may well be greater than that in item a above.

(3) The impact of the flight schedule on the scope of software testing, or stated conversely, the impact of required software testing (which is larger for the 5/0 configuration) on the flight schedule; and

(4) The additional costs associated with the 5/0 configuration.

b. The Panel recommends that:

(1) In order to provide greater confidence in the new General Purpose Computer (GPC), it is recommended that the new GPC be flown on several flights as the backup computer before being used as the primary system.

(2) NASA should conduct a study of the human factors aspect of risk associated with in-flight operation and maintenance procedures, particularly changes in procedures and configurations resulting from response to

some failure. Included in this should be a preliminary design of the 4/1 procedures and training and an assessment of their impact.

9. The Orbiter landing gear system (including brakes and nosewheel steering) has been a subject of concern to the Panel as noted in its reports since 1981. NASA's response to Recommendation VI of the Presidential Commission's report appears to meet the intent of the Panel's earlier recommendations. The Panel intends to monitor these areas to assure NASA completes its stated action plan.

Space Shuttle Operations

1. The Panel reviews of NASA and contractor launch processing operations included "one-on-one" interviews with technicians and quality control personnel doing the "hands-on" work. These have shown that recent efforts are steadily improving the effectiveness of both NASA and contractor activities at KSC.

2. Space Transportation System logistics have improved but there remain some concerns:

a. The completion of the procurement of necessary spares.

b. Design improvements to Line Replaceable Units (LRUs).

c. Procedures to control hardware cannibalization between vehicles.

d. Establishment of required repair sites for Line Replaceable Units to improve turnaround time.

e. The many activities in support of returning to flight ("recovery"), e.g., hazards reviews, which may require modifications which affect logistics requirements.

3. The Panel recommends that the recommended "Maintenance Safeguards" program being prepared by NASA in response to the Presidential Commission report be documented quickly and its impact evaluated as soon as possible.

Safety, Reliability, Quality Assurance

1. The Panel finds that three fundamental weaknesses appear evident. First, there has been a lack of in-line responsibility and authority in the Headquarters organization for establishing policy for the safety engineering function throughout NASA. Second, the elements of the safety functions that have been accomplished at various locations did not include responsibility for defining and controlling the validation and certification programs. Third, there is a conscious lack of quantitative approaches to determine failure-mode probabilities for the purposes of defining acceptable margins, and the relative likelihood of resulting system interactive hazards.

2. The Panel recommends that:

a. Within the newly established Safety, Reliability, Maintainability and Quality Assurance (SRM&QA) organization, NASA should develop the operating policy for all NASA SRM&QA and have the authority to ensure implementation. At each Center there should be a NASA Safety Engineering function reporting to the Center Director. This function should be matrixed into the various programs/projects and should be responsible for implementation of safety policies established by the Headquarters organization.

b. NASA continue to independently review all payload components with regard to their individual inherent safety, and should analyze the safety implications of the potential interactions of payloads in the event of a malfunction of any individual one.

Space Station Program

1. The Panel endorses the initiative to simplify the Space Station design and reduce the extent of manned assembly in orbit using extra-vehicular space suits.

2. The Panel suggests that expendable launch vehicles of greater performance than the Shuttle be included in the launch stable inasmuch as such vehicles may emerge from other national programs.

3. The Panel recognizes that "Safe Haven" and "Life Boat" options are under study in the continuing efforts to define the Space Station. The Panel suggests that both concepts may be required to satisfy ultimate safety requirements for Space Station operations.

4. The Panel is concerned that the computer systems being considered for the Space Station may not be taking into consideration evolutionary changes that will inevitably evolve in the industry in the next two decades. The Panel recommends that the system be designed to allow for the replacement of components as new technology develops. A 32-bit architecture and industry standard bus should be mandatory.

5. The Panel reiterates an old theme: Lessons learned from prior programs must be applied and that such documented material is readily available, e.g., Saturn-Apollo, Skylab, Centaur, Space Shuttle.

NASA Aeronautics

1. The Panel recommends that NASA ensure that the level of the Headquarters Flight Operations Management office and those at the Centers have proper recognition and ready access to their top management.

2. The Panel recommends that the Shuttle Flight Simulators (aircraft) program be completed in a timely fashion so that astronaut training will not be hampered.

3. X-Wing/Rotor Systems Research Aircraft (RSRA) incorporates a number of complex analyses, simulator and test efforts. The Panel recommends the Flight Readiness Review be conducted after completing these efforts and that the correlation between them be carefully examined. Included in this are the following:

a. The raising of the vertical center of gravity of the vehicle by some 18 inches as compared with the standard RSRA vehicle. This is having a pronounced effect on structuring of the flight test program.

b. Aircraft structural divergency prediction from the tunnel tests.

c. Refinement of the flutter and divergence analyses.

d. Results from the powered model tests correlation with predicted downwash interference predicted by analysis.

e. The definition of the telemetry requirements with emphasis on software requirements for automatic monitoring.

4. The X-29 project with so many new technologies involved is an example of a meticulously conducted flight program taking safety into account throughout.

I. INTRODUCTION

A. Scope and Structure

The Challenger accident, January 28, 1986, set in motion a great number of activities, the results of which will impact NASA and its contractors operations for the foreseeable future. The Aerospace Safety Advisory Panel's factfinding and reporting activities were also directed toward supporting the return of the Space Shuttle to a safe flight status. This year's annual report mirrors this in several ways:

- Our efforts this past year have resulted in the report devoting itself mainly to the Space Shuttle Program, then to the Space Station Program and to Aeronautics.

- Three major subjects make up the Space Shuttle section: management, systems and operations, safety/reliability/quality assurance.

- NASA has responded to our January 1986 annual report in greater detail than before with circumstances dictating three separate letters from the NASA Administrator: first, covering aeronautics and aircraft operations; second, covering pressure suits, Space Station and space debris; and third, covering the Space Transportation System. These are found in the Appendices.

B. Role of the Aerospace Safety Advisory Panel (The "Panel")

The Aerospace Safety Advisory Panel was established in the aftermath of the Apollo Command and Service Module spacecraft fire January 27, 1967, at Kennedy Space Center. Shortly thereafter the Congress enacted legislation which established the Panel as a senior advisory committee to NASA and to the Congress.

The breadth and depth of the Panel's activities have been defined, refined and redefined since its inception. The Panel's charter is to conduct reviews of NASA and its contractors management and programmatic activities with regard to the safe conduct of their operations, and to advise the NASA Administrator and senior management, and the Congress of Panel findings and recommendations for their consideration and for their guidance.

C. Overview of Panel Activites During CY 1986

The Panel has three parallel streams of effort:

- Factfinding activities conducted by Panel personnel covering significant facets of the Space Transportation System, Space Station, and Aeronautics.

- Special tasks in direct support of the Administrator, for instance, support of those actions being taken by NASA to implement the Presidential Commission recommendations, NASA's response to the Congressional report of the House Committee on Science and Technology.

- Independent oversight groups such as the National Research Council "Panel on Technical Evaluation of NASA's Proposed Redesign of Space Shuttle Solid Rocket Boosters." Aerospace Safety Advisory Panel member, Melvin Stone, participates as our representative and independent observer. The NRC "Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization" had Panel member Norman R. Parmet as a member of this group which issued its report in October 1986. The NASA Administrator requested NRC to form a panel "Space Shuttle Criticality Review and Hazard Analysis Audit" to respond to another Presidential Commission recommendation. Aerospace Safety Advisory Panel members Norman R. Parmet and Gerard W. Elverum, Jr. are full time members.

The Aerospace Safety Advisory Panel factfinding sessions during Calendar Year 1986 numbered 49, and in addition, numerous ones were associated with the above NRC panels. There were a number of sessions before both the U.S. House and Senate.

In a departure from the Panel's normal factfinding, while at KSC in August and December 1986, a six-man team personally interviewed 48 technicians and quality control personnel doing "hands-on" work for the Shuttle Processing Contractors. The results of this are noted in appropriate sections of this annual report.

II. SPACE SHUTTLE MANAGEMENT

A. Background

In recent annual reports, the Panel has expressed concerns and made recommendations relating to management and organization of the Space Shuttle program. In the 1984 annual report, for example, the Panel discussed the heavy launch processing burden associated with each mission. We cautioned NASA management to avoid advertising the Shuttle as being "operational" in the airline sense "when it clearly isn't." We observed that, in the Panel's opinion, such routine operations would not likely be achieved for 5 to 10 years and NASA should focus on improving the Shuttle's reliability, maintainability, safety, and the allowable flight envelope.

Last year we noted some progress in the Shuttle Processing Contractor's (SPC) handling of the burden of preparing the Shuttle for individual missions. But we also pointed out that problems associated with unplanned vehicle modifications, unexpected anomalies, shortage of spare parts, a generally underfunded logistics program, shortage of qualified technicians, heavy paperwork burden, lack of hardware reliability, and internal planning and communication problems would necessarily limit the flight rate for the foreseeable future. We expressed the view that NASA's goal of 18 to 24 flights per year was not within reach at present and that 12 to 15 per year was the most NASA could hope to achieve. The Panel believed that an "operational" Space Shuttle program was still many years in the future.

Many of these same concerns were raised by the Presidential Commission in the aftermath of the Challenger accident and a number of recommendations dealing with organization and management problems were made. Since then, NASA has made resolution of these problems a high priority. The Administrator appointed General Sam Phillips and his team to review NASA's entire organizational structure. Astronaut Robert Crippen led a study of how to improve the Space Shuttle's program management and internal communications. In November 1986 NASA announced an interim office of space flight management structure. This was finalized with an organizational structure with key personnel assignments announced in February 1987.

The Panel's current observations necessarily take into account these continuing efforts by NASA to respond constructively to the Rogers Commission and to build an organization that can sustain the Space Transportation System with safety and reliability into the next century.

B. Organization

In the past the Panel has urged formation of an entity within NASA charged with full responsibility and authority for Space Shuttle operations. We have urged a stronger leadership role by NASA Headquarters in directing and bringing together the work of the NASA centers. Panel members have commented on what appeared to be a lack of discipline in following internal management instructions and a failure by top management to insist that established procedures be followed. As a result, communication breakdowns and confusion over priorities in the overall Space Shuttle program have occurred. In the opinion of Panel members, NASA's characteristic dedication to excellence as a key ingredient in achieving effective management was being subordinated in some cases to concerns over institutional roles and priorities, i.e., "turf." The extent of organizational change required to fix these breakdowns has been a topic of discussion within the Panel. Since the Challenger accident, we have thought a great deal about these problems and have further refined our views.

The Panel emphasizes that in any management structure responsibility and authority must be clearly identified and delegated. During recent years, NASA has not done this adequately and performance has suffered.

Business management systems are generally self-policed or controlled by the net profit figure. This is a sensitive, effective control system for costs but it is not particularly effective or even desirable for other matters such as maximizing system safety. As a result, we conclude that monetary/financial controls are not appropriate for NASA to use as the principal management control system for the Shuttle. In addition, such financial-based controls do not work well in a bureaucratic system such as the Federal Government. Yearly budgets are politically impacted and must be observed, but this constrains the rate at which the work can be accomplished and can limit the scope of a project.

During the years after Apollo, NASA matured into a more traditional bureaucracy with the attendant problems of self-interest and status quo, and the character and motivation of its managers changed in subtle ways. The program was still important, but more and more attention was paid to the means. Turf battles ensued and communications suffered. Management instructions were not followed in a disciplined manner. In view of this reality, we conclude that you cannot solve this problem simply by changing NASA's Shuttle organization. A key ingredient of success at this time must be a return to the program orientation that was responsible for the earlier successes within the NASA management structure.

The task is no less important and not all that different from the earlier task, and in some ways is more crucial because until the Shuttle can be operated effectively, NASA cannot develop its Space Station. We advisedly say "effective," not "routine" operation. It will be a very long time, if ever, before the Shuttle operation is routine.

Findings and Recommendations:

a. The Panel finds the recent reorganization of Space Shuttle management by creating a Space Transportation Systems (STS) Director, reporting to the Associate Administrator for Space Flight, operating out of Headquarters, and supported by a Deputy Director for STS program matters and a Deputy Director for STS operations is a positive step. The Panel recommends that a priority objective of the new management team must be to determine the correctness of NASA's management instructions, to enforce such instructions, and to define clearly the responsibilities and authority of the NASA Centers--principally JSC, MSFC, and KSC--associated with the STS program. A focus on program success, rather than Center dominance, must be achieved. A willingness of all NASA Centers to pull together, to subordinate parochial interests, and to help each other is absolutely crucial if the Space Shuttle program is to succeed.

b. The Panel finds the problem of worker morale, especially at KSC, is of special concern. This is a classic problem of organizational and inspirational leadership that cannot be solved simply by changing institutional structures. The Panel recommends that NASA's top management, including the Administrator, Associate Administrator for Space Flight, the STS Director, and the Center Directors, take the lead in recapturing or rebuilding a spirit of mutual respect and trust at all levels.

c. The Panel notes that recapturing NASA's self-confidence in managing the Shuttle program is crucial to success and requires NASA's leadership to keep in perspective the activities of the many advisory groups, task forces, and panels that have been created in the aftermath of the Challenger accident. NASA has the ultimate responsibility and authority to manage the National Space Transportation System after giving appropriate consideration to the findings and recommendations of oversight groups. The individuals involved in these review panels, as well as Members of Congress, should recognize that excessive reliance by NASA management on external and internal review groups runs the real risk of destroying NASA's initiative and self-confidence, key elements of success in any human endeavor.

C. Research and Development vs. Operational Status

In 1984, the Panel noted in its annual report that ". . . continuing use of the term 'operational' simply compounds the unique management challenge of guiding the STS through this period of 'developmental evolution.'" The Panel stressed the importance of upgrading the safety and reliability of many of the Space Shuttle's critical systems (e.g., SSME, orbiter structure, avionics, and brakes) and of recognizing that this continuing process of change and improvement would require the discipline and caution of a developmental, as opposed to "operational," program. In the aftermath of the Challenger accident, and taking into account the extensive redesigns and investigations underway, the developmental character of the STS is now clearly accepted by NASA and its contractors. It is still the Panel's view that the Space Shuttle is not likely to achieve operational status in the airline sense.

At the same time, however, NASA must guard against an exaggerated response to this renewed focus on Space Shuttle development. There are activities associated with launch processing, in particular, where achievement of more routine and predictable operations would enhance safety and reliability. For example, a proliferation of data systems still exists with roughly two dozen containing Shuttle data. This complicates development of centralized management information around which a more coherent operation--communication, scheduling, goals, performance, motivation, human resources--can be developed by the Shuttle Processing Contractor.

Findings and Recommendations:

a. NASA needs to recognize that the Space Shuttle is a system with both developmental and operational characteristics. To emphasize either characteristic at the expense of the other is likely to miss key elements of the space shuttle management challenge.

b. Transfer of a part of the Space Transportation System (Orbiter) logistics responsibility from JSC to KSC must be supported with adequate budgets to build a sufficient inventory of spare parts and an upgrading of Line Replaceable Units (LRUs), linked to a capability for timely refurbishment, to eliminate cannibalization of parts from other orbiters and to support orderly launch processing operations.

c. Based on the Panel's reviews of the launch processing activities at KSC, particularly flight critical items, the Panel recommends that those elements of sustaining engineering that are directly related to launch processing should be the responsibility of the launch operations center (KSC). These include the evaluation of launch base test data, generation and maintenance of test and launch procedures, logistics engineering, quick-look launch phase flight data analyses, design changes to GSE and launch facilities, and troubleshooting of hardware. Elements of sustaining engineering that require detailed knowledge of the design and development history of airborne hardware should remain with the design centers and their contractors as NASA now contemplates.

d. NASA, in collaboration with the Shuttle Processing Contractor, should make a concerted push to achieve greater consolidation and upgrading of STS information systems, particularly those related to configuration management and launch procedures. For example, the Problem Reporting and Corrective Action System (PRACA) is not programmed to identify big problems and trends in a timely manner. An improvement in management information will contribute directly to more reliable and predictable launch processing.

D. Human Resources

As with most undertakings, the quality of NASA's human resources in managing the Space Shuttle program will be the single most important factor in determining its ultimate success or failure. Specifically, in view of the opportunity for and potential consequences of human error in Space Shuttle processing, management of employees at KSC by the Shuttle Processing Contractor (SPC) and NASA is of particular concern to the Panel. It would appear that these human resources were stretched excessively prior to the Challenger accident.

It has been reported to the Panel that in August 1985--with SPC employment at 6,100--the overtime rate at KSC was running 10 to 15 percent, with much higher rates in certain critical areas, such as the Orbiter Processing Facility, Pad, Launch Control Center, and Facility Operations and Management. To accommodate the acknowledged schedule pressures, the SPC and NASA were forced to rely on extreme efforts by many key workers, regardless of personal considerations. Workers have told the Panel of considerable internal pressures to work heavy overtime schedules. The Panel has found no evidence of a "safety valve" to balance pressures on the KSC workforce with pressures to maintain a launch schedule. Once the flight rate picks up, the Panel is concerned that reliance on the human endurance of SPC and NASA personnel at KSC may again become excessive.

NASA shares the problem of inadequate salary levels with many other Federal agencies. A program of the technical and management challenges of the Space Shuttle requires the best talent in the Nation if safe and efficient operations are to be achieved. Increasingly, the best often will not work for the salaries that the Federal Government can offer. This fact was clearly confirmed by the recent recommendations of the

Quadrennial Commission on Federal Pay that sought to reduce the 40-percent erosion in top management salaries that has occurred since 1969. Increases as high as 80 percent were proposed by the Quadrennial Commission. The President, however, proposed much smaller increases in the 2-4 percent range that will do little, if anything, to close the salary gap. At this writing it is not known what action, if any, Congress will take in response to the President's recommendations.

As a consequence of this apparent failure to solve the salary problem, NASA, along with many other Federal agencies, will continue to lose key senior managers and will find it difficult to recruit and retain senior personnel from among "the best." This steady erosion of management and engineering talent will make it increasingly difficult for NASA to operate the Space Shuttle in a safe and efficient manner.

Findings and Recommendations:

a. The Panel finds that recent layoffs by the Shuttle Processing Contractor of a large number of workers at KSC to accommodate the STS standdown have lost skilled employees who will be needed in 1987 as preparations intensify for a resumption of Space Shuttle launches. The Panel recommends that the Shuttle Processing Contractor should identify these losses and begin now locating, recruiting, training and retraining the necessary persons with the skills to support all aspects of these preparations, including modifications to the Orbiter and other STS systems that will be identified by ongoing NASA reviews.

b. The Panel finds that uncertainty among Shuttle Processing Contractor workers at KSC as to job security has undermined morale and other management efforts to improve communication and worker participation in launch processing decisions. It is recommended that top Shuttle Processing Contractor and NASA management should personally act to eliminate this uncertainty by dispelling rumors when they arise and leveling with workers as to their future job prospects.

c. The Shuttle Processing Contractor is expanding training opportunities for workers but often this training is not focused on meeting the needs of individual workers. Training opportunities need to be linked more explicitly to expanding worker skills to permit longer term career progression.

d. The Panel finds there still appears to be some difficulties in communication between top Shuttle Processing Contractor and NASA managers with floor supervisors and workers. The paperwork burden remains heavy. Instructions regarding specific processing operations are often inaccurate or incomplete, leading to inefficient scheduling and potentially to safety problems. It is recommended that top managers need to communicate more directly with workers involved in launch processing to provide a clear sense of mission and direction, as well as to benefit from employee initiatives and suggestions.

e. NASA and the Shuttle Processing Contractor need to create a system/procedure that will prevent a recurrence of the condition that developed in 1985 where human resources at KSC were excessively stretched due to schedule pressures.

f. NASA top management should document the growing problem of recruiting and retaining talented engineers and managers due to inadequate Federal salaries. The Panel stands ready to review these data and make appropriate recommendations to the Office of Management and Budget and the Congress.

E. Schedule vs. Budget

Panel members have believed for some time that the Space Shuttle program has been underfunded and that these shortfalls, in turn, contributed to a Space Transportation System that was incapable of meeting the launch schedule NASA projected prior to the Challenger accident. The present review of Failure Modes and Effects Analysis (FMEAs) and Critical Items List (CILs) will likely generate a number of modifications to the Space Transportation System that will have to be accomplished prior to resuming a flight schedule. It is essential that budgetary concerns not unduly limit the designs and modifications that are needed from a safety and reliability perspective. If funds are not available to accomplish this work due to budgetary ceilings or other fiscal limits, the only acceptable alternative is to stretch out the schedule.

Findings and Recommendations:

a. The Panel, in an independent review, concurs with the National Research Council Panel conclusions on Space Shuttle Flight Rates and Utilization, i.e., an upper limit of 8-10 flights per year with a three orbiter fleet and 11-13 with a four orbiter fleet. These projections are based on a number of optimistic assumptions that involve adequate funding resources and the absence of any new major development problems. If these assumptions are not borne out, the flight rates must be reduced.

b. NASA should no longer expect that "heroic" performance by its workers and its contractors can compensate for funding shortfalls. What is needed today is the courage to promise no more than can reasonably be expected given the dollars and people available.

III. SPACE SHUTTLE SYSTEMS

The Panel has continued its process of reviewing all elements of the Space Shuttle systems and operations. Since the Challenger accident, all these systems have been the subject of reviews by both internal NASA and external groups. The objective of this process is to enhance the safety of flight by discovering weaknesses in design or operation that may have lingered or not been discovered and to devise and implement appropriate corrective action. The Panel is participating in these efforts in a variety of ways. These include having individual members serve on several of the oversight committees of the NRC such as the Solid Rocket Booster Redesign panel and by factfinding meetings with the contractor organizations and NASA Centers responsible for elements of the Space Shuttle.

In the following sections the results of these activities are described and recommendations are provided.

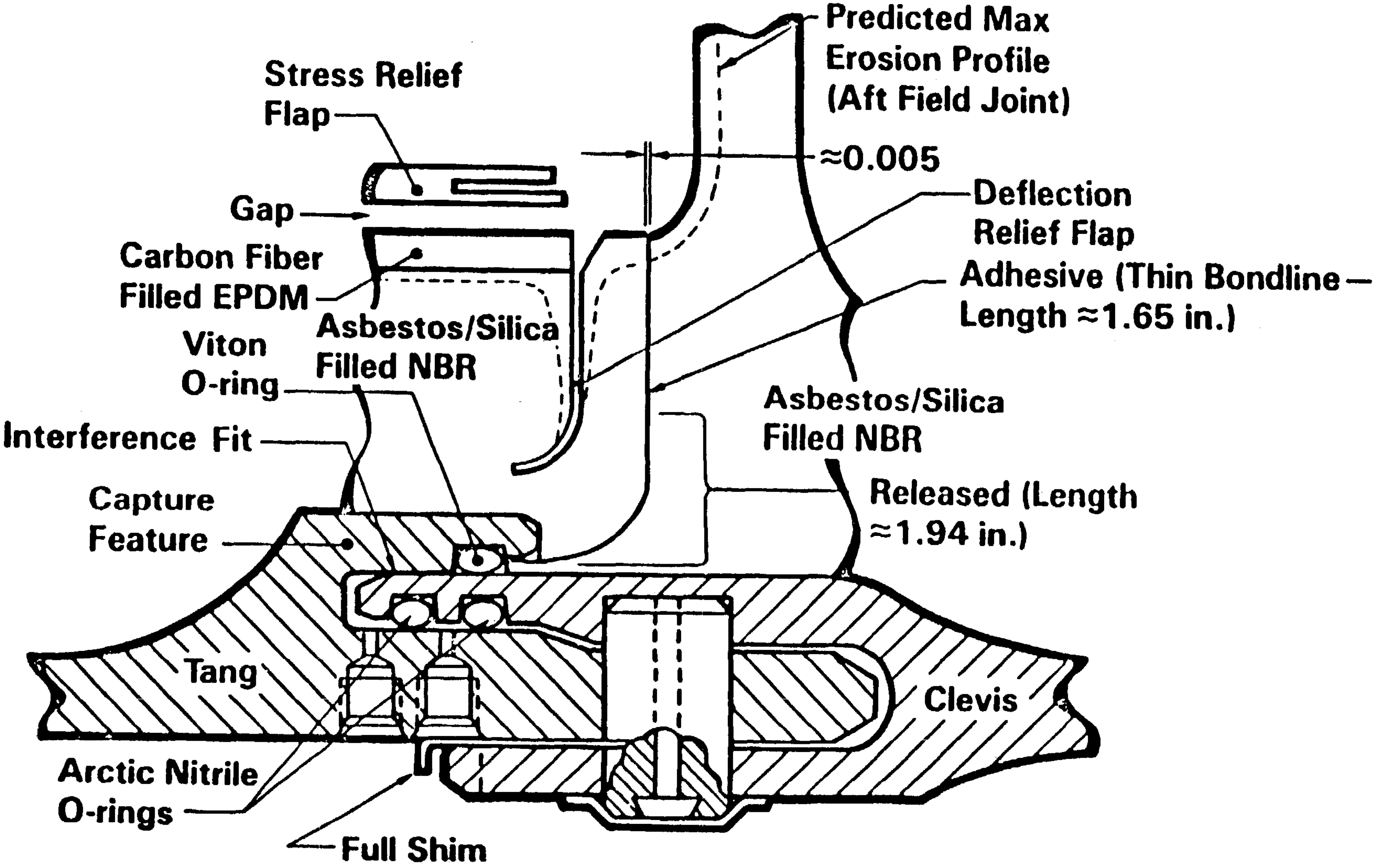
A. Solid Rocket Booster (SRB)

A representative of the Panel is participating in the meetings of the National Research Council (NRC) Panel on SRB Redesign. The following observations are made, based on the information provided at these meetings and additional information brought to the attention of the Aerospace Safety Advisory Panel.

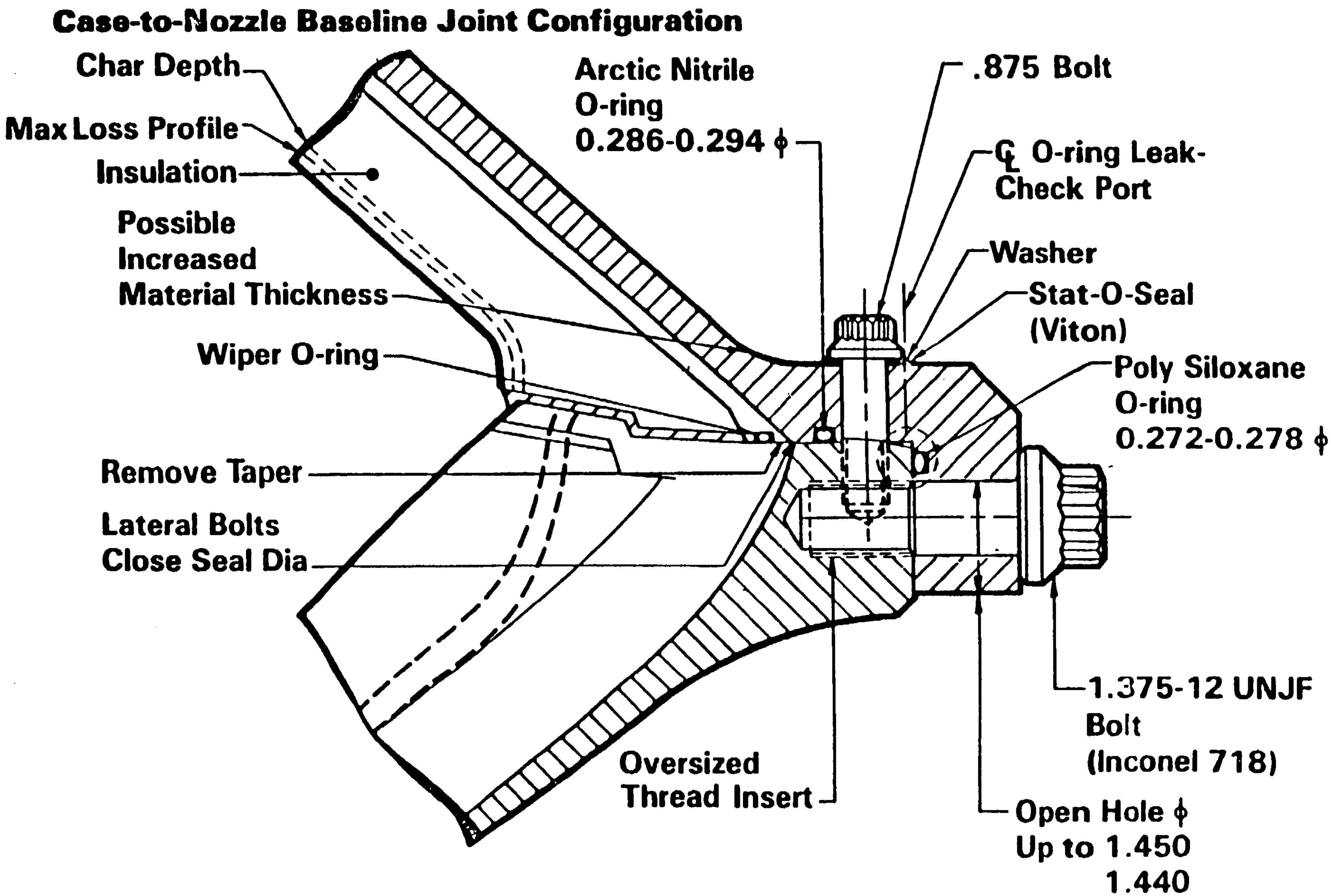
Field Joints: NASA has decided to proceed with a redesign effort for the field joints that make use of 72 existing steel case forgings. This approach entails more risk of not achieving design objectives than would a more sophisticated approach that would offer the possibility of a higher margin of safety. Such an alternate design would, however, require new forgings and would cause a delay of 3 to 5 years in the resumption of Shuttle flights. Such a prolonged delay could result in a loss of national support for the space program. Also, the delay could

CASE FIELD JOINT

Field Joint Baseline Design



SRM NOZZLE RECOVERY REDESIGN



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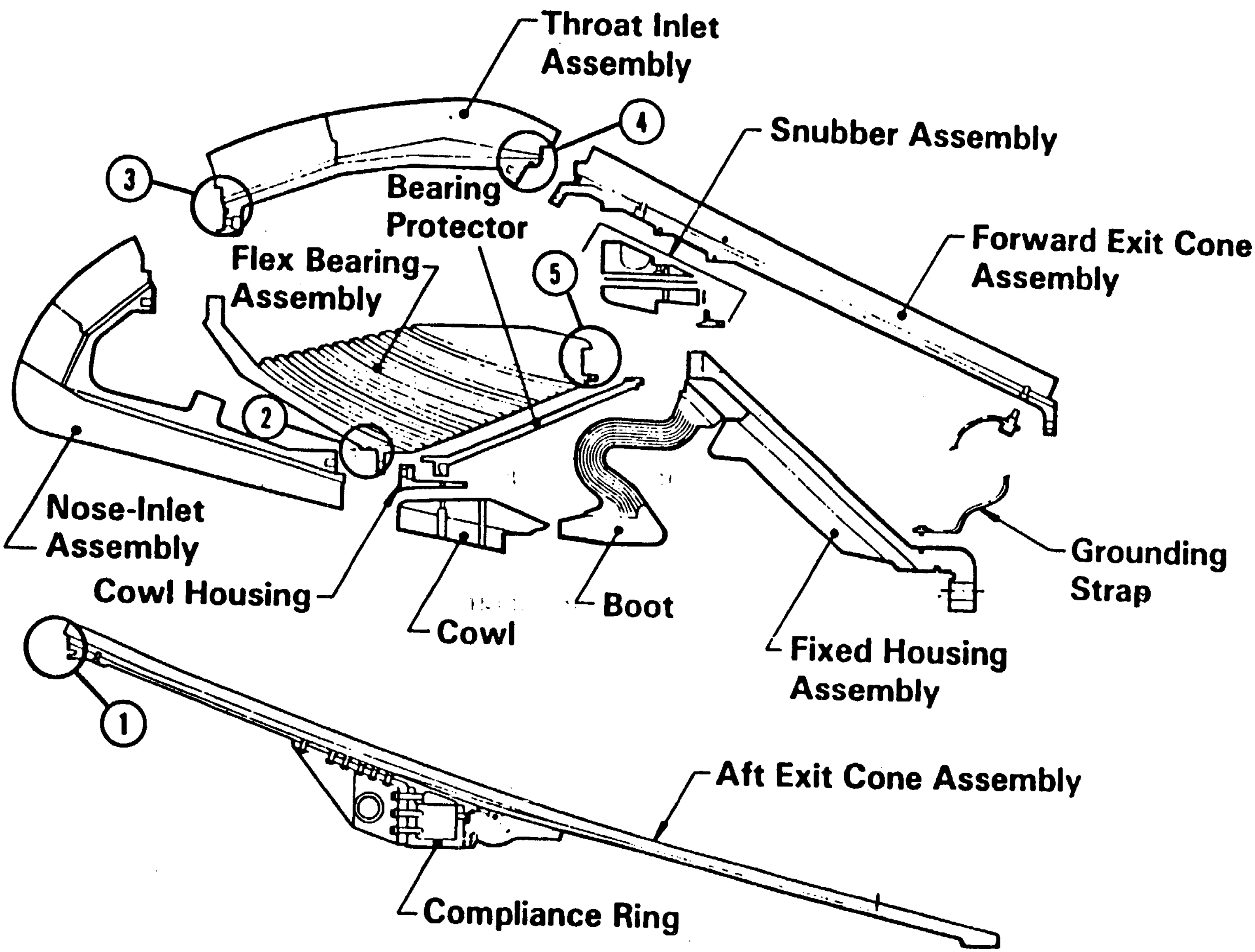

place the United States further behind foreign competition in manned space flight.

Case to Case Joint: The baseline field joint redesign chosen includes an interference-fit capture feature to minimize gap opening that results from joint rotation; three "O"-ring seals with two intervening test ports; improved unvented (bonded) insulation joint configuration to prevent hot gases from reaching the seals; larger seal gland widths to allow axial movement; and a joint heater to control temperature at the seals. Seal materials with improved resiliency and grease compatibility may eliminate the need for joint heaters.

In the baseline design, the unvented insulation at the segment juncture is bonded together. This sealed insulation may be subject to local vent holes which can make it difficult to test under the "worst-case-leak" condition. In addition, it would be difficult to disassemble the segments without damage to the insulation at the joints. The alternate "vented" labyrinth design for this interface between segment insulation has been eliminated due to problems surfaced during thermal calculations. Additional unvented designs with various bonded insulation joints are being pursued.

These configurations will be tested in sub-scale and full-scale hot-firing tests.

Tests have been successfully performed on removable composite ring overwraps with aluminum wedges and tensioning bolts on the existing steel cases adjacent to the field joints. This concept is being fully evaluated as to its effectiveness in reducing field joint rotation in the Engineering Test Motor (ETM) static test using four existing steel case segments.

In addition to the designs just described, NASA is pursuing other field joint redesigns (block II) that may enhance the safety of the SRB for the long term.

Nozzle-to-Case Joint: The redesign of this joint incorporates 100 radial bolts, each with a "Stat-O-Seal" under its head. The bolts are intended to reduce the relative motion between the housing and the aft dome. The new design also includes a third (wiper) seal and a second test port as well as circumferential flow baffles in the insulation.

The addition of the bolts adds multiple potential leak paths and residual stresses in the fixed housing that can reduce the reliability of the joint. The wiper seal bears on insulation rather than on metal. This could limit the pressure that can be employed during leak testing of the assembly.

There are a number of unresolved design questions at this time. Among them are the possibility of hot gas jet impingement or circumferential flow of such gas that could result from an insulation debond, and the ability to disassemble the nozzle from the case without damage to the insulation. Two alternate designs are being considered. One incorporates a metal thermaloc U-seal which maintains contact with the nozzle fixed housing and case aft dome during pressurization. The other concept is to insulate over the case-to-nozzle joint making it a factory joint. This design requires a new "field type" joint in the aft segment case and a redesign of the aft propellant grain. Other contractors have proposed a design wherein joint rotation acts to close the joint against the seal but, unfortunately, this approach probably requires a new forging with attendant schedule impact.

Nozzle System: The existing nozzle seals have performed adequately to date. The new design requirement for redundant and verifiable seals has, however, resulted in a complete redesign of all these seals. All such nozzle internal joints (there are five) are being revised to contain two seals with an intervening seal test port. All of these joints act to close the joint under operating load conditions except for the "number 5" joint which acts to close the inboard seal and open the outboard seal in operation.

In addition to internal nozzle joint seal design changes, the ply lay-up angles of the ablator material on the several rings of the nozzle structure are being changed to reduce, if not eliminate, the pocketing erosion that has been experienced in the past. The cure cycle for the graphite composite material employed may have to be changed in order to limit erosion and charring.

The changes being made are many and complex and to validate their suitability requires full-scale, full-duration, hot-firing tests. The number of such tests required to establish confidence in the reliability of these changes will be large and is yet to be established.

Thus, the categorical application of the requirement that all seals be redundant and verifiable to all SRB joints may affect cost, schedule, and inspection procedures and may also reduce inherent reliability.

Igniter System: The thickness of the igniter aft dome case will be increased to eliminate a negative margin of safety. This redesign is the only change that has been deemed mandatory for first reflight by NASA.

In the past, the igniter joint has exhibited primary seal erosion and blow-by during the full-scale hot-firings. Test should be made to identify the joint leak paths so corrective action can be taken.

Verification of Insulation Bondline Integrity: Major improvements in inspection techniques and procedures are required in order to be able to verify the integrity of the insulation bondline with confidence. The use of new non-destructive evaluation techniques (NDE) to detect a defective bond between insulation and case before propellant casting and prior to final stacking of the segments must be pursued aggressively.

General: The Panel is of the opinion that the redesigned joint is an improvement over the original and can result in a safe structure. Mating, demating, and re-use of the baseline configuration may prove to be a problem, however. Proof of the suitability of the redesign depends critically on achieving satisfactory results from a thorough, carefully planned, conducted, and instrumented test program. At present there is not sufficient definition of the development and certification test programs to permit comment as to their adequacy.

Achieving higher safety margins than that possible with the current baseline configuration would likely require something like the "Langley" design (or its equivalent) for the field joints and the "Hercules" design (or its equivalent) for the nozzle-to-case joint wherein the segment joints tend to close as the motor builds up internal pressure.

Horizontal vs. Vertical Firing Tests: In its report, the Presidential Commission on the Challenger Accident recommended that SRB motor firings to certify the redesign duplicate expected flight conditions as closely as possible and that conducting such firings with the SRB in a vertical attitude be given thorough consideration. The testing planned to verify the corrective action taken to remedy the problem encountered by the Titan 34D solid motor will be conducted in a vertical firing attitude using existing Titan test facilities.

NASA has given thorough consideration to the pros and cons of horizontal and vertical firing attitudes. The Panel concurs with NASA that peak loads that simulate extreme conditions on the joints can be applied to the SRB during horizontal attitude test firings. It is extremely difficult, if not impossible, to simulate such loads during vertical attitude test firings. Other parts of the SRB are not sensitive to firing attitude or are unchanged and have demonstrated their flightworthiness during the 24 successful Shuttle flights. Opting for vertical testing of the SRB would entail large added costs and an additional months of schedule time.

The Transient Pressure Test Article (TPTA) provides the means to test the insulation joint seals and the capture feature over a broad range of temperatures, dynamic conditions, and ignition times, repeatedly.

The addition of a second horizontal firing test stand to the program not only adds test capacity, it includes equipment that enables the simulation of flight-type external dynamic loads. This will enhance the validity of the test program results.

It is the opinion of many experts in solid rocket motor design that the number of tests in the preliminary test program is minimal for the scope of the redesign. The Panel notes that it recognizes that there is no way to guarantee that any number of tests can ensure that all possible operating and loading conditions and assembly differences can be encompassed by a finite test program.

Findings and Recommendations

1. SRB Joint Redesigns

The Panel finds that NASA is proceeding with a redesign of the SRB joints that use existing steel cases and forgings. The redesign is a marked improvement over the original joint design but may have a problem with mating, demating, and re-use. The approach selected entails more risk of not being able to achieve design objectives than would one using new forgings that might permit a more sophisticated design but which would delay the first Shuttle flight for 3 to 5 years. Proof of adequacy of the redesign depends strongly on satisfactory results from a thorough test program. The Panel agrees that the baseline case field joint and nozzle-to-case joint redesigns (and their parallel and alternate designs) along with a thorough and rigorous qualification test program can result in a safe structure.

The Panel recommends that a more complete definition of the certification test program be required in order to determine its adequacy. The Panel also recommends that a concerted effort be made to include additional full-scale hot-firing tests in the final test program plan so as to reduce the possibility of undiscovered weaknesses. Further that during the first year of resumed Shuttle flights, the SRBs be heavily instrumented to obtain both structural and performance data and that these data be considered as part of the certification program.

To attain a SRB design with a higher margin of safety for the long-term use with the Shuttle, it is suggested that NASA proceed with the development of the "Langley" design (or its equivalent) for the case field joint and the "Hercules" design (or its equivalent) for the nozzle-to-case joint in an aggressive effort.

2. SRB Test Firing Attitude

The Panel agrees that   to check the redesigned SRB joints, peak test loads that simulate extreme conditions can be applied to the SRB when it is in the horizontal attitude. It is extremely difficult to simulate such loading with the SRB in the vertical attitude.

A second horizontal-firing test stand is being added to the program. This added test stand will have the capability for the application of external dynamic loads. It will, of course, also permit an increased rate of testing.

The Panel recommends and agrees with the decision to conduct the hot-firing tests of the SRB in the horizontal attitude. The Panel notes that, despite the array of sub-scale, large diameter, and full-scale tests contemplated, there is no way to ensure that the tests encompass all possible loading conditions and assembly differences. The Panel strongly urges, therefore, that during the first year of resumed STS flights, the SRBs be heavily instrumented to obtain structural and performance data and that these data be considered to be part of the certification program.

B. Orbiter Structural Loads

The current loads/stress analysis cycle (designated ASKA 6.0) will provide analyses of the structure of Orbiters OV-103 and OV-104 and this will be finished by February 1988. There are not sufficient funds in the program budget to provide such an analysis for Orbiter OV-102. This would leave this vehicle with a different basis for the definition of structural capability than the others in the fleet. In addition, funds are not available to provide separate ascent and descent load information or for the updating of pertinent load indicators (strain gauge and redlines) or for the preparation of summary strength and loads/stress reports. The technical community agrees that these tasks should be accomplished.

Because the Space Shuttle will be used at least until the beginning of the next century, there will undoubtedly be a need from time to time to refurbish the vehicles, expand the operating flight envelope, and answer questions regarding the structural adequacy of the vehicles under new conditions. Without the data base provided by the analyses and reports noted above, evaluations like those mentioned cannot be made in a timely manner.

Findings and Recommendations - Orbiter Structural Loads

The Panel finds that no funds have been provided to check Orbiter 102 for the loads/stress analysis (ASKA 6.0) or to check all vehicles for separate ascent and descent loads, update load indicators and redlines, and for the preparations of summary loads/stress and strength reports.

The Panel recommends that NASA provide funding to accomplish these tasks as the information developed is required for decision-making and should be readily available. These tasks should be performed as soon as the loads/stress analyses (ASKA 6.0) are completed.

C. Experimental Verification of Orbiter Flight Loads

For the Space Transportation System flight in early 1986, Orbiter 102 was instrumented with approximately 250 pressure transducers on both upper and lower wing surfaces as well as with a number of strain gauges on the wing structure. This instrumentation was provided to obtain experimental data under flight conditions that would permit the verification of the structural load/stress analyses. It was determined that the pressure transducers read incorrectly (low) because of the roughness of the surface in the vicinity of the islands in the insulating tiles containing the instruments. The pressure transducers are, therefore, not suitable for use in determining wing loads in flight in their present installation. Wind tunnel testing and experimentation with installation techniques are required to determine whether techniques can be devised that will permit pressure data to be used for reliable determination of wing loads in flight.

Until it becomes possible to use pressure data with confidence, verification of analytical loads must rely on data from strain gauges. It is estimated that data derived from at least four flights will be required to correlate strain gauge derived information with the ASKA 6.0 loads/stress analyses. In order to do this with a sufficiently high confidence, Orbiter-102 should undergo a loads calibration test program while the fleet is grounded so that the strain gauges can be accurately calibrated, the instrumentation system "wrung out", and answers to questions regarding the number of gauges employed answered.

Findings and Recommendations - Experimental Verification of Orbiter Flight Loads

The Panel found that data from the pressure gauges installed on vehicle Orbiter-102 cannot be relied upon for predicting wing loads accurately, and therefore data from the installed strain gauges will have to be used to verify the ASKA 6.0 loads/stress analyses. The strain gauges installed on the vehicle have never been calibrated as installed.

The Panel recommends that Orbiter-102 undergo a loads test program to calibrate the strain gauges installed so that flight data from these strain gauges may be used with confidence to obtain wing loads in flight. This testing should be accomplished during the present hiatus in STS flights.

D. Space Shuttle Main Engine (SSME)

As reported in prior years, a multiphase program has been underway to improve the operating margins and/or the time between replacement for many of the critical engine components. This program had focused its resources primarily on what was designated as the Phase II part of the program. The work consisted of specific improvements in various turbo-machinery components and their incorporation into two Phase II engines to be "certified" for operation at 109 percent of rated thrust. One of these engines had completed its certification testing in 1985 and the second engine was in test before the STS 51-L accident.

Following its review of 51-L, the Presidential Commission recommended that NASA reassess its critical items and hazard analyses to ensure that all Criticality 1 items were properly identified and that actions were taken to minimize their risk. This review was initiated throughout NASA and its contractors in March 1986. The NASA strategy for safely returning the Shuttle to flight status included the following:

- All waivers on Criticality 1 and 1R items be revalidated and submitted for new approvals.

- All items for which an acceptable revalidation and waiver could not be justified using more stringent guidelines for adequacy of the retention rationale were to be redesigned and certified for flight.

In response to this NASA direction, a major program was undertaken on the SSME. This program encompassed a number of different areas of effort which, when completed, would provide a basis for defining a modified engine configuration having better margins of safety and an improved validation test program. In addition, a more sophisticated risk assessment methodology would provide criteria for operational constraints which would govern use of modified engines in the return-to-flight program. These constraints might encompass power limitations of only 100 percent of rated power on the first few flights as it might not be possible to provide engines of full margin configuration until a year or two after first flight.

This program was reviewed in considerable detail by propulsion specialist members of the Panel in May, June, October, and November of 1986. The primary elements of the program are listed below.

<u>Element 1</u>: Establishment of a modified engine configuration based on the Phase II certification program and conversion of

Phase I to Phase II engines prior to their next flight use. The new engine configuration must incorporate a number of additional changes to the current Phase II configuration that are necessary to resolve many issues currently identified.

Element 2: A thorough re-do of the Failure Modes and Effect Analysis (FMEAs) and Hazard Analyses and Criticality categorizations of identified failure modes for the Phase II engines. This re-do was carried out by Rocketdyne (the engine contractor) and, separately, by an independent contractor, the Martin-Marietta Company.

Element 3: A thorough review of the Interface Control Documents between the engine and the Orbiter and external tank.

Element 4: A review of all discrepancy reports on the "fleet leader" engines and turbo-machinery and the re-establishment of the engine redline rationale and the launch-commit criteria.

Element 5: A revalidation of the KSC Operating and Maintenance Instructions based on the Phase II engine design and operating constraints, the changes arising from the 51-L reviews, incorporation of all pertinent "unwritten" limits in prior use, and the elimination of prior exceptions and waivers by making the required changes.

Element 6: A review of the Flight Readiness Review and Countdown Decision Making processes with recommendations for improvement to be provided to NASA.

Summary and Assessment of the Program

The engine configuration to be incorporated in the next series of Shuttle flights will be based on the Phase II engines which were being certified for 109-percent of rated thrust. These Phase II engines will incorporate new turbopump component designs developed during the Phase II improvement program carried out in 1984 to 1986. During the course of the Phase II effort, several additional engine hardware issues surfaced that also required resolution. The resulting design modifications will also be incorporated. In addition to such hardware issues that arose from the ongoing engine test program, the 51-L accident led to considerable rethinking of such issues as redlines, instrumentation, and operational constraints. Also, the results of the re-do of FMEA/CIL and hazard analyses in this program identified a number of areas wherein the effect of a given failure mode might be reduced or eliminated by changes in hardware, redlines, software, or inspection procedures. Therefore, the new engine configuration must account for all of these issues in a way that will result in high confidence that Shuttle flights can be resumed safely.

The several issues may be put in the following categories:

1. Those that require changes regardless of the operating flight power level.
2. Those that require additional changes for operation at 104-percent maximum.
3. Those that require additional changes for operation at 109-percent maximum.

In all three categories, acceptable solutions may be either hardware design changes or other techniques such as a new redline, life limit, or inspection procedure. In addition to those changes that are considered mandatory prior to the next flight regardless of thrust level or flight profile, a number of items have been identified that effect additional improvements in margins of safety at given thrust levels or enhanced life cycle limits and, hence, cost effectiveness for LRUs. Some of these changes are under development (albeit very slowly) in the so-called Phase II+ and Precursor programs about which we reported in previous years.

In a session at Rocketdyne in November 1986, the changes required for the next flight were reviewed. As of that date, there were 25 items identified that require resolution and changes to either hardware or operating limits. These items are listed in Table I. Of those listed, the Panel reviewed those marked with an asterisk (*) in considerable depth as they concern the most significant issues to be resolved before the next flight irrespective of the thrust level selected. They can be grouped as follows:

1. High Pressure Turbopump Blade Cracks
2. Bearing Ball Temperatures in the Oxidizer Pumps
3. High Pressure Fuel Turbopump Coolant Liner Buckling

TABLE I

NEXT-FLIGHT CHANGES IN ADDITION TO PHASE II

1. 1st Stage High Pressure Fuel Turbopump (HPFTP) Turbine Lobe Cracks*
2. 2nd Stage HPFTP Turbine Face Cracks*
3. HPFTP Coolant Liner Maximum Pressure*
4. HPFTP 1st Stage Impeller Hub Cracks
5. 1st Stage High Pressure Oxygen Turbopump (HPOTP) Turbine Shank Cracks*
6. HPOTP Bearing Ball Temperature*
7. Low Pressure Oxygen Turbopump (LPOTP) Bearing Ball Temperature*
8. Main Combustion Chamber (MCC) Outlet Neck - Electro-Deposited Nickel (EDNi)*
9. Main Injector Liquid Oxygen Inlet Seam Weld Defects
10. Nozzle Steerhorn Weld Life
11. 4000 Hz Gimbal Bearing Accelerometer Vibration*
12. Fuel Preburner Diffuser Crack
13. Low Pressure Fuel Duct Buckling
14. MCC Liner Leak Control

15. Main Fuel Valve (MFV) Leakage with On-Pad Abort
16. Purge Check-Valve Failure
17. Anti-Flood Valve Leak Detection
18. Fuel Preburner Oxidizer Valve/Oxidizer preburner Oxidizer Valve (FPOV/OPOV) Window Opening
19. High Pressure Fuel Duct Cracking
20. HPFTP Turbine Temperature Sensor Reliability
21. Gaseous Oxygen Control Valve Leakage
22. Controller Delay Line and Diode Block Failures
23. Hydraulic Actuator Servo Coil Redesign
24. Flight Acceleration Safety Cutoff System (FASCOS) Erroneous Vote
25. Baseline Flight Software

High Pressure Turbopump Blade Cracks: NASA assembled a team of 44 specialists from industry, universities, USAF, Rocketdyne, and NASA to analyze the three types of blade cracks observed:

1. HPOTP First Stage Shank Cracks
2. HPFTP First Stage Lobe Cracks
3. HPFTP Second Stage Face Cracks

This team will provide detailed review and evaluation of the design changes currently proposed for solving these blade-life problems. Because these cracks have been observed over a long period of time, considerable work has already been done to provide improved margins and cycle life.

HPOTP 1st Stage Shank Cracks:

- Cracks are caused by high-cycle fatigue
- Cracks initiate at small spots of subsurface carbides and other grain flaws
- Currently planned solution is use of a two-piece damper
- Further improvement in the future may result from the

use of a single-crystal alloy (PW 1480 SC) with the two-piece damper

The two-piece damper is expected to provide a cycle life improvement of about 10-times. It is currently in test with the standard MAR-M-246 material and should be certified for next flight use by October 1987.

HPFTP 1st Stage Firtree Lobe Cracks:

- These cracks are caused and propagated by low-cycle fatigue in the presence of hydrogen where a critical grain flaw porosity exists.
- The cracks can be monitored from one run to the next.
- Considerable structural margin exists even after a crack has propagated significantly. Therefore, they can be inspected for and the turbine replaced before the crack reaches anywhere near a critical depth.
- Several options are under test which will resolve this issue:
  - Custom-fitting to reduce strain levels
  - Shot-peening to reduce porosity
  - Hot-fire wheels to screen out susceptible blades
  - Use of PW 1480 SC single crystal blade material.

Whatever combination is finally selected, the safety margin can be expected to be high throughout any given engine duty cycle after inspection. The resolution of the problem is thus more related to life cycle and replacement costs than to safety of operation.

HPFTP 2nd Stage Firtree Face Cracks:

- Similar in cause to the first stage lobe cracks, these second stage turbine blade face cracks in the firtree area are the result of overstrain and initiate at surface carbide spots. They propagate by thermal stress loads and are accelerated by the presence of hydrogen.

- There is a reasonably high probability of initiating these in a blade root (5 percent) and they occur on first mainstage load cycle if they are going to initiate. They tend to be self-arresting but, if run for a sufficient number of duty cycles, can approach critical flaw size.

- Some of the corrective actions for the first stage blades are applicable to these blades and are being tested. These include shot peening, increased radius at the root, addition of a thermal barrier material, and plating. The single crystal material is also a good candidate.

- As with the first stage blades, the cracks arrest on each mainstage cycle. Therefore, conservative replacement criteria can be established that would provide high safety margins on any flight. The corrective design changes have leverage on replacement cycle costs.

Oxidizer Pump Bearing Ball Temperatures: The Phase II pump design with improved whirl margin, damping seals and bearing load sharing has provided greatly increased bearing wear life in tests to date. However, as a result of current studies of critical items and SSME acceptability for flight, a concern has been raised regarding the possibility of ignition of the bearing balls in the high-pressure oxygen environment. Close examination of the balls indicates dark surfaces along the normal run-line circle around the balls. These discolorations indicate potential local microsurface temperatures of the line of up to 1200-1300 degrees F.

Some cases result in dark bearing lines after only one full-power run while others gradually darken over four to six duty cycles. Several changes are planned to reduce the bearing loads and skidding as well as to improve the ball cooling. However, the only real safety issue is a potential for autoignition of the ball surface and a sustained metal combustion zone leading to pump failure and fire. This remote potential is being examined analytically and, to some degree, experimentally. It is the Panel's belief that the results of the experiments will be ambiguous, at best, and that statistical evaluation of the SSME's entire test and flight history can be used to make an adequate risk assessment. Combined with a large amount of other experience in ignition of metals in high-pressure oxidizers and, given the very high thermal diffusivity of a sphere to a line heat source, this SSME history provides a convincing indication of an acceptable configuration having a very low probability of sustained autoignition at least up to the 104-percent power level.

High Pressure Coolant Liner Buckling: This problem has been around for several years and has complex factors involved. First is the range of collapse pressures resulting from configuration variables such as wall thicknesses, weld mismatch, material properties, and actual operating temperature environment. Second is the variation in startup manifold transient pressures resulting from leakage of seals and use of dual pilots. At the bottom line for Phase II pumps, the coolant liner pressures at startup overshoot badly and this gets progressively worse as the seals wear. Many tests show overshoots at values equal to the buckling values for "worst case" configurations. This situation is unacceptable as the term "failure" should be defined, for purposes of risk assessment, as overshoot above those values that would result in a safety factor of 1.4 for the minimum dimension configuration.

The corrective action plan comprises several items:

1. Improved weld quality specifications and inspection techniques.

2. Reduction of nominal coolant liner pressure through re-orificing.

3. Redesign of the static seals' travel capacity to prevent plastic deformation causing current progressive leakage. The seal materials will also be changed to provide higher operating temperature without permanent deformation and protection from hydrogen embrittlement.

These changes and the certification of peak pressure margins of at least 1 1/2 times for the worst-case geometries should provide high confidence in flight safety.

Main Combustion Chamber Coolant Outlet Neck: The structural failure of the coolant outlet neck on engine 2308 in 1985 has led to a detailed re-examination of the specific design and fabrication control for this part. It also raised questions concerning the weld characteristics and inspectability and strength margin criteria for other similar zones in the engine. While tighter control of inspections and X-ray assessments can hope to catch non-fully configured areas in existing and future parts, it appears prudent to modify the outlet design for higher strength and fatigue margins.

The current design in work is based on using an electro-deposited nickel reinforcement layer encompassing all of the neck welds. The operating stress should be reduced by 50 percent. The dynamic stress in the fuel turbine duct region will, however, increase about 40 percent and this must be evaluated carefully, along with all other effects on the rest of the adjacent manifold regions. For the future beyond the next series of flights, a new one-piece machined outlet can provide added simplicity and better configuration control.

4000 Hz Pressure Resonance in Liquid Oxygen (LOX) Inlet Region:

This phenomenon has occurred only rarely in the history of the SSME. Observations on two engines in 1985 gave a more definitive indication of a potential failure mode and has resulted in an in-depth investigation of the causes and potential corrective design changes. The amplitudes of the vibration are very dependent on power level and, of course, the phenomenon became more apparent as a result of operation at 109 to 111-percent thrust. The frequency is independent of power level indicating a structural-hydraulic resonance coupling.

A careful survey of earlier engine data logs indicates that 9 out of 42 engines have exhibited the resonance at levels above 5 g's on the thrust-cone accelerometer.

The issue is not the vibration per se as it is confined to a small region of the engine's head end and, at 4000 Hz, does not propagate to nor stimulate any other significant structure. The concern is the result of a shift in frequency observed in several engines that has been traced to cracking of the splitter vanes in the inlet tee. This, of itself, is also not a safety issue unless the vanes can break off and a piece thereof get into the oxygen region of the main injector and cause distortion or plugging of flow.

The issue can be resolved in several ways. Engines which exhibit this phenomenon do so from the beginning of their life. Thus, they can be screened out and re-built in the inlet region. Although this may be costly, it will be effective. An alternative is to demonstrate that the way in which the vanes are attached to the manifold prohibits any detachment even after the (stress relieving) cracks occur. Thus, no safety issues would exist. Eventually, the vanes could be redesigned to incorporate a less resonance-inducing leading edge shape or, alternatively, the flow region could be otherwise detuned from the 4000 Hz band.

Precursor Program

The work on the Precursor program which, includes a number of significant improvements in engine hardware designed to provide significant improvements in margin above those of the Phase II and II+ programs, were found to be at a literal standstill. The two-duct power head and the wide-throat combustion chamber have been fabricated and an engine partially assembled. Testing of this new configuration is being held in abeyance because of funding limitations and the lack of test stand time availability.

Findings

An extensive re-examination of the design and test history of the SSME was conducted during 1986. The objective of the effort was to identify any safety issues that might have been overlooked in the past and to establish and validate an engine configuration for use in the next series of flights.

The engines planned for the next series of flights will basically be the Phase II engine configuration that was being certified for flight for operation at 109-percent rated thrust during 1985 and 1986. These engines incorporate many of the improved cycle-life turbopump components developed as part of the Phase II improvement program described in the Panel's 1984 and 1985 reports. During the testing in this program several additional issues arose and design modifications to resolve them will be incorporated in the "first flight" engines.

The results of the FMEA re-visit identified a number of areas where changes in hardware, software, redlines, or inspection criteria could reduce the probability or effect of certain failure modes. Such changes will be incorporated in the engines. As of November 1986, 25 such items had been identified. Of these, the more significant ones requiring resolution before flight are High-Pressure Turbopump blade cracks, High Pressure Fuel Turbopump Coolant Liner Buckling, Main Combustion Chamber Coolant Outlet Neck Cracks, and 4000 Hz Vibration phenomenon in the thrust-cone region.

Another issue relating to contact line temperature on the bearing balls in the High Presure Oxygen Turbopump is also receiving much attention.

The engine contractor is making considerable progress in developing a more useful risk assessment and margin validation methodology. This should result in an improved understanding of the safe operating regime of the engine and better control of the critical aspects of the engine configuration.

The Panel was disappointed to find that work on the Precursor (advanced margin) engine hardware is still proceeding very slowly because of limited funds and lack of test stand availability.

Recommendations

The changes described above primarily address hardware reliability, firmer redlines and configuration control and improved hardware cycle life. In only a few instances will there be any significant improvement in margin to failure. The Panel recommends, therefore, that the Phase II engine be constrained to operate at 104-percent rated thrust or less. Furthermore, it must be noted that a significant increase in operating margin of safety can be achieved by operating at 100-percent rated thrust. It would be prudent, therefore, to operate at 100-percent thrust until the Phase II engines have accumulated significant flight operating time so as to provide a meaningful data base.

The Panel recommends that the Two-Duct Hot Gas Manifold and the Large Throat Combustion Chamber be tested and certified as soon as possible. It is the opinion of the Panel that these changes will produce lower stress environments and improved margins at 104-percent and 109-percent thrust levels.

It is also recommended that NASA and its SSME contractor continue the development of improved methods for actually demonstrating critical operating failure mode margins and the more rigorous Risk Assessment analytical procedures. It is suggested that, as part of such procedure, the term "failure" be defined as a violation of any of the governing design criteria for a component rather than as an event such as structural failure or burn-through. By way of illustration, crack growth to the point where a calculated stress margin falls below 1.4X should be called a "failure" rather than when it reaches the "rupture critical flaw size."

E. Shuttle Computer Systems

Among the more complex parts of the Shuttle is its on-board computer system and there is concern that it could be a source of failure in some future Shuttle flight. As part of its overall activity in reviewing safety matters regarding the Shuttle, the ASAP has begun a review of this computer system. Two issues are of principal concern:

1. The configuration of replacement and existing computers to be used in future Shuttle flights.

2. General software development, change, and test procedures used with Shuttle software.

As our study was begun late in the year and it was not possible to contact all relevant parties during 1986, only preliminary observations are available at this point.

Computer Configuration

The current Shuttle computer system uses a set of five computers to operate the vehicle and the experiments on it. Four of the computers are connected in a tri-redundant configuration for high reliability. During critical phases of ascent and re-entry, all four of these computers perform the same operations. If deviations in outputs occur, the offending computer is disabled. In addition, the fifth computer acts as a backup system (making the whole system quad-redundant); it must be invoked manually by the crew and, once so invoked, control cannot be reverted to the primary system.

The hardware in the quad-redundant system has been adequate protection in all flights thus far. The worst actual flight case saw two of the primary computers fail. Once, in a pre-flight test, three of the primary computers failed. The source of each of these failures has been determined and eliminated from all other processors. There has never been a case in which it has been necessary to invoke the backup system.

The computer in use at present in the Shuttle has been obsolete for some time and its limited memory size severely hampers both experiments that people would like to perform during Shuttle flights and the size of flight changes. An upgraded version of the general purpose computer (GPC) has been designed and built. The new GPC is 2.5 times faster than the original, has substantially more (though still somewaht limited) memory, is smaller and uses less power. The original GPC has a mean time between failure (MTBF) of 5,000 hours. The new GPC is projected to be initially delivered with a 6,000 hour MTBF and it is expected that the flight systems will be at 10,000 hours MTBF.

The Problem: The onboard flight computer system will be upgraded using the new computers in late 1988 or early 1989 (corresponding, roughly, to STS-30 or 31). There are two proposals for configuring the new onboard computer system:

1. Use four of the new GPCs for the quad-redundant primary system and one of the original GPCs for the backup, i.e., 4/1.

2. Use the new GPCs for all five computers in the system, i.e., 5/0.

The two alternatives will be designated as the 4/1 and 5/0 designs, respectively. The use of either option involves operating system changes to both the Primary Avionics Software System (PASS) and the Backup Flight System (BFS).

The rationale for the first proposal is that there is considerable experience with the original computer and that by having two different kinds of processors (called "dissimilar redundancy"), the probability of a generic failure that causes loss of a mission is reduced. The arguments for the second are that the first choice forces a spreading of software verification resources among two systems, may complicate the operational procedures used, and may thus actually reduce the reliability of the primary system.

Discussion

The opinions of NASA and Rockwell personnel on the implications of the 4/1 and 5/0 choices vary considerably. The actual implications will depend upon budgetary considerations and testing and design decisions not yet made. There are several important considerations:

1. The ability to quantify the risk protection provided by using dissimilar hardware.

2. The extent and impact of necessary software changes.

3. The impact on software testing procedures.

4. The impact on operational procedures.

5. The ultimate configuration.

6. The relative reliability of the original and new GPCs.

Dissimilar Redundancy: Dissimilar redundancy is accepted by many in the aircraft industry as being an important method of guarding against generic faults. It is used in three operational, three experimental, and seven developmental aircraft types. It is, however, generally agreed that there have not been enough flight hours to verify or disprove its importance. Under the conditions that both the 4/1 and 5/0 designs are operationally equivalent and equally tested and verified, the 4/1 design certainly does provide greater protection (again, it is not possible to determine how much) than the 5/0. It is thus necessary to examine the differences in system operation and the levels of testing possible within cost constraints to try to deduce any difference in risk arising from operational and testing differences.

Extent of Required Software Changes: First, compare the software changes involved in a typical "Operational Increment" (OI): It is important to note that both PASS and BFS must be changed regardless of which option is chosen as it is desired to be able to reconfigure one of the new GPCs to function as a backup system in case of failure of the backup computer system and it is desired to maintain only two sets of code (PASS and BFS) and not three (as would occur if two versions of the BFS were kept). Thus, the basic software changes are the same for either the 4/1 or 5/0 choice. It is also important to note that, once changed, the BFS code will be able to run, unchanged, in either a new or old GPC. As shall be seen, the size changes required to accommodate the new computers are small in comparison to the changes that are normally made during a year's time.

Roughly speaking, the code in the PASS and BFS can be divided into two parts, the kernel code and the application code. The code associated with different applications is typically independent, while most applications make use of the code in the kernel. The system is thus more sensitive to errors in the kernel code.

The kernel code for the PASS requires only a 210-word (out of 104,000 words in the system) change. This code involves two kinds of functions: local delays and synchronization among the processors. On the other hand, operational instructions have involved changes to about 15,000 words of PASS code. Similarly, only 114 halfwords of code in the BFS must be changed, again to manage timing in a machine-independent manner. In this case, the changes only involve initialization code and no run-time code. Up to 7,000 words of BFS code have been changed in an operational instruction. Thus, the size of the operating system code changes to accommodate the computer hardware upgrade is only about 1.5 percent of the size code that has been changed (and tested) in an operational upgrade which occurs, normally, although this 1.5 percent is perhaps more difficult to code than much of the OI code and its affects a greater percentage of the system.

Software Testing: There are two areas in which the 4/1 configuration affects the system negatively and which must, thus, be weighed against the positive benefits of dissimilar redundancy in hardware. The first of these arises from the fact that in a 4/1 configuration, all changes to the BFS software must be tested in both the old and the new GPCs., This testing will occur during the flight software tests performed using the flight simulator in the Shuttle Avionics Integration Laboratory (SAIL). This testing phase is quite extensive and performed prior to every flight to test the software configuration for that specific flight. Thus, duplicate testing would have to be performed for all flights, not just once when the new configuration is introduced.

There are only two options with respect to testing a 4/1 configuration. Increase the level of testing for each flight or reduce the number of tests of the 4/1 configuration (in comparison to needs for testing a 5/0 configuration). An unknown at this point is the difference in testing requirements between the two configurations. JSC personnel do not feel comfortable in estimating this difference without performing a detailed testing plan. However, 10 - 15 percent would probably not be too poor an estimate. As flight simulation tests are very expensive, this difference represents a substantial amount of money. Equally important, it represents a longer turnaround between flights and would reduce the frequency of Shuttle flights (there is only one Shuttle Avionics Integration Laboratory (SAIL) facility and it is already in operation two shifts per day).

From the history of software and hardware failures detected during flight simulation tests, it would appear that a 10-percent reduction in testing could possibly result in missing the detection of a software failure sometime within 10-20 flights. Thus, NASA should pay the extra testing costs and not reduce testing if a 4/1 configuration is chosen. It would also be important that JSC personnel be protected from undue pressure to reduce or limit testing costs in the face of increased testing needs.

Operational Procedures: The second area of concern is the fact that the reconfiguration management in event of a BFS GPS failure is potentially more complex with a 4/1 configuration than for a 5/0 configuration. Again, the exact nature of the differences cannot be determined until additional design decisions are made in the future. Also, the opinions of NASA personnel about the nature of the changes is varied. It is possible that in the event of a BFS computer failure in a 4/1 configuration, one would be faced with either having the astronauts manually physically rearrange the computers in the system or fly the remainder of the mission without a backup computer. Either choice introduces additional risk.

It is also important to recognize that there is some increase in the level of complexity that the human astronauts must manage and that there has already been a near-disaster due to pilot error. It was mentioned above that during the STS-9 flight, two of the computers failed. One was re-started and placed back in service (but in a reconfigured system). When the Shuttle touched down, that computer failed again. When the pilot switched it out, he forgot about the reconfiguration and switched out a good string of one of the good computers. Had such an error occurred before touchdown, a major disaster would have been likely. This error occurred because of the complexity of the system operation. Increasing the complexity of in-flight operation does, therefore, increase the risk involved.

Ultimate Configuration: There are also considerations that arise with respect to whether or not a 5/0 configuration is adopted ultimately. If a 5/0 configuration is not adopted, the Shuttle will be flying for a long time with very obsolete hardware. This obsolete hardware is also aging and will eventually become unusable, at which point a 5/0 configuration seems inevitable (unless yet another generation of new hardware is added).

If a transition to a 5/0 configuration is ultimately made, there will be an additional round of modification, testing, and training involved and, hence, additional expense incurred.

Reliability of New and Old GPCs: It seems clear that, on paper, the new GPC is more reliable than the original but it does not have the flight testing of the original. All of the problems found in the original GPC have been corrected in both the current versions of the original GPC and the new GPC. If an original GPC is used, it will be a processor that has been in use for several years, not a new production copy of the original design. This has potential for both positive and negative effects. Through its use any initial manufacturing defects have been eliminated. However, as it has been in use for several years, one must question the effects of aging.

Findings

The principal factors between a 4/1 and a 5/0 configuration are:

1. The additional safety provided by dissimilar hardware (remember that there already is dissimilar software);

2. Human factor contributions to risk - part of the safety provided by the computer redundancy is achieved through astronaut training and in flight operations and maintenance procedures performed by the astronauts. There would be some differences in the training and in these procedures between a 4/1 and a 5/0, and correspondingly a difference in the risk introduced by human factors. This risk difference may well be greater than that in item 1 above;

3. The impact of the flight schedule on the software testing that will be possible, or stated conversely, the impact of the software testing (which is larger for the 5/0 configuration) on the flight schedule, and;

4. The additional costs required for a 5/0 decision.

It is not possible to quantify the first of these. Though there have been a few claims regarding the second, there has not yet been a careful study of this factor. The third has also not been studied in detail, but 10-15% is a reasonable estimate. The fourth has also not been studied.

The second item has strong safety implications beyond the decision between a 4/1 or a 5/0 configuration. It is clear that some current operational and/or in flight maintenance procedures performed for the purpose of improving computer reliability may require the astronauts to do things in a different manner than that in which they were trained. This results in a significant additional risk, and has already resulted in a near disaster.

Recommendations

1. In order to provide greater confidence in the new GPC, it is recommended that the new GPC be flown on several flights as the backup computer. Since several flights are scheduled with the old GPC's before the changeover, this should be possible.

2. NASA should conduct a study of the human factors aspect of risk associated with in flight operations and maintenance procedures, particularly changes in procedures resulting from response to some failure. Included in this should be a preliminary design of the 4/1 procedures and training and an assessment of their impact.

Software Development Procedures

The software development procedures used are critical to the reliability and cost of the on-board computer system. As it is not yet possible technically to automatically guarantee the correctness of real-time embedded programs of the size and complexity of those running the Shuttle, extensive testing is essential. Techniques and languages have been developed, however, that ease the problem somewhat, reducing the cost and amount of manual testing required. The review of these activities for the Shuttle has just begun and has not reached a stage where useful comment can be made. This review will be a major activity of the Panel during the coming year. Among the concerns are the following:

1. The methods of determining and validating the 8,000 I-LOADS that must be defined for each Shuttle flight. These constants define the mission to be flown and are as important as the software and computers to the success of a mission.

2. Implications of proposed flight schedules on flight software testing on the SAIL facility. In particular, there are concerns that the increased flight schedules will force reduced per flight testing.

3. The methods by which software tests are generated. The quality of the resulting software is highly dependent upon these procedures.

4. The methods by which compiler upgrades are tested. The compilers translate the program written for the Shuttle into the code executed by the computers.

5. More detail on the redundancy management among the computers, in particular, timing and comparison methods.

6. General hardware and software support system upgrade policies. It is not clear that NASA has general procedures. In the aftermath of the GPC upgrade, it would be a good idea to examine this issue and encourage NASA to develop suitable procedures.

In addition to these technical concerns, there are several concerns about personnel matters:

1. The salary structure for technical persons within NASA is of concern. It appears that in order to progress in

terms of salary, people must move into management ranks, making it difficult to keep experienced, highly qualified people in the technical ranks. Moreover, it appears that the salaries of NASA technical people are substantially below corresponding industry salaries.

2. Much of the knowledge of Shuttle computer development and operation resides in the corporate memories of the employees who have worked on the system. The age distribution of the employees working on the computer system is of concern. There have been initial inputs that the current staff is heavily skewed toward the older age groups and that there is a dearth of employees in the mid-age group.

3. Some concern has been expressed about pressure from above to state that adequate tests can be performed within budget, whether or not they can be; it is also implied that if individuals do not conform, someone else will be found who will.

F. External Tank

At this time the External Tank is the Shuttle element that has been least affected by the activities undertaken in the aftermath of the Challenger accident. This is not to imply, however, that there have not been activities to ensure continued confidence in the External Tank. As with other elements of the Shuttle, a review and assessment of all the requirements for the External Tank is being made. This review includes design, test, integration, and FMEA/CIL hazards analysis. Thus far, no significant issues have surfaced although the External Tank Tumble System was the first subsystem to go before the Level II Program Review and Control Board for a waiver subsequent to the re-visit of the FMEA/CIL process.

G. Orbiter Landing Gear System

The Orbiter landing gear has been a subject of concern to the Panel and has been discussed in its reports since 1981. The Presidential Commission commented on this system and on other aspects of the landing phase in the section of its report entitled "Landing: Another Critical Phase." In this section the concerns discussed by the Panel were highlighted. NASA has responded to Recommendation VI of the Commission's report; the response meets the objectives of the Panel's earlier recommendations. The actions undertaken comprise test, operational, and redesign activities. The significant elements thereof are summarized below:

1. Operational:

   a. Shuttle landings will be planned for Edwards Air Force Base until satisfactory structural safety margins have been demonstrated.

   b. Gear load reduction by means of appropriate positioning of Orbiter elevons during the period from nose-wheel touchdown through high-speed roll-out will be implemented.

   c. Planning will include the determination of optimum Transatlantic Abort sites including any needed upgrade thereof.

   d. A runway overrun barrier is to be used at Dakar, Senegal.

   e. Improved wind measuring equipment will be installed at both launch and landing sites.

2. Test:

a. Prior to first reflight, a heavyweight brake dynamometer facility will be assembled and used to verify braking capability.

b. High-energy "wear-ins" or "green-runs" will be conducted on brake assemblies.

c. Tests will be conducted to assess the characteristics and adequacy of the anti-skid system.

d. Tests will be conducted to determine braking capacity taking into account the maximum brake pressure capability and response time of the crew under the known post-flight physiological condition and capability of crew members.

e. Tests will be conducted to determine the feasibility and consequences of a "roll-on-rim" capability.

f. Tests to determine the effects of fifteen (15) knot crosswinds (completed).

3. Design:

A number of changes to the brake system will be designed and implemented. Among these are the following:

a. Thickened brake stators.

b. Modifications to balance brake system hydraulic pressures to eliminate the apparent 60/40 energy distribution between inboard and outboard brakes.

c. A six-orifice brake hydraulic system to alleviate hydraulic chatter that has been observed.

d. Stiffened axles to alleviate relative motion between stator and rotors to increase effective rubbing area contact.

e. The development and installation of a tire pressure monitoring system.

f. Develop tire improvements. Development tests are to be conducted at Langley Research Center and at Wright-Patterson Air Force Base.

Additional areas are being investigated as part of the effort to improve the Orbiter braking system. These areas have not, however, been designated as mandatory for first reflight. They include items such as use of an Orbiter drag chute, up grading of nosewheel steering system, and wheel spin-up devices. Also, landing and roll-out simulations are to be conducted at the Ames Research Center flight simulators. The Panel will continue to monitor progress in these areas.

IV. Space Shuttle Operations

A. Launch Processing

The Panel has continued to review and assess the multitude of activities that comprise the preparation of the Shuttle for flight and the launch of a mission. Emphasis was placed this year on determining the effects of actions being taken to recover from the Challenger accident and the identification of areas that, in the Panel's opinion, might require added management attention and/or might affect the ability to achieve a safe first reflight on schedule.

In the course of its reviews, the Panel drew information from a variety of sources but concentrated its efforts at the Kennedy Space Center (KSC). As part of the review process, Panel members held discussions with more than 40 "hands-on" technicians, quality control inspectors, and schedulers. Detailed discussions were conducted with senior and mid-level managers from KSC and from the Shuttle Processing Contractor (SPC).

Among the subjects examined were the status of facilities and flight hardware; the organization of both the KSC and the SPC and changes that occurred, the effectiveness of internal and external communications of these organizations; the status of personnel training, morale, and motivation especially as affected by the stand-down from flights and by personnel reductions during this period; the logistics and safety, reliability, maintainability, and quality assurance activities; the results of the recent activities of the SPC Risk Review Board and Safety Advisory Board (these topics are covered in another section of this report); and finally, the response to Presidential Commission recommendations.

Status of Facilities: There is much activity in process to bring the facilities at KSC to a state of readiness to support the program when flights are resumed. Among the major facilities, the following are of note:

1. Pad "B" is almost complete with all modifications considered necessary prior to the first re-flight. The latter include items such as rain protection system, ET vent, and debris plate changes.

2. Pad "A" modification projects are running behind those of pad "B". Because of the availability of pad "B" and a limitation of resources, there is a slower construction rate in effect for pad "A". Current plans indicate that construction work on this pad will be completed about December 1987.

3. Mobile Launch Platform Number 3 is in the activation process and will be placed in a "minimum maintenance mode" from February 1987 through September 1988.

4. The Orbiter Modification and Refurbishment Facility now has an operational readiness date of April 1989.

5. The Orbiter Thermal Protection System (TPS tiles) Facility has an operational readiness date of April 1987.

6. The contract for the Orbiter Processing Facility Annex is scheduled to be let in early 1987.

7. The Payload Hazardous-Servicing Facility is in work.

Operations: NASA has selected McDonnell Douglas Astronautics Co. to perform payload ground operations at KSC, Vandenberg AFB, and at Shuttle landing sites. It is anticipated that work under the contract can begin in early 1987.

The issue of weather forecasting has been under review for some time as it affects operations at KSC. The need for more accurate and timely weather data, particularly winds aloft and rain, has been apparent and became more apparent as the pace of operations increased. From this review has come a plan that includes support from the National Research Council. Among the items being pursued is a development activity that will examine the feasibility of using a specially instrumented aircraft to determine wind velocity and direction in near real-time as it flies a trajectory that approximates that of the planned Shuttle ascent. The technique in use for this purpose at present yields data that can be as much as 3 hours old. Under these circumstances it is necessary to make allowances for uncertainty in the persistence of the wind conditions in predicting the structural loads that will be experienced by the Shuttle during ascent. Obviously, reducing the allowances for such effects will improve the assessment of loads and permit more informed control of risk.

In response to concerns raised by the Presidential Commission, the Associate Administrator for Space Flight established a review team to examine and assess the implementation of the Shuttle Processing Contract at KSC. The team was to give particular attention to the relationship between the SPC contractor and the several flight hardware contractors. This team has begun its activity and the Panel plans to meet with this group to exchange views.

In response to a request from the USAF, NASA is evaluating potential use of Vandenberg AFB Shuttle facilities during the period of "caretaker" status, now estimated to extend to 1992 or later.

<u>General</u>: On the basis of the discussions described at the beginning of this section, the following observations are noteworthy:

1. The magnitude of the documentation required at KSC for a typical mission illustrates the complexity of the launch preparation and launch processes. There are some 3,000 separate documents required comprising some 200,000 pages. When the number of copies required are factored into the consideration, some 15 million pages of documentation are distributed for each launch! If a launch is "scrubbed", some 2-3 percent of the pages (i.e., 300 to 450 thousand) pages must be reissued.

2. Facilitating internal NASA communications continues to be a key ingredient for KSC to meet its goals. This is recognized by all those involved and as the operations organization evolves under the changing STS organization, senior management attention must continue to be focused on this area to be sure that the communications system does not lose its efficacy during the transitional period.

3. There is a substantial amount of unplanned and previously deferred work at KSC. This is particularly true for the Orbiters. This work must be carefully scheduled and accomplished.

4. It was observed that, with lay-offs completed, the morale of the employees, particularly those of the SPC, has improved. This could be a transient phenomenon if any further personnel reductions are not handled adroitly. Frequent impromptu visits by senior managers to the work sites are an effective means for maintaining morale and motivation among the "hands-on" personnel. This is also true when the tempo of activity increases in preparation for the resumption of flight.

5. Workers often expressed the opinion that training should employ real or equivalent hardware and situations so that

the trainee can attain proper understanding of the hardware, software, and procedures. It was also suggested that competent supervisors and/or engineers should give the technical training courses rather than a training staff considered to be unfamiliar with the "real world."

6. The "hands-on" personnel exhibited respect for and reported satisfactory relations with most engineers. There was, however, concern expressed about the lack of experience and/or ability of many of the newly hired engineers.

7. The concerns about the use of "shop aids" that had been expressed by the Panel have been addressed most effectively and thoroughly. All the organizations involved--KSC, MSFC, JSC, and their contractors--are to be congratulated.

There are no specific findings or recommendations to be made in this area, other than these related to Shuttle management set forth in Section II and the Executive Summary. Launch processing is a complex activity and requires constant attention and discipline, along with adequate budgets and schedules, to be effective and safe. The Panel will continue to monitor activities in this area during the next year.

B. Logistics

The subject of logistics has been thoroughly reexamined by NASA since the Challenger accident. The concerns expressed by the Panel in previous annual reports have been fully borne out by this review. One positive result has been the safeguarding of funds designated for logistics--they can no longer be "transferred" or "re-programmed" to satisfy needs in other areas. There remain important issues and problems that must be addressed forcefully and solved so that NASA can believe, with assurance, that it has established an effective logistics system for the long term. These issues/problems lead to the following recommendations:

1. Complete the procurement process for necessary spares.

2. Establish procedures for the control of cannibalization with the ultimate objective of eliminating the practice.

3. Establish control of the pipeline for the repair of Line Replaceable Units (LRUs), in particular, as well as for other components. This will probably include the need for a repair depot on-site at KSC. Although it will still be necessary to return certain sensitive units to the manufacturer for repair, the number of such units should be kept to a minimum.

4. Determine, as soon as feasible, the impact of the "Maintenance Safeguards" program. If there is a financial effect (i.e., increased spares requirements) necessary budget modifications should be made promptly.

5. Ascertain the effect of the planned maintenance program on logistics. Make necessary adjustments to spares required. If the maintenance program planning is not yet complete, do so promptly in order that the effect on spares requirements may be known and incorporated into the recovery plan.

6. Determine the effects, if any, of the results of the ongoing Shuttle Design Review program (if any) and factor them into logistics planning.

7. Re-examine and assess the logistics targets to ensure

that they are compatible with realistic flight rates.

8. Establish a program to determine which components, devices, or parts are no longer available or may become so as a consequence of the supplier going out of business or ceasing their manufacture. Establish an activity to obtain equivalent hardware.

9. Reduce pipeline turnaround times for all critical LRUs.

C. Shuttle Flight Simulators

The Shuttle flight simulator program requires an additional airplane because the current three airplanes are aging and will soon require major modification. The restart this year of the astronaut mission related training program will require the fourth airplane in order to maintain the proposed flight schedule. Although this is approved, it appears to be suffering from lack of top management attention.

Recommendation:

NASA Headquarters should ensure that this program is continued and completed in a timely fashion so that astronaut training will not be delayed or restricted.

V. SAFETY, RELIABILITY AND QUALITY ASSURANCE

A. The NASA System Safety Program

Following the Apollo 204 tragedy, NASA spent several years putting in place a basically new type of safety program. An organization was set up at Headquarters and the methodologies were developed for an overall safety program. These methods were incorporated into the various volumes of the NASA document NHB 1700.1 "NASA Safety Manual." Other documents describe "Reliability Program Provisions," NHB 5300.4(1A), and "Quality Program Provisions," NHB 5300.4(1B).

At the core of NASA's safety program was the idea of "risk management" through the control of "hazards." Residual hazards that could not be designed away would be controlled at least to the level consistent with program objectives and cost constraints. The definition and analysis of hazards associated with a system and its operation was to be performed by "System Safety Function." The level of hazard control was not always expected to be perfect, and a "residual risk analysis" would be performed to provide a "retention rationale" for continuing to operate.

In parallel with the "Systems Safety" activity was a "Reliability" activity. This function was basically concerned with establishing a data base for selection of components which would meet allocated failure probability requirements, performing "failure mode and effects analysis," establishing redundancy criteria and configuration definitions, maintainability criteria and life limits, and the preparation of "critical items lists," containing items with single-point failure modes which could cause catastrophic results.

In principle, the failure modes and effects analysis should be both a design tool to provide an impetus for design change and an evaluation tool of the final configuration to define the necessary control points on the hardware.

The identified "critical items" would require a supporting "risk assessment and retention rationale" in order to be included in the overall system configuration. The hazard analyses being performed by the system safety function and the failure mode analysis and critical item identification performed by the reliability function came together in the generation of Safety Analysis Reports (SARs) and subsequent retention rationale for the critical items.

A third element in the overall safety program was "Quality Assurance." This function, as defined by NASA, would be responsible for ensuring that the hardware and software produced for the system was produced in a controlled way and met all requirements of the quality control criteria documents. This assurance role also included supervision of personnel certification and establishment of non-destructive testing methods to detect flaws and non-conforming materials.

At the beginning of the Shuttle program, the basic system safety policies and methods to be used were established by NASA Headquarters and used many of the approaches evolved during the Apollo program. The responsibility to implement these requirements was tiered down to various program levels and centers by management instructions and other requirements documents. During the earlier development phases of the STS program, NASA Headquarters retained a daily strong role in directing the overall safety program. However, by the time of the Challenger loss, the Headquarters organization was only minimally staffed, and had basically only a limited review and audit function. They were essentially a Headquarters Level 1 staff organization with no explicit responsibility and corresponding authority for system safety engineering throughout NASA. Headquarters field representatives at the Centers began to report directly to the program managers, and were simply reviewing data and specific problem areas rather than leading a comprehensive safety engineering activity. Annual audits by Headquarters declined to biannual and became merely surveys of limited scope with minimal staffing.

The implications of this relatively weakened safety organization was highlighted in the President's Commission Report when they said in Chapter VII that "the Commission was surprised to realize after many hours of testimony that NASA's safety staff was never mentioned."

Discussion of the NASA Safety Program

The Panel recognizes, as does NASA, that modern hardware systems such as aircraft or weapons or the STS are not only incredibly complex, but usually demand high performance and, therefore, are subject to significant risk. The objective of a System Safety Program in any enterprise or organization should be to manage such risk to an acceptable level (not zero) throughout the operational life of the system. In our view, the elements of such a Total System Safety Program are comprised of the following:

1. System Safety Engineering
2. Program Quality Assurance
3. Operational Safety Doctrines

In some organizations the first two elements are sometimes combined into a function called Product Assurance and is many times organized and thought of as the "Quality Assurance and Reliability Function." Within the Space Shuttle Program they were grouped in 1979 (NHB 5300.4(1D-2)) into what is even now referred to as Safety, Reliability, Maintainability and Quality Assurance (SRM and QA). Experience teaches, however, that under this "ility" structure, the system safety function loses its "engineering" role. Further, as operated in NASA, it does not have the authority to ensure that safety is designed into the system, does not control the system safety validation, and eventually becomes an analysis, record-keeping and audit function populated with personnel having that type of background.

However, beyond the disturbing decline in safety engineering stature throughout NASA, we believe there are also issues with the basic methodology used to ensure that risks are adequately projected (quantitatively) and then controlled to the levels accepted.

The Presidential Commission recommended that NASA should review all Criticality 1, 1R, 2, and 2R items and Space Transportation System hazard analyses. NASA responded during 1986 by performing a massive rework of all Shuttle program failure modes and effects analyses, an update of the resulting critical items lists, and a review of all hazard analyses all of which continues today. Although this may have value in identifying any new critical failure modes that may have been missed earlier, or subsequently introduced through changes, the crucial problem with the safety methodology is not really the failure mode nor hazard identification process. The procedures used do indeed result in definition of the critical modes of failure and their resultant hazards, and also the hazards which result from external influences beyond the system hardware and software. The crucial issue with the process is the "retention rationale" used to accept the hazards and which justify a waiver for using Critical 1 and 1R items. In many instances the stated rationale is really only qualitative "rationalization."

Criteria for quantitative risk assessment and explicit definition of the operating constraints to which the waiver is subject are not explicitly required by NASA's safety program guidelines. Although the Panel is quite aware of the pro's and con's of trying to establish "likelihood" or "probability" of failure, we believe a more realistic quantitative assessment of the critical hazards is crucial to overall risk management. There are many analytical tools and test methods that can provide data for such assessments. Among the most important inputs are the validation of critical design criteria and the demonstration of actual margins to failure modes.

The Panel believes that NASA could achieve a significantly better level of Operational Risk Control by recognizing Safety Engineering as an engineering design and hardware/software validation function; that Program Quality Assurance is a "total configuration control" function; and that Operations Safety Engineering is an "operational doctrine and control function." Within such an overall framework, the System Safety Engineering function should be carried out within clearly established policies and guidelines by means of specific organizational units directly responsible to teh NASA Center Directors and operating under policies established by the new Associate Administrator for Safety, Reliability, Maintainability and Quality Assurance. This new Headquarters office must have more than the loose oversite role in overall safety exercised by the Chief Engineer's Office over the past few years. The Associate Administrator should be made responsible for NASA system safety engineering in the broadest definition of that function (see below) and given the authority necessary to impose safety methodology, policy, and approval authority for system implementation. NASA safety engineering personnel should be part of the NASA Headquarters organization, although they would be matrixed into the various programs and projects. Their professional stature, career paths, and rewards should be a part of a respected Safety Engineering organization.

The System Safety Engineering function skewers through the overall hardware and software engineering activities. Among other things it should embody the following elements:

1. Overall system safety analysis

2. Hazard analyses and relative risk assessments

3. Failure modes and effects assessments and critical item definition

4. Critical components and subsystems reliability analysis and redundancy criteria

5. Criteria for design safety factors and operating margins

6. Component validation and systems certification test program requirements and implementation criteria

7. Specification of all environmental constraints at every level to ensure control of the validated margins on each subsystem

8. Evaluation of all flight data and modification of operating constraints as required to stay within validated margin regimes

The reason the Panel recommends that Safety Engineering be responsible for establishing safety factor and operating margins criteria and for defining the component and system certification programs is that these areas have the highest leverage on overall risk assessment and control. To be made responsible for system safety without authority over all of these critical functions that control the real risks is not viable.

Mission Operations Safety Engineering should also be the responsibility of the Systems Safety Engineering Organization. The function of Operations Safety Engineering is to ensure conformance with the policies and constraints under which the mission operations of the system will be carried out so as to sustain the certified configuration. These policies and constraints should encompass launch commit criteria, flight validation policies, and environmental constraints. The overall NASA policies in this area should be the responsibility of the new Associate Administrator for Safety, Reliability, Maintainability and Quality Assurance.

The Safety Engineering Organization should not be responsible for NASA Occupational Safety which should be a totally separate function under a Health and Safety Organization. It is most important that the Safety Engineering functions in NASA be perceived and operated as a true engineering discipline. The engineers should have significant professional training in safety engineering methodology and be incorporated into the earliest phases of the planning and design phases of every major hardware system program.

The third element of overall program risk management is Quality Assurance. Quality Assurance should be viewed as a configuration control function. As such it provides the certified documentation that the hardware and software have been produced to the exact designs which delineate the validated and qualified components and integrated systems. The "configuration" includes all aspects of the hardware and software including the applicable environments which in any way influence the properties of materials or stress margins or temporal behavior of components and systems. This function should be performed by a separate Quality Assurance organization and should not be a part of the responsibility of Safety Engineering (although there is certainly an interaction). The Quality organization should be the direct line responsibility of each NASA Center (and, of course, each Contractor) with the Director of Quality Assurance reporting to a top level of management to retain its independence and full integrity. Its purpose is not to engineer but to control and assure. As part of this function it does control the entire set of final released engineering documents describing the complete configuration of the system.

In the fall of 1986, responsibility for policy and oversight of this function was also included in the new Associate Administrator's Office. This is important because overall risk management and total Systems Safety is dependent on the Quality Assurance function throughout NASA.

Findings:

At the time of the Challenger loss, the safety function at NASA Headquarters had significantly declined in both function and staffing levels from its early role in the STS program. The Panel's perception from many briefings, documents, and discussions was that it had become basically a reviewing and auditing activity with little explicit authority for establishing and implementing System Safety Engineering policy throughout NASA.

The Panel's investigations into NASA's safety engineering methodology led us to believe that even had the activities been fully staffed, there still remained questions about how effective the safety program could really be. The safety engineering function has been basically lumped into a Safety, Reliability and Quality Assurance staff-oriented organization. At the present time, our understanding of the new office of safety, reliability, maintainability and quality assurance, is that it is still basically a staff function with responsibiity to define roles, requirements, and organizational structures in safety, reliability, maintainability and quality assurance. Three fundamental weaknesses appeared evident. First, there was a lack of in-line responsibility and authority in a Headquarters organization for establishing and directing the safety engineering function. Second, the elements of the safety functions that were being done at various locations did not include responsibility for defining and controlling the validation and certification programs. Thus, there was no way that the safety organizations in NASA could take responsibility for assuring that failure mode margins were acceptably demonstrated nor assure that the hazard analyses on which the risk assessments were based were valid. Third, there was a conscious lack of quantitative approaches to determine failure-mode probabilities for the purpose of defining acceptable margins, nor for the relative likelihood of resulting system interactive hazards.

Recommendations:

The Associate Administrator for Safety, Reliability, Maintainability and Quality Assurance should have full responsibility to establish a total Systems Safety Engineering program throughout NASA and be given the authority to assure its full implementation. A Systems Safety Engineering organization reporting to the Associate Administrator should generate the overall safety program policies to be followed. It would also define the critical safety design criteria to be used and the testing program methodology necessary to assure that those criteria have been properly validated. This Headquarters organization would also establish requirements and methods for performing overall system integrated hazards analysis and for the generation of quantitative risk assessments tied to controllability of failure mode margins and test and flight results.

Reliability, Configuration Maintainability and Operations Safty Engineering should be integral parts of this Systems Safty Engineering organization and it would provide policy direction for these functions throughout NASA. The definitions of policies and operating instructions for the Quality Assurance functions which are a vital part of risk management should also be the responsibility of the Associate Administrator.

The policies and implementation directives should be implemented by System Safety Organizations reporting to the Director's office at each NASA Center. As appropriate, personnel from these organizations could be matrixed into the various programs. A significant part of NASA funds to be spent in safety areas should be allocated directly to the Systems Safety Organizations. This would provide assurance that necessary safety engineering activities can be controlled independently of the funding tradeoff pressures which always exist within the programs.

B. Non-Destructive Evaluation/Quality Assurance

Special attention is being given to non-destructive evaluation (NDE) test methods to assure quality (conformance to the design and build methods) for critical items, e.g., the internal components associated with the various joints in the solid rocket motor. In support of accomplishing this a meeting of national experts was held at the NASA Langley Research Center (LaRC), November 20-21, 1986, to discuss techniques for non-destructive evaluation (NDE) for qualifying critical Shuttle components. LaRC's expertise lies in detection sensors, signal processing and enhancement and data interpretation techniques.

The measurement technologies which Langley Research Center believes are candidates for assessing many of the questions of Solid Rocket Motor integrity are related to acoustic and thermal propagation. Both of these appear capable of detecting the various bond line problems that have been identified as critical failures modes. X-ray techniques which may play an important role will take a number of years to be of value. The thermal methods seem, at this time, to be the most practical in that they can determine properties over large surfaces efficiently and effectively. For example, it has been shown by a major contractor that hot water can be used to heat the rocket motor case to "see" into the insulation with infrared imagers. LaRC tests have shown that one can determine quantitative physical properties of materials with a thermal NDE system consisting of scanning lasers, IR detectors, and computer controls and analysis models. However, the interpretation of the thermal data for the complexities of the solid rocket motor requires further lab testing. Ultrasonic energy is an ideal proble for finding debonds. However, the rocket motor geometry is more difficult to test since it consists of a steel case which is an acoustic resonator with insulation which is a laminated acoustic absorber. Recent tests by LaRC on a delamination problem of the X-29 R&D aircraft show that significant improvements in resolution can be achieved by methods which have the potential to remove the steel case from the signal and concentrate on the weak insulation energy.

The Panel recommends that NASA should emphasize development of NDE techniques for assistance in qualifying critical STS elements.

C. Reliability and Probabilistic Risk Assessment

There is a distinction between "reliability" which has a generally accepted definition as the probability a device will operate for a specified period under specified conditions, and "reliability engineering" which is a much broader and more appropriate term to describe a part of the design process. Reliability engineering is that portion of the design process which concerns itself with assuring that the hardware will perform as intended. It utilizes such analytical tools as the Failure Modes and Effects Analyses and the Critical Items List to focus designers' and management's attention on the relatively few failures which can have catastrophic results so that they can be eliminated from the design or their effects can be mitigated. There is also the responsibility for assuring that a vigorous process of recurrence control is applied to design related failures. It assures that proven or tested parts and materials are selected and emphasizes design techniques such as derating and redundancy. Reliability Engineering sometimes utilizes statistical tools to quantify probabilities. The concept of probability when one is dealing with extremely low probabilities is best described as a measure of the odds of a fair bet on whether or not the event will occur. These odds are usually derived from a combination of expert opinion and of operating experience, and change with experiences. As stated by Dr. Harold W. Lewis, in his paper "Probabilistic Risk Assessment Merits and Limitations":

> "It also serves as a systematic means for the quantification of the performance of a plant under upset conditions, and thereby is a means for the identification of weak points in design or operation . . . the major need . . . is a systematic purging of the conservative influence on the conduct of probability risk assessment, so that the results (including the uncertainties) are given generally understood meaning."

VI. SPACE STATION PROGRAM

A. Background

The Challenger accident has forced reconsideration of important space policy issues including the proposed Space Station. Whereas NASA, after many months of intensive Phase B definition studies, had established what it believed to be a "baseline configuration" now finds this to be wanting in several respects. The extensive extravehicular activity planned for assembly and maintenance is now considered beyond that to be feasible or safe. Also the Shuttle performance (payload pounds to orbit) has deteriorated somewhat and the flight rates envisioned are now considered unreasonable. The accident also raises concerns about the escape and rescue philosophy that dominated the early concepts. All of this led to the formation within NASA of task forces charged to review the design and operational concepts, including Center assignments and management responsibilities.

The Panel offers the following observations:

1. The Panel endorses the initiative to simplify the Space Station design and reduce the extent of manned assembly in orbit.

2. The Panel suggests that expendable launch vehicles (ELVs) of greater performance than the Shuttle be included in the launch stable inasmuch as such vehicles may emerge from other national programs such as Strategic Defense Initiative.

3. The Panel recognizes the problems associated with the "safe haven" and "life boat" concepts and suggests that both options may be required to satisfy ultimate safety requirements.

4. A concern has been registered that the computer systems being considered for the Space Station may not be taking into

consideration evolutionary changes that will inevitably evolve in the industry in the next two decades. The Panel suggests the system be designed to allow for the replacement of components as new technology develops. A 32-bit architecture should be mandatory as well as a standard bus.

We appreciate that many of the systems being explored for the space station are in a state of flux and that some of the concerns expressed here may already be under scrutiny. It is intended that many of these areas will be reviewed by the ASAP in the future.

B. Management

Reorganizational concepts emphasize that overall program guidance will be centered at NASA Headquarters, Washington, DC, under the Space Station Office directed by the Associate Administrator for Space Station. Day-to-day direction and control of the program will be conducted by the Program Director who heads the Space Station Program Office (SSPO) located in Washington, DC. Detailed performance of the development activities are assigned to NASA field centers. Assignments for specific areas are as follows:

Electric Power System.................Lewis Research Center
Data Management ....Johnson Space Center
Thermal Control
 *Internal.....................Marshall Space Flight Center
 *External.............................Johnson Space Center
  *(These refer to pressurized and unpressurized areas)
Communication..........................Johnson Space Center
 Internal Audio and Video.....Marshall Space Flight Center
Guidance, Navigation and Control.......Johnson Space Center
Environmental Control/Support..Marshall Space Flight Center
EVA Systems............................Johnson Space Center
Man Systems....................Marshall Space Flight Center

User Servicing..................Goddard Space Flight Center
Assembly and External Systems
Maintenance............................Johnson Space Center
Mechanisms/Gimbals......................................N/A

An Architectural Control Document (ACD) responsibility is assigned to Johnson Space Center. This responsibiity encompasses all functions and components of the system--inside and outside--with respect to the standard responsibilities of being the ACD agent. Marshall Space Flight Center has the design and engineering responsibility for assigned systems components consistent with the ACD documentation. JSC retains end-to-end system analysis and verification responsibility. The foregoing assignments to the various Centers impose special Space Station management requirements on the Headquarters Space Station office both as they regard program content and cost.

C. Technical and Resource Risks

From the point of view of Space Station safety there are three general categories of Space Station threats: hardware/ software, human performance, and logistics/resupply. In brief it would appear that these are some of the risks:

1. Human performance errors should be a major concern of Space Station design and operation.

2. The docking, electrical, flight control, and instrument systems have great potential for adversely affecting Space Station operations.

3. A major logistics/resupply threat is the unreliability of launch vehicles.

The baseline Space Station program associated with the "build-to-cost" concept is a resource risk. The difference between the stated $8 billion cost and the resources needed to achieve the current requirements (in the request for proposal due out in early 1987) is sizeable. These technical and resource risks result from such things as the following:

1. Compatibility between the current assembly scenario for the Space Station baseline configuration and the transportation system this Nation will have in the early to mid 1990s.

2. Extensive Shuttle-based and time-constrained extravehicular activity required for assembly and maintenance of the Space Station baseline configuration.

3. Adequacy of safety margin provided by the "safe haven" and/or "life boat" concepts currently considered for the Space Station configuration.

4. Adequacy of the proposed assembly scenario for the Space Station baseline configuration to support early scientific utilization.

D. Space Station Computer Systems

The Space Station designs developed over the next 18 months will impact the Station's utilization and safety for probably two decades. It is thus particularly important to ensure that the utmost care and planning go into the design. It is, therefore, appropriate for the Panel to investigate the planning. This preliminary report is, therefore, more a statement of principles than a detailed set of findings. The examination of this subject will continue during 1987.

Design Evolution

Almost nothing changes as rapidly as the state of the art of computer hardware systems. We can predict with great certainty that any of today's computer systems chosen as the basis for the Space Station will be out of date before the first launch of the Station's components, and that three or four generations of computers will pass before the Station becomes obsolete. The same will be true of other components as well, of course, but to a lesser extent. It is thus essential that the Station be designed for evolution so that components can be replaced and extended as new technology permits. The costs of not being able to accommodate new technologies effectively can be expected to be very high; much higher than the savings that might be realized initially by cutting corners.

There are two things that can and should be done in planning for evolution. First, technology forecasts can give a hint of expected technology developments. One can then develop a set of technology vectors that point toward forthcoming technologies. The Station designs should not only fulfill immediate objectives, but take these technology vectors into account. More specifically, the Station designs should explicitly identify the technology vectors which they endeavor to take into account. Further, the extent to which the designs cover the forecasted technology vectors should be one of the evaluation criteria for proposed designs.

Technology forecasts can, however, predict neither the unusual breakthroughs that occasionally occur nor the applications that might arise from such breakthroughs. To try to minimize the inability of the Station to accommodate unexpected breakthroughs, one can perform a limitations analysis on the design decisions that are made to indicate the directions in which these decisions will impede future evolution. The designs accepted should be chosen to minimize the limitations they impose on future evolution.

Computer system areas in which these principles should be observed for the Space Station include the following:

1. The implementation language chosen. (This should be a small number, probably no greater than two.)

2. The networking protocols chosen.

3. The communication media chosen.

4. The instruction set architectures chosen. (There may justifiably be two or three needed.)

5. The bus structures chosen.

Of particular immediate concern is the selection of the instruction-set architecture, which will be made in the near future. There have been some indications that a 16 bit architecture or an architecture that will be available from only a single vendor might be chosen. A decision for either of these is cause for considerable concern. Long before the Station is placed in orbit, 32-bit architectures will be the standard of the industry. Also, reliance on a single vendor has many well-known disadvantages. The requirements developed by NASA for the computer structures for the Space Station should take these concerns into account.

Status and Areas Needing Study

The implementation language chosen can buffer many changes in the underlying hardware as programs can be recompiled to operate with new hardware as it is developed. NASA's decision to adopt Ada as its principal implementation language is a very good decision. Ada is basically a good language; incorporating many modern software engineering concepts and having excellent extensibility capabilities. It is just now maturing, and will be a stable mature language long before the Station is ready for launch. Due to DOD's emphasis on standardization, compilers for any architecture the Station is likely to adopt will be available and the porting of code to new processors will be straightforward. Moreover, its life time will exceed that of the Station.

There has not been time to study the other areas mentioned more than superficially, nonetheless there is concern from the preliminary information obtained that unnecessarily limiting decisions might be made. These areas will be investigated further in the coming year.

Automation and Robotics in the Space Station

The observations and comments are made above with respect to the computing resources of the Station are equally applicable to automation and robotics capabilities. This is another area which needs attention during the coming year.

Findings:

1. The design choices for the Station's computer systems that will be made over the next 18 months will significantly affect the utilization and safety of the Station.

2. There are indications that a 16-bit architecture might be chosen for the Space Station computer system.

3. Technology forecasts and limitations analysis can aid in design decisions that will permit the evolution of the station computer capability as technology advances.

Recommendations:

The Station's computer systems should be designed so as to permit evolution of capability as technology advances. Specifically, a 32-bit architecture and industry standard bus should be selected.

The requirements and specifications developed by NASA for the computer structure for the station should recognize the future standardization of the industry of the 32-bit architecture and the inadvisability of locking into a single-source architecture.

E. Life Sciences

Specifically those Life Science projects needed to assure success of long duration human residence in space must be scheduled and funded in a timely fashion to support future long duration missions. The Life Sciences Advisory Committee (LSAC) is pondering the best way to gain knowledge on the proper path to follow in gaining what it perceives as its objectives for the Space Station. Life Sciences probably needs to establish a more effective mechanism within NASA so that it can compete for available funds.

F. Lessons Learned

This is to reiterate the same theme noted in our last year's annual report: "Since there are many similarities between the STS and Space Station programs, looking into the "lessons learned" relating to the early days of the Shuttle might better define Space Station actions to preclude missteps. This understanding of possible pitfalls for the Space Station program might include insight as to what not to do, thereby preventing inefficient use of resources (money, people, schedule)."

In support of this, the the Panel Staff Director, using data collected through Panel factfinding, prepared and issued a panel document "Lessons Learned--An Experience Data Base for Space Design, Test and Flight Operations." The following taken from the report's preface is the story:

> "This document summarizes specific and generic lessons that have been "learned" as a result of the factfinding activities of the Aerospace Safety Advisory Panel. As a program matures, it is advantageous to pause and reflect on the lessons learned during the conduct of the program and to record these reflections while they are fairly fresh in mind so that other programs can benefit from the experience. These lessons learned are intended primarily for use by those involved in any critical NASA program or project and who are somewhat familiar with the disciplines covered here. Thus the format used here favors brevity over excessive detail. In effect, it is an attempt to record some of the pitfalls a program has experienced, with a goal of alerting others to potential trouble spots and to suggest solutions which might improve the reader's program or project."

A candid treatment such as this may permit the drawing of incorrect inferences as to the general efficacy of NASA/industry management and technical proficiency, particularly by those uninitiated to the complexity of some of the "deficiencies" noted. Recommendations and actions described are not necessarily the only or best approaches. They reflect mainly the Space Transportation System experience (plus help from other ongoing aero and space work) which must be tailored to the "new" situation and should be accepted by the reader as one input to the many facets of both technical and management decisions. As such, they should be used to help identify potential problems in a timely manner and benefits should accrue when applied to projects in their early stages as well as the more mature ones.

VII. NASA AERONAUTICS

The NASA emphasis on aeronautical flight activities has increased significantly with the award of major contracts for development of the National Aero-Space Plane (NASP); the roll-out of the X-Wing vehicle; the accelerated flight envelope extension and the addition of the high angle-of-attack investigation to the X-29 aircraft program; testing of the gearless ducted fan engine and the advanced prop fan program; plans to flight test a variable-sweep oblique wing mounted on an F-8 Crusader; and the joined-wing flight test program. The Panel attention was directed primarily to the X-Wing since it has entered the Flight Readiness Review phase with the first flight scheduled for sometime in 1987. The X-29A technology demonstration flight program was reviewed periodically with particular attention paid to the next phases of the flight program. The NASP program is aimed at a manned flight demonstration and is ambitious in both a technical and financial sense and therefore is also being reviewed for general familiarization of the program plans for safety and for early identification of safety issues.

Other NASA safety-related aircraft activities that were reviewed during the year were the NASA/FAA airborne wind shear program, the Takeoff Performance and Monitoring System effort, the Heavy Rain Effects on Aircraft Performance program, and problems associated with certification of General Aviation Aircraft that use laminar flow airfoils.

A. Flight Operations Management

The appointment of a new Director, Aircraft Management at Headquarters places the flight management staff in a better position to be recognized as a major player in assuring continued flight safety within NASA's administrative organization. In order to ensure that flight safety remains a paramount objective of NASA, flight operations requires continued representation at the highest management level to assure that efforts to maintain and improve operational safety receive appropriate attention. A similar type of situation exists regarding flight operations offices at the various centers except for the Ames/Dryden Flight Research Facility.

Recommendations:

The Panel recommends that NASA assure that the Headquarters Flight Operations Management Office and those at the Centers have proper recognition and ready access to their senior management.

B. The Rotor Systems Research Aircraft//X-Wing Flight Test Program (RSRA/X-Wing)

The objective of the RSRA/X-Wing program is the successful demonstration of the capability to design a rotor system that can be flown and controlled in either a fixed wing or a rotory wing mode; and that can be converted from one mode to the other without loss of lift or control during the conversion. The selection of the RSRA vehicle was based on safety considerations--the vehicle can be flown as a fixed wing airplane (a separate conventional wing) independent of the rotory system. Since the rotory wing incorporates a circulation control system and depends upon exacting modulation of blowing through slots in the blades, it absolutely requires a digital automatic (fly-by-wire) flight control system. The conventional fixed wing utilizes a standard manual control system; however, there are interconnects between the two systems which add to the complexity of the overall system.

Of primary concern is the raising of the vertical center-of-gravity of the vehicle by some 18 inches as compared with the standard RSRA vehicle. This situation is having a pronounced effect on the structuring of the flight test program and the planning of the Flight Readiness Review activities. The current plan is to build up to the first rotor-on (stopped) flight with four flights beginning at 28,000 pounds with the rotor and associated equipment off; then increasing the vertical position of the center of gravity and aircraft weight up to the rotor-on gross weight and center of gravity position. Control of the vehicle will be maintained using the mechanical system.

1. Flight Readiness Review: The flight readiness review (FRR) of the RSRA/X-Wing has been structured to include five preliminary reviews and a final meeting of the committee just prior to the first flight. The X-Wing flight test program is to be conducted in two phases. The first phase includes testing of five aircraft configurations with a buildup in weight and vertical C.G. position. The first flight will be of a configuration that very closely duplicates the fixed wing flight of the original RSRA aircraft and will be without rotor, hub, compressor, standpipe or standpipe support structure. The next two flights will add the compressor and rotor support structure and the final two configurations will be with the hub and two blades followed by the final Phase I test of four-bladed configuration (all fixed unloaded rotor). The full up loaded rotor testing will begin in Phase II. The six scheduled flight readiness reviews are:

1. Vehicle dynamics and flight control.
2. Unique X-Wing structure, power train, and other systems.
3. Handling qualities.
4. System safety, reliability and quality assurance, emerging escape system, flight test plans, and project pilots report.
5. A wrap-up session for assessment of actions taken since the previous reviews on the respective subjects.
6. A final review of all requests for actions generated from all previous sessions.

The Flight Readiness Review Board (FRRB) is structured in a way that will assure complete and adequate coverage of the X-Wing design activity. Included should be an evaluation and assessment of all data from the various X-Wing test and simulation activities.

The first session of the Flight Readiness Review Board was held on July 28-30, 1986, and included an assessment of the flight controls and vehicle dynamics.

There were a number of action items that the Panel believes to be critical--ones that should be monitored closely. These include the following:

1. Adequate correlation of dynamic analysis with the stopped rotor wind tunnel tests is not clear. Also, the plan for showing a wind tunnel/analytic correlation should be improved.

2. The structural divergence prediction from the tunnel tests were not conclusive--some differences in the data are not accounted for.

3. The flutter and divergence analyses results performed by Northrop need further refinement. It is difficult to address the meaning of the results of the flutter analysis.

4 Various aerodynamic models for downwash interference are being used. Results from the powered model tests are not in agreement with predicted analytical model results.

5. Current Northrop controls/dynamic analysis is conducted for 200 kt/2.50 angle of attack. The analytical method may not cover 140 kts - 250 kts of the flight envelope.

6. Better definition of the telemetering requirements with

emphasis on software requirements for automatic monitoring is needed.

There is a need for a well thought-out written plan that describes the expansion of the flight envelope in a methodical manner to ensure avoidance of flutter divergence and tail buffet. The flight data should be correlated with the analytical and wind tunnel test data at each point as the envelope expansion proceeds.

2. Propulsion System Test Bed (PSTB) and Other Simulation: The PSTB is an "iron bird" representation of the X-Wing Rotor system, the Allison T-51 engines, transmission, compressor and pneumatic system, and the rotory wing flight control system. The mechanical architecture is identical to the aircraft and therefore serves the purpose of gaining operating experience during the period that the aircraft is being fabricated. Design problems may be discovered in time to formulate modifications prior to the completion and ground testing of the aircraft. The PSTB is scheduled for 50 hours of testing of operational adequacy and another 30 hours of endurance testing for a total of 80 hours. The aircraft will be subjected to 25 hours of tie-down testing which, in addition to the PSTB hours, should be sufficient to ensure the absence of weak points in the design. The aircraft is only programmed for 40 hours of flight time; the successful completion of 80 hours of PSTB testing will provide a great deal of confidence in the mechanical design of the system. The PSTB testing is programmed to lead flight testing by no less than 2 to 1 in total numbers of operating hours.

Another important aspect of the PSTB is the verification of the adequacy of the rotor wing control system. The digital automatic flight control system of the X-Wing is a most complex design and the ability to test the algorithms with the actual rotor dynamic response is a valuable asset to the program that is needed to verify the veracity of the computer simulation. The

Vehicle Management System Laboratory (VMSL) including the systems Integration Test Stand (SITS) and the Vehicle Motion Simulation (VMS) are being utilized to develop the flight control system software which will be incorporated in the PSTB before the rotary wing flight test begins.

There have been a number of problems that have been discovered this year during the PSTB testing. The gap at the middle seal between the rotating inner cylinder and the stationary middle cylinder closed causing metal-to-metal contact which could have caused failure of the hub if it had happened on the flight vehicle. The seal design had to be modified to correct the situation. Another problem was the failure of the flexible duct in the pneumatic system caused by a faulty clamp. Excessive overboard venting of the air/oil from the compressor gearbox has been observed, as well as excessive heating of the compressor. The most serious problem was a gearbox failure which occurred in the throughshaft to the compressor gearbox bearing assembly.

Finding:

It is apparent that due to the unique equipment and designs of the heavy mechanical equipment of the X-Wing, oil starvation, or vibration problems can add to fatigue failures. The PSTB has already proven invaluable detecting flaws that otherwise may not have been identified before the flight program.

Recommendation:

Additional running time be allocated to the PSTB.

3. Powered Wind Tunnel Model Testing: An important element of the X-Wing program is the wind tunnel testing of a 1/5 scale powered model. The results of the tunnel test are used in the simulation programs for predicting the stability characteristics

of the vehicle and also for the prediction of the flight loads needed to verify the structural integrity of the rotor system. The tunnel results for the fixed rotor have not agreed well with the analytically predicted values. The Panel will continue to monitor this situation during the remainder of the FRR phase.

4. X-Wing Safety: The Panel found the safety effort for the program has been increased substantially over the last year. In addition to the hazard analysis, a top-down event model has been generated to provide an analytic and systematic safety analysis. Of particular concern to the Panel is the emergency escape system which includes a blade severance device.

The Panel recommends that NASA should complete fault and failure analysis to provide an adequate level of confidence for its use.

C. X-29 Flight Test Program

1. Current Status: The X-29 aircraft has completed over a hundred flights since the flight test began on December 14, 1984. The program has been remarkable when measured by the absence of safety or other significant flight problems. This excellent record is particularly impressive when one considers the advanced technologies that are integrated into the design and are being tested for the first time. They include the following:

a. An aeroelasticly tailored forward swept wing
b. Close-coupled canards
c. A thin supercritical wing airfoil
d. Discrete variable camber
e. A three-surface pitch control
f. A high degree of static instability
g. An advanced fly-by-wire flight control system

This Panel believes that Defense Advanced Research Projects

Agency (DARPA), the Air Force program office, the NASA flight test team, and the Grumman Aerospace Corporation should be commended for this well conceived and executed effort.

With so many new technologies involved, the first phase of the flight test program has been engaged in a meticulous expanding of the flight envelope. Fundamental to the program in examining the various technologies is the demonstration of their combined relationships at all flight regimes normally experienced by fighter type aircraft--subsonic, transonic, supersonic, and at a wide range of altitudes.

2. Flight Test Methods: Of particular concern during testing of the aircraft is its high level of longitudinal instability. Control of this extreme instability made special demands on the X-29 flight control system design. For example, extensive lead compensation, high canard surface displacement, and rate capability were required. In addition, traditional flight control system stability margins had to be relaxed. These margins were reduced to 3 db high-frequency gain margin and 22.5 degree phase margin, which are half of the typical design values. This compromise could only be accepted in the presence of real-time monitoring and on-line analysis of the flight test data.

In this connection, since the consequences of pitch control surface limiting or extended periods of surface rate limiting in the X-29 can be disastrous (the time to double attitude pitch angle is .15 second), flight testing of the aircraft requires special approaches and methods. The flight control considerations related to the extreme instability, wing structural divergence, and aerolastic effects dictated a cautious incremental approach to envelope expansion with thorough analysis of all of the data.

Both traditional and specialized flight test approaches are used on the X-29 program to monitor overall aircraft and control system stability during envelope expansion. A key element of the approach is an accurate, hardware-in-the-loop simulation of the X-29. The extraction of accurate longitudinal stability derivatives with three active control surfaces and the extreme pitch instability is very difficult. Because of these difficulties and the fact that the flight control system clearly dominates the X-29 responses, direct monitoring of the health of the flight control system as a flight safety issue has taken precedence over all other aspects of monitoring.

In general, the agreement between the flight data and the predicted data has been quite good. In fact, the quality of the real-time frequency response data has been good enough that monitoring of stability margins has become the primary flight safety tool during envelope expansion. A principal advantage to this method is that the effects of any nonlinearities, for example, rate limits, hysteresis, or transport delay, are immediately reflected in the measured control system stability margins.

3. Handling Quality/Safety Relationships: As a direct result of precautions taken in the design of the flight control system to ensure flight safety, the handling qualities of the aircraft have been somewhat degraded. The X-29 has half the natural frequency of the F-18 feel system and can fairly be labelled "slow." If the time delay measurements are related to stick position, not stick force, which eliminates the feel system, then the correlation with the military specification boundaries and the pilot ratings is more reasonable. The X-29 appears to have significant time delays but, certainly in the roll axis, does not exhibit the flying qualities problems expected with these delay levels. No pilot induced oscillation (PIO) tendency has been observed in the roll axis during precision formation tasks, for example. The X-29 results bring into the question the present MIL-8785C requirements on time

delay and the more general questions of whether stick force or position is the important parameter for precision tasks. The X-29 example also gives some indication that "slow" feel systems may indeed be a beneficial element with which the control system designer can smooth out high gain system deficiencies without paying the penalty of increased time delay.

In summary, the X-29 results raise several fundamental flying qualities issues which are potentially important to the design of future flight control systems. As a result of the X-29 experience, a spin-off flying qualities experiment is now underway using the Air Force variable stability NT-33 aircraft to help resolve these issues.

4. Langley Support for X-29 High Angle of Attack Maneuverability Program: The second X-29, by current plan, is to be used for exploration of fighter maneuverability at very high angles of attack. NASA Langley, coordinating its work with engineers of the Dryden Flight Research Facility, is supporting this program with free-flight model studies. The first X-29, now flying at Dryden, has been arbitrarily restricted to a maximum angle of attack of 20 degrees.

Throughout the Langley program a continuing effort will be made to improve control laws of the digital avionics to enhance system capability, suitability, and safety.

The Panel believes this research will further the achievement of flight safety during both high angle-of-attack operations and recovery in the case of accidental spins.

D. National Aero-Space Plane (NASP) Safety Considerations

The National Aero-Space Plane (NASP) program has completed its conceptual phase (Phase I) and is currently directed towards a future flight demonstration. The schedule for development of the manned hypersonic research vehicle is divided into two phases. Phase II (in progress) is primarily directed at a propulsion system development, technology advancement (aerodynamic codes, materials, structures, etc.) and vehicle configuration analysis studies. The Phase III (to follow in 1989) is slated for fabrication and flight testing of the vehicle for flight at speeds up to Mach 25.

One important key to this program is the ability to predict internal and external flow fields. A major technical issue is the establishment of an adequate data base and overall validation of the design of the experimental manned transatmospheric research vehicle since the full-scale vehicle cannot be groundtested through the full-range of its operational flight speeds, Mach numbers, and altitudes. A thorough evaluation of existing ground research facilities, their modernization and upgrading needs, the need for new ground facilities, as well as possible flight research facility options must be established and the corresponding budget requirements defined. This facility evaluation is necessary in order to ensure the ability to verify analytically determined design parameters associated with uncertainties such as the interaction between vehicle and engine flow fields, inlet region effects of forebody crossflow and viscous influences, inlet spillage flow effects with angle of attack variations, dynamic interactions between the engine operation and the vehicle motion, flight control dynamic responses to nozzle lift/thrust and pitching moment variation, etc. The ability to determine the characteristics and parameters of a complex flow field accurately has been greatly improved through the use of high-speed computer simulation that uses numerical solution methods. Traditionally, analytical methods have been used in the initial design of air vehicle and propulsion systems but the final design has always required and has been the result of extensive wind tunnel and flight tests. With the development of advanced computational capability, significantly less hardware testing will be required; however, the computational tools are far from perfect and the code development must be accompanied by a vigorous and systematic program to provide comprehensive experimental verification and correlation of analytical predictions. Confidence in the codes can only be gained by a carefully structured verification program expanded to cover the full range of configurations and aerodynamic/thermodynamic phenomena to which the computational procedures are applied. It is important to realize that experimental verification is a vital element of the overall computational aerodynamics program, and it must receive at least equal emphasis to the development of the codes and computer facilities themselves. To do otherwise will result in less than desirable return on investment and could, if experimental verification is slighted, waste a portion of a vital national resource and increase the likelihood of a flight mishap.

The use of large quantities of liquid hydrogen over relative long flight durations at high mach numbers where extreme heating on the exterior of the vehicle and low cryogentic temperatures of the interior will pose a set of unique structural challenges and basic safety questions and concerns which will undoubtedly provide ammunition for vigorous debate at and before the Flight Safety Board grants approval for the first high mach number manned flight.

E. NASA Safety-Related Aircraft Programs

There are several NASA activities that are directly related to flight safety that have been reviewed by the Panel during the year. The Panel supports the continued research activities as noted below.

1. Takeoff Performance and Monitoring System: In response to the Airliness Pilots Association (ALPA) and SAE S-7, a takeoff performance monitoring system (TOPMS) has now been implemented for both pilot and copilot positions in the Langley fixed-base

simulation for the Transport Systems Research Vehicle (TSRV) (a Boeing 737). The display is now being evaluated and developed using Langley research pilots, and it looks very promising. ALPA and industry transport pilots will soon be invited to evaluate it. The next step will be to implement the display in the research cockpit of the actual B-737 airplane. The purpose of TOPMS is to provide guidance to the pilot for takeoffs and aborts including cues for helping make the critical decision. The TSRV simulation is to qualitatively evaluate the system and is utilized to solicit pilot suggestions for improvements.

2. NASA/FAA Airborne Wind Shear 5-Year Program: The seriousness of the microburst wind shear problem is now recognized as a highly significant aviation hazard, although encounters are infrequent. It has been the causal factor in 27 U.S. accidents since 1964, resulting in more than 50% of U.S. accident fatalities during the 1975-1985 time period. The object of the NASA/FAA program is to develop and demonstrate technology for low altitude wind shear risk reduction through airborne detection, warning, avoidance and/or survivability. The basic requirement is to provide an airborne capability that promotes flight crew awareness of the presence of wind shear or microburst phenomena with enough time to avoid the affected area of escape from the encounter. The program has three primary elements: (1) the characterization of the hazard, including the modeling of the wind shear physics and its impact on flight characteristics; (2) the development of optimum sensor technology, which includes the use of doppler radar, lidar, and the fusion of the two; and (3) the flight management system requirements, displays for the pilot, procedures and other techniques that can aid the pilot in recognizing the presence and severity of shear in time for appropriate action.

3. Heavy Rain Effects on Aircraft Performance: Heavy rain associated with downbursts has been found to cause a significant loss in maximum lift (premature stall), particularly for high

lift (flaps extended) configurations. Wind tunnel tests of a high lift configuration with an NACA 64-210 airfoil have shown significant lift and drag changes with rainfall rate at relatively low Reynolds number. Tests with a larger model will be performed on the Langley outdoor landing loads track near full-scale conditions.

4. Certification of General Aviation Aircraft Using Laminar Flow Airfoils: With the advent of very smooth and stiff composite materials for aircraft construction there has, appropriately, been an increased application of laminar flow airfoils to minimize drag, particularly to general aviation aircraft. These airfoils are shaped to have, in cruise, a falling (favorable) pressure gradient from the leading edge as far aft as possible over the top, or suction side, of the lifting surface. This tends to keep the boundary layer from slowing due to friction and becoming turbulent or separating from the surface. These airfoils have generally been considered highly sensitive to surface irregularities and contamination, resulting in adverse changes in lift and drag.

Surprisingly, recent flight investigations have shown extensive laminar flow over the wings of several general aviation aircraft using these airfoils, even with small-scale contamination (bugs, dirt, light rain, etc.), or disturbances such as caused by the propeller slipstream. Propellers with such sections also have shown sizeable areas of laminar flow. However, heavy rain, large bugs or deposits of mud, de-icer boots, leading edge or surface damage, severe turbulence, or hard maneuvers may cause breakdown of the laminar flow into turbulent flow, thus increasing drag. Of greater concern, however, is that laminar breakdown may lead to premature stall (perhaps asymmetrically), reduced lift curve slope of wing and tail surfaces (leading to reduced stability), and a reduced control effectiveness. These effects could occur abruptly and unexpectedly.

Because of these potential uncertainties, the FAA will review the current Part 23 Airworthiness Standards and the certification flight test requirements. One test technique is to apply "trip strips" at the leading edge of lifting surfaces to induce and ensure non-laminar boundary layer conditions to establish baseline characteristics. These "trips" could be applied in various locations on the aircraft to examine likely situations. The aircraft involved would probably be required to meet the minimum standards for Part 23 aircraft in the worst case.

FAA and NASA plan a joint flight investigation with a single engine general aviation aircraft having laminar flow airfoil sections on wing and tail surfaces as well as on the propeller. Flight test requirements and additions to the Standards are expected to result, but results will not be immediate. In the meantime, special consideration will have to be given each case.

IX. APPENDICES

This section includes an overview of the Panel membership, activities during Calendar Year 1986, proposed activities for 1987, and the detailed NASA response to the Panel's annual report, dated January 1986, along with a current status of last year's open actions. This information is provided under the following three sections:

A. Panel Membership/Consultants/Staff
B. Panel Activities During Calendar Year 1986
C. Panel Proposed Activities Calendar Year 1987
D. NASA's Response to Panel's Annual Report

A. Panel Membership/Consultants/Staff

The Panel membership has had significant changes during this past year. The current membership is listed below.

Mr. Joseph F. Sutter, former Executive Vice President of the Boeing Commercial Airplane Company, now an aerospace consultant, was selected to succeed Mr. John C. Brizendine as the new Chairperson of the Aerospace Safety Advisory Panel.

Mr. Norman R. Parmet was selected as the Panel's Deputy Chairperson.

Dr. Richard A. Volz, Professor/Director Robotics Research and Systems Division, University of Michigan, was selected to succeed Dr. Richard H. Battin covering the computer hardware and software disciplines.

Dr. Charles M. Overbey, Director of the Human Performance Division, National Transportation Safety Board, was selected as a consultant to the Panel to cover human factors associated with ground and flight operations.

Panel membership is set by statute at no more than nine members with the number of consultants commensurate with required activities. None of the current Panel members are NASA personnel. In addition, the new NASA Associate Administrator for Safety, Reliability, Maintainability and Quality Assurance, George A. Rodney, is the ex-officio member of the Panel.

CHAIRMAN

Joseph F. Sutter
Aerospace Consultant
Retired Executive Vice President
Boeing Commercial Airplane Company

Harold M. Agnew
Consultant
Retired President of
General Atomic

Charles J. Donlan
Consultant, Institute
for Defense Analysis

Gerard W. Elverum, Jr.
Vice President/General Mgr.
Applied Technology Group
TRW Space Technology Group

John F. McDonald
Aeronautical Consultant
Retired Vice President,
Maintenance and Engineering
TigerAir, Inc.

Norman R. Parmet
Aeronautical Consultant
Retired Vice President,
Engineering and Quality
Assurance, TWA

John G. Stewart
Assistant General Manager
Tennessee Valley Authority

Melvin Stone
Aeronautical Consultant
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Mechanics, Douglas Aircraft

Richard A. Volz
Professor and Director
Robot Systems Division
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Panel Consultants

Herbert E. Grier
Consultant
Retired Senior Vice
President, EG&G, Inc.

Seymour C. Himmel
Consultant
Retired Associate Director,
NASA Lewis Research Center

Norris J. Krone
Executive Director
University of Maryland
Research Foundation

Charles M. Overbey
Human Performance Division
National Transportation
Safety Board

John P. Reeder
Former Chief, Research
Aircraft Flight Division
NASA Langley Research Center

Ex-Officio Member

George A. Rodney
NASA
Associate Administrator for
Safety, Reliability, Maintainability
and Quality Assurance

Staff

Gilbert L. Roth
NASA
Staff Director

Susan C. Esmacher
NASA
Staff Assistant

B. PANEL ACTIVITIES FOR CALENDAR YEAR 1986

DATE	SITE	SUBJECT
2/3-4-5	Ames Research Center	Life Sciences Advisory Committee Meeting
2/11	HQ	Statutory Annual ASAP meeting with Administrator
2/21	Langley Research Center	X-29A Aircraft
3/11	Langley Research Center Control	Shuttle Landing Gear and Tires, Structures, Stability and
3/10-13	Sikorsky Pratt & Whitney West Palm Beach	X-Wing Propulsion Test Program and Safety
3/18	MSFC	STS Element Status
4/1-3	JSC	Space Shuttle, Space Station, Aircraft Operations
4/10	Lewis Research Center	Centaur management and technical status
4/22	Lewis Research Center	Centaur program discussion with staff from House HUD-Independent Agencies subcommittee
4/29-30	PAFB, FL	Intercenter Aircraft Operations Panel
4/30-5/1	HQ	STS, Space Station Logistics
5/8	U.S. Senate	Senate Testimony regarding ASAP Annual report and "where do we go from here."
5/15-16	HQ	Life Sciences Advisory Committee Meeting
5/15	U.S. House accident	Testimony concerning 51L
5/20	Rocketdyne Canoga Park, CA	SSME status and activities for first flight

5/21	Vandenberg Air Force Base, CA	H2 exhaust duct problem, activities leading to first mission, SPC operations.
5/21	U.S. House	Quality Assurance Hearing
5/21	Langley Research Center	National Aerospace Plane
5/21-22	Sikorsky, CT	X-Wing Discussions on Flight Simulators and Rotor Blades
6/17-19	MSFC	SRM Redesign, SSME status
6/19-20	JSC	Space Station Engineering and Operations Safety Review
7/1	Vandenberg Air Force Base, CA	Hydrogen Exhaust Problem
7/24	HQ	Systems Safety
7/24	JSC	Space Station Engineering and Operation Safety Review
7/24	Lewis Research Center	National Aerospace Plane (propulsion system)
7/29-30	Sikorsky, CT	X-Wing RSRA Flight Readiness Review
8/7-8	HQ	Life Sciences Advisory Committee Meeting
8/12-13	Sikorsky, CT	X-Wing RSRA Flight Readiness Review
8/19	Sikorsky, CT	X-Wing Safety program
8/20	HQ	Probabilistic Risk Assessment Approach
8/25	HQ	ASAP Activities
8/26-27	KSC	NASA/SPC Launch Processing Operations
9/23-25	Denver, CO Martin-Marietta	FMEA/CIL, Space Station Safety
9/23	MSFC	Probabilistic Risk Assessment

10/3	HQ	PRCB/FMEA/CIL
10/7	HQ	ET Tumble Valve Waivers
10/16	HQ	SRM Preliminary Design Review
10/17	Seattle,WA	ASAP Activities
10/22-24	Harlingen TX	Intercenter Aircraft Operations Panel
10/21-23	Ames Research Center	X-Wing Flight Readiness Review
10/29	JSC	Probabilistic Risk Assessment
11/7	HQ	Probabilistic Risk Assessment
11/14	JSC	STS Computer Hardware/Software
11/20	HQ	Meeting with NASA Administrator re: ASAP Factfinding
11/20-21	Langley Research Center	Non Destructive Evaluation for Solid Rocket Motor
11/24-25	HQ	Life Sciences Advisory Committee Meeting
12/4-5	KSC	NASA/SPC Launch Processing Operations
12/15-16	JSC	Space Shuttle, Space Station, Computer Hardware/Software
12/17	HQ	Probabilistic Risk Assessment

National Research Council Review Panel Participation

7/7-8	Los Angeles, CA	NRC Solid Rocket Motor Redesign Panel
7/17-18	Morton Thiokol	NRC Solid Rocket Motor Redesign Panel
7/21-22	Washington, DC	NRC Panel on STS Flight Rate and Utilization
8/6-8	KSC/MSFC	NRC Solid Rocket Motor Redesign Panel
8/11-12	Washington, DC	NRC Panel on STS Flight Rate and Utilization

9/10-12	MSFC	NRC Solid Rocket Motor Redesign Panel
9/16-18	Washington, DC	NRC Panel on STS Flight Rate and Utilization
9/22-23	Washington, DC	NRC Criticality Review and Hazard Analysis Audit Panel
10/9-10	Washington, DC	NRC Solid Rocket Motor Redesign Panel
10/27-28	Rocketdyne Canoga Park, CA	NRC Criticality Review and Hazard Analysis Audit Panel
11/10	Washington, DC	NRC Criticality Review and Hazard Analysis Audit Panel
11/20-21	Washington, DC	NRC Solid Rocket Motor Redesign Panel
12/15-16	JSC	NRC Criticality Review and Hazard Analysis Audit Panel

C. Panel Proposed Activities for Calendar Year 1987

The direction to be taken by the Panel is strongly influenced by the NASA and contractor activities associated with the Space Shuttle recovery for reflight, the Space Station Request for Proposal for Phase C/D (now in preparation), and the more significant aeronautic R&D efforts.

As stated before, the Panel's interests and efforts are those which further NASA program/project goals and reduce adverse events associated with meeting those goals. As expected, Panel activities are divided into "on-going" and "new" areas. These are both internally generated by the Panel and those requested by NASA senior management or suggested by the Congress.

1. Space Transportation System/Space Shuttle

- o Continue participation in activities of the National Research Council review panels (SRM redesign and hazard/risk assessments).
- o Review, through factfinding sessions, the more significant actions being taken to return to a safe first reflight of the Space Shuttle. For example, the launch processing activities at KSC, the implementation of the "mandatory for first reflight changes" for all Space Shuttle elements, the implementation and impact of management reorganization at NASA Headquarters and JSC, MSC and KSC, operation of safety organization, etc.
- o As requested by MSFC Director, the Panel will participate in periodic reviews of the Tether Satellite System regarding safety of its operations with the Space Shuttle.
- o Use of Radioisotope Thermoelectric Generator systems on spacecraft to be carried in the Orbiter payload bay.

2. Space Station

- o Space radiation, orbiting debris, extravehicular activities and life science areas as they apply to the Phase C/D efforts.
- o Space Shuttle and Station interfaces with emphasis on safety of combined operations.
- o Escape and rescue approaches.
- o Life sciences applied to on-orbit activities.
- o Implementation of the new Space Station organization and its impact on safety related operations/organizations.

3. Aeronautical Operations

- o X-Wing Rotor Systems Research Aircraft flight readiness process, including software validation, safety emphasis and preparation for first flight phase.
- o X-29, continue to follow activities to assure that if safety related activities are impacted that they are covered properly.
- o Continue participation in the Intercenter Aircraft Operations Panel activities.
- o Assess administrative activities associated with research and development and administrative flight activities.

As in the past, the Panel will continue to respond to NASA management and the Congress regarding safety of NASA activities.

D. NASA's RESPONSE TO JANUARY 1986 ANNUAL REPORT

To assure adequate time to develop thorough responses to the many Panel recommendations and comments, NASA has provided three separate response letters covering aeronautical programs, the Space Station, and the Space Shuttle Program (in that order). As in last year's annual report, the Panel notes here the status of each item ("open" or "closed") contained in the NASA letters. Also, the final status of each "open" item from last year's report is provided. Those listed as "closed" means that actions were both planned and essentially completed; those called "open" indicate either plans and/or implementation of required activities are incomplete and/or are not well enough known at this time. The numbering sequence follows that found in the NASA letters.

(Note: The NASA response dealing with the Space Shuttle Program is shown here in final draft form).

SUBJECT	CURRENT STATUS

1. STATUS OF "OPEN" ITEMS FROM JANUARY 1985 REPORT AS REPORTED IN JANUARY 1986 REPORT.

Subject	Current Status
o Space Transportation System Operations Contract (STSOC) at JSC goes into effect January 1, 1986. Panel is requested to follow this as they did the SPC at KSC.	OPEN--A continuing activity
o Review the launch constraints being modified in order to increase launch probability and turnaround mods as well.	OPEN--Being done as part of recovery activity
o Comprehensive maintenance plan supposed to have been released September 1985.	OPEN--Being implemented
o Initial lay-in of spares to be completed by October 1987. Status, impact of reduced funding . . . particularly if it affects safety.	OPEN--Being implemented
o SSME precursor test program to be completed during CY 1985.	OPEN--Extended schedule
o Filament Wound Case followup including vehicle excursions, lift-off loads alleviation, lift-off drift concerns, flight control stabililty impacts due to elastic properties, FRF impact on structural adequacy of "single-use" first flight segments.	CLOSED--Program shutdown with delivery of six sets No flight, or demon-strations expected in near future.
o Results of Rockwell's detailed fracture/fatigue analyses for test article LI-36 (wing/mid-fuselage/aft-fuselage structure being conducted June 1985 to January 1986.	OPEN--Deferred to FY 1988
o Shuttle/Centaur to adequately conduct tests within current schedule and the availability of resultant analyses is a concern. (OPEN)	CLOSED--Program cancelled

2. STATUS OF ITEMS COVERED IN EACH OF THREE RESPONSES INCLUDED IN THIS SECTION COVERING ANNUAL REPORT DATED JANUARY 1986.

a. Aeronautical Programs, letter from Dr. Fletcher to Norman R. Parmet, September 24, 1986.

Subject	Current Status
(1) NASA should appoint a qualified operations manager as head of Aircraft Management Office. Reduce time to produce and approve flight operations documents.	CLOSED

(2) Current status of X-29A and X-wing research aircraft programs and associated safety activities. — CLOSED

b. Pressure Suits, Space Station, and Space Debris, letter from Dr. Fletcher to Joseph F. Sutter, January 9, 1987.

(1) Extravehicular Activities (EVA)/ Space Suits — OPEN--NASA activities ongoing

- o NASA support of the development of an advanced flexible higher pressure suit.
- o NASA support of development of necessary data to establish, with confidence, what maximum stay in space should be. — OPEN--NASA activities ongoing

(2) Space Station

- o NASA should re-examine the Space Station integration resources required to ensure organization and human resources are sufficient. — CLOSED--New organization and work packages using SE&I contractor
- o Space Station ability to meet program objectives in a timely manner within current budget allocations. — OPEN
- o NASA should determine possible means to alleviate the payload bay interface environment and design requirements which drive some of the Space Station element and "user" designs. — CLOSED
- o NASA should establish a small team composed of current and retired NASA/contractor persons to define the management and technical lessons that can be learned from Space Shuttle program and applied to Space Station to preclude missteps. — OPEN

(3) Space Junk (Debris)

"Efforts to resolve this issue internationally must be intensified before it moves from the concern to the problem condition. Any solution must consider not only the large trackable units but the small debris that represents an — CLOSED--Although not completely implemented, proper attention is being given unavoidable collision hazard. The Panel would urge NASA through appropriate channels to establish an international consideration of this issue before it becomes a critical problem."

c. Space Transportation System (STS), letter from Dr. Fletcher to Joseph F. Sutter,

I. Orbiter

A. Orbiter structural life certification

o An abbreviated conservative analysis should be documented to fulfill the certification program.	OPEN--To be accomplished in FY 1988
o It should be noted that a loads calibration program will not be conducted on the Orbiter wing, but may be required if the flight results are questionable.	OPEN--NASA plans to conduct a loads calibration program on the OV-102 wing prior to its next flight.
o Other structural components, e.g., the crew module, will not be well documented.	CLOSED--The crew module is excluded from the "structural article" by design and, therefore, will not be included in the structural article certification documentation.

B. Orbiter Structural Adequacy: "ASKA 6" Loads/Stress Cycle Program

The Panel agrees with the arbitrary force approach taken at this time. However, the primary load path structure and thermal protection system analysis should be a stand-alone report, fully documented and referenced even if the September 30, 1987, end date slips. An operating restriction report and strength summary (external loads and vehicle stress) report for each Orbiter should be prepared in order to have quick access to information for making future decisions.	OPEN--Until 6.0 loads/stress cycle work is complete

C. Redlines and Modifications	
To provide 85-percent launch probability redlines, the wing modifications should be made, even if slightly conservative, in some structural areas. Redlines on OV-103 and OV-104 should be specifically examined and changed as required.	OPEN--Launch redlines being reviewed
D. Orbiter Avionics and Software	
o Monitoring of applications software and procurement of new GPCs.	CLOSED
o Mass Memory Unit upgrade.	CLOSED--Upgrade on indefinite hold
E. Brakes and Nose-Wheel Steering	OPEN--Redesign, tests, procurement still in process
F. Landing Handling Qualities	CLOSED
G. Automation	
If the automatic Orbiter flight system for ascent is relied upon, then why not the automated flight system for landing?	CLOSED--Auto land available as required
H. Fuel Cells	
Review to ensure that design of accessories is conservative.	CLOSED--Additional studies underway to reconfirm and hardware upgrade in process

II. Propulsion

A. Space Shuttle Main Engine	
o The recertification approach selected by NASA permits different parts of the engine to be "certified" for different flight times. This results in a somewhat questionable data base regarding true engine	CLOSED--The philosphy, which has been adopted by the program, is to test for a given number of cycles and replace the flight motors after half of those cycles have

configuration operating margins and valid Mean-Time-Between-Replacement values.	been expended. NASA approved in August 1986 the alternate pump program to provide a new, longer life pump with much higher safety margins. The desirable goal would be to perform limited testing to show margin and this is under consideration.
o The Panel recommends that the engine be operated at power levels above 104% of rated power only when mandatory. Also, when engine operation above 104% is necessary, the power level selected be only the value required for the particular mission and not taken all the way to 109% except when mandatory.	CLOSED--The 109% used for routine flights will be no earlier than 1993. Until then, 109% is for emergency mode only.
o The Phase II development and demonstration program should provide a data base for the modified turbopumps that can be used to estimate new Mean-Time-Before-Replacement criteria for the turbomachinery.	CLOSED
o We further recommend that the "precursor" (future) program improvements be supported at a level such that they can in fact be incorporated as soon as possible into the flight engines.	CLOSED--The precursor program will have to be delayed until the design and certification of critical items required for the first flight are accomplished. At that time (mid to-late 1988), NASA hopes to accomplish the testing of the precursor candidates.

B. Solid Rocket Boosters

o The Solid Rocket Booster holddown bolt calibration tests should be carefully examined at this time to aid in obtaining meaningful final test results.	CLOSED
o Filament Wound Case rocket motor activities. Appropriate Analyses	CLOSED--FWC Project suspended and such analyses

and tests have to be conducted prior to flight use of these motor segments.	and tests appropriate to shutdown are in process.
o A search is underway for an insulation replacement since the use of asbestos is no longer legal. This is a real concern...	CLOSED--The overall schedule and development/quality plan for the replacement of the internal insulation and other asbestos-containing materials in the Shuttle SRM is being updated and is available.

III. STS Operations

A. Flight Crew Training

o "NASA must commit the funds in a timely manner to ensure an adequately sized fleet of training aircraft to meet the flight crew training needs, without reduction or compromise to the Orbiter flight training syllabus."	CLOSED--Plans are being formulated to purchase and modify an additional (4th) aircraft that may be available in FY 1988.

B. Logistics and Launch Processing

o NASA management should monitor closely the effects of the recent reorganization at KSC to make sure that it has accelerated and simplified management of launch processing.	CLOSED--A continuous activity on part of NASA and the Panel.
o "NASA should examine the feasibility of developing data systems under management of the SPC, such as configuration management, that will centralize and augment KSC's operational launch capability."	OPEN--In work
o NASA should continue to give high priority to acquisition of spare parts and to upgrade the reliability (planned life) of hardware.	CLOSED--In work. Panel will continue to follow.
o NASA should explore whether better coordination could be achieved between those persons	CLOSED--In work. Panel will continue to follow.

determining manifests for specific flights and those persons charged with launch processing.	
o Facilities should be provided to minimize turnaround times of the Shuttle and Line Replaceable Units (LRUs).	CLOSED--Orbiter Maintenance and Refurbishment Facility being constructed. Plans to implement LRU repair facility.
o VAFB Launch Complex development issues.	CLOSED--VAFB moth-balled until at least 1991
o KSC and Shuttle Processing Contractor (SPC) activities re burden of work and flight rate.	OPEN--Panel to follow implementation of NASA and SPC Station actions

IV. Payload Interface Standardization

ASAP Recommendations: "There will always be peculiar requirements for special payloads, but insofar as is feasible, there should be increasing effort to preparing and carrying payloads in a standardized fashion."	CLOSED--Panel will reexamine later. Current NASA system is stated as providing a generic system to accommodate complex and simple payloads.

V. Shuttle Centaur	CLOSED--Project cancelled. However, this decision should not be interpreted as total exclusion of the use of cryogenic stages as Shuttle payloads on future flights.

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

SEP 24 1986

Mr. Norman R. Parmet
Acting Chairman
Aerospace Safety Advisory Panel
5907 Sunrise Drive
Fairway, KS 66205

Dear Norm:

Inasmuch as the ASAP's presentation to NASA on the results of the 1985 investigations was made before my nomination to Congress as NASA Administrator, I did not receive the benefit of your annual presentation. I have taken the opportunity, however, to review the Panel's findings and recommendations which are provided in the 1985 Annual ASAP Report.

The Panel's observations and recommendations to NASA are welcome, and we will respond to them with a view toward positive accomplishments. Due to the changes which NASA has been experiencing this year, multiple response letters to the 1985 report covering the aeronautical programs, the Space Station, and the Space Shuttle Program will be forthcoming. The enclosure provides the first NASA response to ASAP's recommendations, namely, those for the aeronautical programs. In addition, I am including commentary on the appropriate ASAP discussions which are provided within the fact finding section of the 1985 Annual Report.

With respect to the aeronautical reviews during 1985, the Aircraft Management Office (AMO) and the Intercenter Aircraft Operations Panel (IAOP) have enjoyed a professional liaison with both you and Gil. You have been a welcome addition to all of the IAOP meetings, as well as center aircraft operations reviews. Both the AMO and the IAOP look forward to a continuing dialogue with ASAP. I would like to thank ASAP for its recommendations, and I believe that the AMO's redefined role and delivered products during 1985 clearly demonstrate the incorporation and implementation of previous ASAP recommendations as well as those for 1985.

I would like to express my appreciation for your assuming the chair position on short notice and keeping the panel's activities moving forward. NASA looks forward to the Panel's participation as we conduct crucial reviews toward regaining a flight-worthy Space Transportation System. The panel's ideas and recommendations are appreciated and are carefully considered.

Sincerely,

James C. Fletcher
Administrator

Enclosure

NASA RESPONSE TO THE 1985 ANNUAL ASAP REPORT
APPENDIX 1: E. AIRCRAFT OPERATIONS

ASAP RECOMMENDATIONS:
NASA should appoint, as soon as possible, a qualified operations manager as head of the Aircraft Management Office (AMO). Determine methods to reduce the time it takes to obtain review and approval for critical flight operations guidelines and policies which are generated at Headquarters.

NASA Response:
Mr. Elwood P. Driver has recently been selected to fill the position of Director, Aircraft Management Office. Mr. Gerald T. McCarthy serves as the office's Deputy Director. Actually, a director, as well as two aviation safety professionals, had been selected for the AMO during 1985. Two highly qualified engineers, specializing in the areas of aviation safety and human performance, were brought on board. In August, the Director-designee of the office declined the position after having previously accepted it. The position was readvertised in October, and a Senior Executive Service (SES) panel reviewed the applications of the candidates. Due to the NASA hiring freeze, the Associate Administrator for Management had been unable to offer the position to a selected candidate. Even though the AMO had been without a nominal director during this time, however, two points should be emphasized. First, there had been an Acting Director designated. Second, and perhaps more significant, not only were the functions of the AMO successfully accomplished by the staff working in the office at the time, but also they were significantly enhanced.

In response to previous recommendations made by the ASAP and by ECOsystems center reviews, the AMO underwent a redefinition and reemphasis of role and functional implementation during 1985. There was a significant enhancement in the office's central coordination of aircraft operations policy and standardization, as well as flight operations reviews and aviation safety management. The AMO, which is the Headquarters focal point for agencywide aircraft operations, management, and operational aviation safety, is responsible for, and has been effecting the following principal functions during 1985:

1. Developing and issuing NASA policy guidelines governing aircraft operation, operational safety, aircraft maintenance, flight crew qualifications, and related training activities;

2. Reviewing and evaluating the adequacy of field installations organizations and procedures for aircraft operations;

3. Coordinating Headquarters' reviews and evaluations of proposed acquisitions, reclassifications, reassignments, and dispositions of NASA-controlled aircraft;

4. Providing institutional and functional management of all NASA administrative aircraft;

5. Developing and implementing a NASA Aviation Safety Program;

6. Developing and establishing guidelines for implementation of human performance concepts in NASA flight operations;

7. Supporting activities of the Intercenter Aircraft Operations Panel (IAOP);

8. Maintaining liaison with other agencies and the private sector on matters pertaining to aircraft operations (FAA, DOD, NTSB, ATA, NBAA, etc).

We recognized the need to reduce the documentation approval time and shared the ASAP's concerns. Stricter compliance with NASA Management Instructions (NMI), as well as the Headquarters' institution of the NASA Priority System, have significantly reduced the time required to obtain review and approval for aircraft operations guidelines and policies. There have been numerous products during this time period which demonstrate the significant enhancement of this office's management of NASA aircraft operations. Some of the AMO products in 1985 were as follows:

1. Established first NASA guidelines on pilot aging, aviation medical standards, flight approval authority, and maintenance inspections. Although the guidelines were not published as an NMI during 1985, due to the extensive NASA coordination cycle, the procedures outlined in the guidelines were established through directive letters from the Associate Administrator for the Office of Management in 1984 and were published as NMI 7910.3 in April 1986.

2. Published in January 1986, NASA Handbook (NHB) 7920.3, "NASA Administrative Operations Manual."

3. Established the AMO as focal point for NASA operational aviation safety and aircraft operations incident reporting. For example, the AMO represented Headquarters in the Convair 990 aircraft and Challenger accident investigations, as well as aircraft incident reporting.

4. Developed an Aviation Safety Program Plan.

5. Developed an Aircraft Operations Human Performance Program Plan.

6. Provided first AMO aviation safety/human performance evaluations during X-Wing operational and safety reviews at Ames Research Center.

7. Enhanced activities and effectiveness of the IAOP including: establishment of a new maintenance subpanel; reduced production time of IAOP meeting minutes and center review reports; development of IAOP Center Review Schedule through 1987; and establishment of a recommended follow-up tracking system.

8. Developed an action plan for the installation of crash recorders on NASA aircraft.

9. Documented the need to upgrade Dryden Flight Research Facility chase aircraft, resulting in the current acquisition of F-18's from the Navy.

10. Developed a five-year plan for the replacement of the Gulfstream 1 aircraft.

11. Reduced AMO written response time to ECOsystems recommendations.

The ASAP suggests in their fact finding section of the report that the ideal management structure for flight operations would be an office which reports directly to the Administrator or the Deputy Administrator. That office's function would encompass all aircraft operations, whether administrative, developmental, or research. While this would accomplish ASAP's objective of aircraft operations budget centralization, it would remove the knowledgeable and responsible research and development office from the program accountability of the flight test programs, which they now have, and would place the flight test operations program under an office which is more attuned to standard operational aircraft operations. The AMO is not staffed to undertake enhanced NASA operational functions. We believe it is in NASA's interest for the responsible research Center Director and program Associate Administrator to retain the present accountability. The present system is functioning satisfactorily.

APPENDIX 2: RESEARCH AIRCRAFT PROGRAMS

We are pleased that the Panel considers that NASA has been exercising the appropriate safety initiatives on our research aircraft programs and, therefore, no recommendations were formally provided in the "Findings and Recommendations" section of your report. It is appropriate, however, for us to address your comments provided within the "Fact-Finding Results of Calendar Year 1985." Before I discuss the two aircraft research programs, it is important to note that both programs, as well as other NASA programs, use composite materials for primary structure. We have been experiencing some problems with quality of the composites, particularly with delaminations. The Panel's investigations and insight into this subject are welcome.

a. X-29A Research Aircraft

The Panel should be made aware that the 80 percent operational design limitations will remain as the limiting load factor. We elected to maintain this limit rather than perform structural load tests.

We agree with the Panel that speed brakes would be desirable and would potentially enhance overall safety of the flight aircraft. They were rejected at the time of the program's initiation for several reasons. The dominating reason being the implementation cost. It was concluded that the proposed flight program could be safely accomplished without speed brakes. Since that time, the scope of the program has been changed. A follow-on program has now been approved which will significantly extend the duration and complexity of the flight program. With this in mind, it is desirable to revisit the speed brake issue. We now plan to fund a design study to determine the possible speed brake options available and their associated costs. Once these results are available, we will decide if speed brakes should be added to the X-29A.

b. X-Wing Rotor Systems Research Aircraft (RSRA)

With respect to program schedules, the milestones are presently holding firm. Roll-out is planned for August 1986; the first flight test without the rotor is planned for October 1986. However, if uncertainties arise with regard to safety, we will not hesitate to move the milestones to a later date. A decision has recently been made to accomplish all flight work at the Dryden Flight Research Facility. This revision to the flight test plan should simplify operations and thereby enhance safety. A Flight Readiness Review (FRR) Board has been established to resolve all safety issues prior to the first flight. As the Panel observed, there are many aspects and organizations involved with the overall safety program. Some of these are independent of the principal program activity which we consider to be healthy. You should be aware that the Ames Research Center Director, whom I hold fully accountable for the safety of this vehicle, provides the focus for these safety activities.

Your discussion regarding aeroelastic flutter and divergence was very interesting and I deeply share your concern. The model testing is late in supporting the fixed wing FRR, but I assure you that the first flight will not occur until I am satisfied that this matter is technically resolved and agreed upon by the particular NASA technical community which has the expertise. I would also appreciate the panel's review and advice on this matter prior to first flight commitment.

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

JAN 9 - 1987

Mr. Joseph Sutter
Chairman
Aerospace Safety Advisory Panel
9311 Fauntleroy Way
Seattle, WA 98131

Dear Joe:

As promised in my earlier letter to Norm Parmet dated September 24, 1986, I am providing NASA's second response to the ASAP's 1985 Annual Report. The content of this response covers the pressure suits, Space Station and space debris. The Space Station is rapidly evolving not only because of its concluding the Phase B preliminary design, but also because of changes mandated as a consequence of the Challenger accident. Our detailed response is provided in the enclosure, but I would like to state in summary that NASA is accomplishing the Panel's recommendations.

I look forward to your comments and recommendations in the 1986 report, as a measure against the progress which NASA is making during our recovery from the Challenger accident. Your suggestions for changes and improvements will receive the utmost attention by NASA. Our response to the sections dealing with the Space Shuttle Program is forthcoming.

Sincerely,

Jim F

James C. Fletcher
Administrator

Enclosure

1. "C. Extravehicular Activities (EVA)/Space Suits"

ASAP Recommendations:

"NASA should continue to support the development of a more flexible, higher pressure EVA suit and fund the development in an appropriate manner."

Other ASAP References to EVA/Space Suits:

1. Executive Summary. Page 3. "STS-Payload Related Issues."

   "It also points up the continuing need for a more flexible space suit or alternatively an end-of-arm manipulator to perform the normal hand functions--perhaps both."

2. "Fact-finding Results of Calendar Year 1985," "4. Life Sciences," pages 60-61.

   "However, there is a perceived need for a more flexible suit in the future that has the capability of operating at a higher pressure than the current suit and its development should be encouraged so that it can succeed the current suit on an attrition basis."

   "NASA's management must continue to support the efforts of the life sciences group to develop the necessary data to establish, with confidence, what the maximum stay in space should be."

   "Perhaps the way to go is not to change suit pressure but to design these arms and legs as replacement for the current ones."

NASA Response:

NASA is continuing to support the study of advanced EVA space suits and a regenerative, non-venting, portable life support system. Alternative higher pressure space suit designs with expanded capabilities are being pursued at the Johnson Space Center and Ames Research Center. The intent is to identify the advantages of alternative design approaches and, if feasible, to pursue a full scale development of the optimized design.

There is not, however, total agreement within NASA on the need for or the desirability of a high pressure suit. The Experimental Assembly of Structure in Extravehicular Activity (EASE) and Assembly Concept for Construction of Erectable Space Structures (ACCESS) experiments flown on STS-61B proved that improvements in glove design for improved ease of operation and wear characteristics will be essential. Clearly, the operational flexibility of a glove operating at twice the present pressure of the current design offers a challenge that needs to be met. An improved operational glove is essential to the successful EVA operations which will be placed upon the crew in the Space Station era. I am committed to the achievement of that goal, regardless of the suit's operational pressure. We are presently evaluating two competitive glove designs, one by ILC and the other by the David Clark Company. Ames is investigating an end effector which would assist in hand operations and is examining hazard reductions from micro-meteorites and space radiation that may result from the hard suit.

Clearly, the advantage of the 8 psi suit is its need to be operationally flexible in the 15 psi Space Station cabin atmosphere. Pre-breathing for low pressure suits in the shuttle program is minimized by a reduction of cabin atmosphere to 10 psi approximately a day in advance of the EVA. This has the disadvantage requiring the shuttle cabin to be operated at a higher percentage of oxygen (30%).

We could reduce the overall flammability hazard of the Space Station by lowering the percentage of oxygen content. At standard conditions of 1 atmosphere, the oxygen content is 21% of the total atmospheric pressure. In a 16% oxygen environment most burning self-extinguishes. This has been verified by tests conducted and represents the partial pressure of oxygen at an altitude of about 7500 feet, the lowest acceptable oxygen limit to man. A nominal value of 18% offers significant improvements in flammability reduction while offering a reasonable operational atmosphere equivalent to 4000 feet. It should be noted that the biomedical science user community has expressed a strong desire for the 21% oxygen atmosphere.

There is a concern that too much reliance is being placed upon EVA as part of the Space Station's design and assembly. One of the goals of the Critical Evaluation Task Force (CETF) held at Langley during August-September 1986, chaired by Ray Hook, was to evaluate the current baseline to determine whether design changes could be made to reduce the substantial EVA requirements. The task force has reported their findings to me which have resulted in some reduction of EVA. Extensive EVA, however, will remain a hallmark of the Space Station era.

Economics, safety, operational flexibility, and operational ease are strong considerations in the selection of a suit. The new high pressure suit undertaking comprises a major departure from our EVA operational data base at 4.3 psi. Suit development must be competently performed; otherwise, flight suit cost overruns could become enormous and could account for a significant portion of the Space Station budget. At the present time, we are still looking at options and alternatives for new designs. We have demonstrated operations at higher pressures, but the suit must be made more comfortable to be crew compatible. In FY'86 approximately $650K was spent on the new design. The program option is to maintain the present design, which is now certified for 21 hours, and recertify it to 40 hours of useful life as now planned, with pressure environmental restrictions on the pre-EVA activities. Obviously, any such restrictions would result in adverse effects upon Space Station operations in terms of both prebreathing and reduced number of EVA's. We are at the prototype stage of development, and I will review suit progress before a final commitment is authorized. The ASAP's evaluations would be welcome, particularly any thoughts which you may have regarding the safer pressure level.

Response:

The post Skylab era life sciences program has been approached managerially as a level of effort activity. We are taking steps to provide long term strategic planning to accomplish ASAP objectives. Over the past two years consolidation of the life sciences community has been implemented through the integration of the science planning conducted by the Space Biology and Medicine and Planetary Biology with Chemical Evolution Subcommittees of the Space Science Board, National Academy of Sciences. Also, an ongoing effort has been mounted by the NASA Advisory Council through its Life Sciences Advisory Committee to coordinate these scientific objectives into a cohesive activity. In addition, the NASA Advisory Council has chartered a special strategic program planning task force under the Chairmanship of Dr. Frederick Robbins to formulate a long range strategy for the life sciences programs for NASA. This also includes considerations of the cooperation among national agencies, universities, and international partners either now involved or else those interested in participating in space biomedical and biological research. I am anticipating that all these activities should culminate in organizing the NASA life sciences efforts into a cohesive program, responsive to NASA's long term goals by setting forth research priorities and supporting missions scenarios which will enable us to proceed with a timely program necessary to assure safe and medically sound human exploration of space.

2. "D. Space Station"

ASAP Recommendations:

"NASA should re-examine the resources required to conduct the many facets of the Space Station integration effort to ensure that the organization and human resources are sufficient to properly fill this role, now and in the future."

Other ASAP References to Space Station Resources and Organization:

1. Executive Summary, "Space Station," Page 4.

   "The panel foresees management/organizational concepts and arrangements, consistent funding support, and judicious funding allocation as being the key factors in successfully achieving the President's objectives for the Space Station Program."

2. Fact-finding Results of Calendar Year 1985.

   a. Page 57. "a. The Space Station organizational structure is quite complex with roles and missions and responsibilities difficult to discern at times. There is and will be occasional frustration in coping with the myriad of management prejudices and opinions that exist."

   b. Page 58. "b. There is some question as to whether NASA is adequately qualified to handle the complete integration of Phases C and D -- the hardware and software development."

   c. Page 58. "Meeting the Space Station Program objectives within a stringent budget requires early, quick, definitive action on the part of program management at all levels with emphasis on assuring that system engineering and integration organizations have the responsibilities and authority as reflected in the organizational structure."

NASA Response:

I concur with the Panel's observations regarding organization and funding. As recommended by the Panel, NASA has re-examined the resources required to conduct the many facets of the Space Station integration effort to ensure that the organization and human resources are sufficient to properly fill this role, now and in the future. The Space Station system engineering and integration function, previously performed by the Level B personnel at the Johnson Space Center (JSC), will be realigned for the next phase of Space Station development (Phase C/D) by realigning the system engineering and the system integration tasks. While we are considering retaining the system integration function in Houston (responsible to a program director located in the Washington, DC area), system engineering and analysis will become the responsibility of a new organization located in the Washington DC area. It is planned that this new organization will be assisted by a system engineering and analysis support contractor. The Space Station systems integration job will be further clarified through realignments in the content of the work packages managed by the NASA centers. These work package adjustments are intended to consolidate design and integration responsibility for all the various subsystems of a Space Station element (for example, the habitable module) under a single element manager. The realignments outlined will also clarify subsystem management accountability and design sensitivities for continuing alternative assessments.

I, too, have concerns regarding the budget. If an "anytime return to earth" capability (escape as compared to safe haven) is provided, those associated costs could consume a large portion of the program funds. Prior to the Challenger accident we had baselined safe haven, but that has been reviewed by the Engineering and Operations Safety Panel with the recommendation to the program manager to provide an escape capability. Furthermore, there are new demands and requirements which are being placed upon EVA. A new, high pressure suit development program could consume a significant portion of the development budget. A new power system to increase the power capability over past programs must be developed. These represent some of the budget threats, and of course, there are many others.

The basic configuration has been under review. A Critical Evaluation Task Force (CETF) headed by Ray Hook of Langley, was established in August to critically evaluate the current baseline configuration for optional designs and assembly sequences. This was evaluated in conjunction with the loss of the Challenger and bringing orbiter 105 on-line, and fitting the Space Station into the revised mission model. The task force focused on four areas: transportation limitations, the substantial EVA requirements, adequacy of the safe haven concept, and adequacy of early scientific utilization. For that purpose there were seven teams established: Transportation, EVA, resource assessment, configuration, users, cost, and safety. This activity was completed in mid-September, at which time I was briefed on the task force findings. As a result, greater reliance will be placed upon robotics to relieve the EVA load.

ASAP Recommendations:

"NASA should determine possible means to alleviate the payload bay interface environment and design requirements (vibration, accelerations, loads) which drive some of the Space Station element and 'user' designs."

Other ASAP References to Environmental Requirements:

Fact-finding Results of Calendar Year 1985.

Page 58. "c. . . . it may be worth the effort to alleviate the ascent environment requirements which drive much of the design for the Space Station equipment and 'user' hardware."

NASA Response:

NASA is well aware of the stringent design requirements placed on the Shuttle payloads for aerodynamic flight hardening of STS equipment for the ascent and entry phases. The Space Station operational environment is relatively benign by comparison. These facts are being taken into account in design of the Space Station hardware. However, since the STS is our only means of transportation to and from orbit, the Space Station Program will necessarily design for the ascent and entry environments.

ASAP Recommendations:

"NASA should establish a small team composed of current and retired NASA/contractor persons who have first-hand knowledge of the early activities (1972-1976) on the Space Shuttle program. The team should define the 'lessons' that can be 'learned' in both management and technical areas, including the real possibility of using today's technology to meet Space Station needs."

Other ASAP References to Lessons Learned/Technology:

1. Executive Summary. Space Station. Page 5. "The technologies needed to produce and deploy the Space Station are essentially in-hand (relatively little 'new technology' is required compared to the STS Program)."

2. Fact-finding Results of Calendar Year 1985

a. Page 58. "d. Since there are many similarities between the STS and Space Station programs, looking into the 'lessons learned' relating to the early days of the Shuttle might better define Space Station actions to preclude missteps."

NASA Response:

NASA agrees with the Panel's recommendation to establish a small team to define the "lessons" that can be "learned" from early Space Shuttle activities and that could be applied to Space Station needs. A team of individuals who have first hand knowledge of early space shuttle activities and who have remained current in today's technology, will be assembled.

NASA feels that the present technology base needs to be expanded to meet the demanding challenges set forth for the Space Station Program by the President and by Congress. New technology thrusts have been initiated by NASA to anticipate the final requirements to be established for the initial orbital capability (IOC) station. In all, 14 disciplines are defined in the Space Station Advanced Development Program. Personnel in each area have been asked to develop specific hardware or software products that contribute to a better understanding of which high-leverage technologies will be able to meet the technical, cost, and schedule constraints associated with their inclusion in the development phase.

For example, the anticipated high power demand at IOC and beyond compels NASA to develop solar-dynamic technology for more efficient power generation. The presidential directive for a permanently manned presence in space demands new technology in environmental control and life support systems (ECLSS) and in extravehicular activities (EVA), such as a space-based suit. The Congressional mandate to NASA to use the Space Station Program to advance the field of automation and robotics in space requires that new technology be devised and developed. The growth and evolution goals set for the Space Station Program dictate new developments in all fields of spacecraft systems, including structures, thermal control, materials, power transfer, and fluid management.

3. "Space Junk", Executive Summary, page 5:

ASAP Comment:

"Efforts to resolve this issue internationally must be intensified before it moves from the concern to the problem condition. Any solution must consider not only the large trackable units but the small debris that represents an unavoidable collision hazard. The Panel would urge NASA through appropriate channels to establish an international consideration of this issue before it becomes a critical problem."

NASA Response:

1. The Panel's observation regarding space debris is proper. Where measured, the hazard from small man-made debris (less than one centimeter) is either greater than or comparable to, depending upon particle size, the hazard created by the natural debris environment. For particle sizes larger than one centimeter, the hazard from the man-made debris, to the extent to which we have been able to define it, is an order of magnitude greater than the natural environment. A safety problem clearly exists which must be resolved either through preventive design measures such as shields, also a costly item, or by hazard avoidance through the minimization of debris generation. The hazard minimization route is normally preferred, and the most effective technique would be through international cooperative efforts as the Panel suggests. Hazard detection means also constitute a potential part of the safety activity which requires further examination.

2. NASA is expediting work in this area. There are significant activities underway to address both the policy issues and the technical issues.

3. Prior to the establishment of or participation in any international forum, a U.S. policy should first be established. In addition to NASA, other federal organizations are involved, including the Air Force, Strategic Defense Initiative Organization Office (SDIO), Federal Communications Commission (FCC), National Oceanic and Atmospheric Administration (NOAA), Department of Transportation (DOT), International Telecommunication Union (ITU), and National Telecommunications and Information Administration (NTIA). We are working closely with the SDIO who has concerns about the problem. This is a critical subject which involves the SDI

programs and cost implications to NASA programs to implement.

4. Preceding any establishment of a national policy must be the establishment of a NASA policy. The Headquarters Office of Space Flight is presently the NASA organization focusing on space debris. They are working in conjunction with the Safety, Reliability, Quality Assurance, and Maintainability Office which has policy and standards responsibilities. An Orbital Debris Working Group (ODWG), chaired by Lee Tilton, Code MT, has been established with membership from the Headquarters program offices, the SRQM Office, and the International Affairs Office. Frequent meetings are being held to prepare an integrated technical plan and to develop a NASA policy position. JSC has the lead role in preparation of the technical plan. The plan and the policy position are scheduled for completion in January 1987 and will be followed by a presentation to senior management.

5. When the NASA policy position is in place, we anticipate increased efforts with the aforementioned agencies. Some activities have already commenced. NASA and the State Department's Bureau of Advanced Technology have held discussions regarding the international efforts. They have transmitted a paper entitled "Space Debris: A Policy Discussion Paper" for our critique. We would look to the State Department to take the lead in the establishment of an international forum. Mr. Don Kessler, JSC, has delivered papers to COSPAR, an organization providing an international technical, rather than governmental, forum. We have been working with the Air Force, who is examining sensors and warning devices as well as debris bumpers. NASA funds are being expended at the level of approximately one million dollars per year. The Air Force has also committed additional funds. A memorandum to define areas of cooperation between the two organizations is being discussed.

6. NASA has already taken some steps to ensure that space debris generated in orbital operations is minimized. For example, stages in orbit are vented rather than allowing pressure build-up to tank failure. The effects of debris on the Space Station operation and design are being studied under the direction of a Configuration and Analysis Panel, chaired by Dr. George Strouhal, JSC. This panel has a Space Station Natural Environment Design Criteria Working Group chaired by Dr. George Fichtl, Chief of the Atmospheric Science Division of MSFC. The

"Natural Environment Design Criteria Definitions" has been baselined to JSC 30000 as JSC 30425. It includes the meteoroid and debris environments.

7. The Space Station Program is baselining meteoroid design criteria and is being worked under CR number BB 000123. The Program Definition Requirements Document, section 3, is being updated per that change request. The goal presently proposed is 0.97 probability for "no penetration" of the habitable module element over a 10-year lifetime.

8. The Air Force Scientific Advisory Board has formed an ad hoc committee on space debris, chaired by Dr. Carl Bostrom of Johns Hopkins University. His committee is studying all aspects of the problem and is in the process of preparing a report on their activity. They appear to be concentrating on protection technology and are concerned with definition of the debris environment. The ground based radar systems are limited to 10 centimeters. A Shuttle flight experiment has been proposed by JSC to further refine the debris environment.

9. Space Debris is of growing concern also to astronomers. Dr. Arthur Hoag, Director of the Lowell Observatory, published a letter in the September 1986 issue of Sky & Telescope magazine which expressed the concerns exhibited by the science community. The article notes that the debris increased from 5,600 objects (4 inches and up) in 1985 to 5,900 in 1986 over an 8-month period, a sizeable increase in a short period. Dr. Michael M. Shara and Dr. Mark D. Johnston wrote an article entitled "Artificial Earth Satellites Crossing the Fields of View of, and Colliding with, Orbiting Space Telescopes," for Publications of the Astronomical Society of the Pacific, August 1986, page 814. The authors concluded that debris will cross the Hubble Space Telescope's (HST) field of view with "distressingly high brightness and frequencies." The Faint Objective Camera and the Wide-Field Planetary Camera are science instruments which will be affected. They calculated a 1% probability of the HST being "destroyed" by a fragment greater than 10 centimeters during a 17-year mission. The authors point out that even greater susceptibilities exist for future space telescopes which are anticipated to have larger apertures and cross sections. There is interest by the scientific community in participating in the preparation of policy.

10. Again, we would like to assure the Panel that NASA recognizes both the seriousness and the criticality of the "space junk" issue. The NASA policy position and technical plan will be forwarded to the Panel under separate cover as soon as they are finalized.

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

DRAFT

Mr. Joseph Sutter
Chairman
Aerospace Safety Advisory Panel
9311 Fauntleroy Way
Seattle, WA 98131

Dear Joe:

The third and the final NASA response to the ASAP's 1985 Annual Report is provided in the enclosure. This response pertains to recommendations and issues regarding the Space Transportation System (STS). It is grouped into the following five parts: Orbiter, propulsion, shuttle operations, payload interface standardization, and Shuttle Centaur.

After considerable technical and managerial evaluations, as a result of the tragic Challenger accident, I am confident that NASA is taking appropriate measures to return the STS to a safe flight status. On July 14, 1986, I reported to President Reagan on NASA's implementation of each of the Presidential Commission's recommendations. That process is now under way. I would welcome any thoughts and recommendations which the Panel may have regarding the program as you undertake your reviews and deliberations.

Sincerely,

James C. Fletcher
Administrator

Enclosure

FINAL RESPONSE TO 1985 ASAP REPORT

I. ORBITER

A. Orbiter Structural Life Certification

1. ASAP Recommendations: "An abbreviated conservative analysis should be documented to fulfill the certification program." (p. 7)

   NASA Response: The fracture/fatigue analysis for LI 36, the wing/mod fuselage/aft fuselage structure has been deferred to FY 1988 due to budget constraints in FY 1986. NASA plans to conduct and document the required analysis in FY 1988. This will complete the structural article life certification.

2. Fact-Finding Results Concerning Structural Certification: "Orbiter Structural Adequacy and Certification Program." (p. 33)

   a. ASAP Comment: "The last remaining wing root fatigue and fracture analysis has been started, but will not be completed due to lack of funding at this time. ... However, in order to have a complete structural life certification program, a short-cut analysis should be made and documented." (pp. 33, 34)

      NASA Response: Fatigue life assessment and certification will be completed in 1988.

   b. ASAP Comment: "However, it should be noted that a loads calibration program will not be conducted on the Orbiter wing, but may be required if the flight results are questionable." (p. 35)

      NASA Response: NASA plans to conduct a loads calibration program on the OV-102 wing prior to its next flight.

   c. ASAP Comment: "Other structural components, e.g., the crew module, will not be well documented." (p. 35)

      NASA Response: The crew module is contained internally within the Orbiter forward fuselage and as such is protected by the forward fuselage structure. Accordingly, primary emphasis has been placed on structural certification and documentation of the forward fuselage assembly.

d. ASAP Comment: "These modifications should be the end of any required wing mods." (p. 36)

NASA Response: Unless other mods are found to be required as a result of 6.0 loads/stress analysis or instrumented OV-102 flight test, no further changes are planned.

B. Orbiter Structural Adequacy: "ASKA 6" Loads/Stress Cycle Program

ASAP Recommendations: "The Panel agrees with the arbitrary force approach taken at this time. However, the primary load path structure and thermal protection system analysis should be a stand alone report, fully documented and referenced even if the September 30, 1987, end date slips. In addition, it is felt that an operating restriction report and strength summary (external loads and vehicle stress) report for each Orbiter should be prepared in order to have quick access to information for making future decisions." (p. 7)

NASA Response: Stand alone reports will be issued at the conclusion of the 6.0 Loads/Stress cycle. Reports will be issued for the primary structure, the tile system and the leading edge structural system.

The operating restrictions for each Orbiter are contained in JSC Document 08934, "Shuttle Operational Data Book, Volume 1, Shuttle Systems Performance and Constraints Data."

The Orbiter loads are summarized in Rockwell Document SD 73-SH-0069-2D, "Structural Design Loads Data Book, Volume 2-Orbiter Structural Loads." This document will be updated to reflect the 6.0 Loads/Stress cycle.

Post 6.0 loads/stress analyses activities include a task to provide a strength summary and operating restrictions report.

C. Redlines and Modifications

ASAP Recommendations: "In order to provide 85 percent launch probability redlines, the (wing) modifications should be made, even if slightly conservative, in some structural areas. Redlines on OV-103 and OV-104 should be specifically examined and changed as required." (p. 8)

NASA Response: Wing Mod Group Numbers 1, 2 and 3 will have been installed on each of the Orbiter vehicles as required prior to each vehicle's return to flight. The launch redlines will be revised as required for all vehicles.

D. Orbiter Avionics and Software

1. ASAP Recommendations: "NASA must monitor this most carefully since applications software can be very expensive to change and retest. Discipline with regard to the new computer codes may be more difficult to implement than management thinks ... it was tried on the Apollo program with little or no success. The wisdom of procuring one new computer each year may well lead to the same problem with spares found throughout the LRU program, and deserves additional attention, especially with increasing flight rate and the use of "new" computers." (p. 8)

   NASA Response: All changes to flight software will have to be approved by a Level II Board (Orbiter Avionics Software Control Board).

2. Fact-Finding Results:

   a. Mass Memory Units

      ASAP Comment: "This load can be, theoretically, accomplished from the ground but the process is slow and has never actually been tried. For a mission abort, the MMU must be used to load the entry program and is, therefore, a critical flight-safety item." (p. 37) ... "The Panel supports the upgrade. However, the cost and schedule (18 months to two years) require NASA's continuing attention." (p. 37)

      NASA Response: The mass memory unit upgrade program was put on an indefinite hold due to budget constraints.

   b. Central Processor/Input Output Units

      ASAP Comment: "Although IBM would, of course, continue to provide logistic support for the old shuttle computers by keeping a special line open, NASA would be the only customer and the cost to NASA could be unreasonable." (p. 37) ... The panel "questions the adequacy of this decision (to buy 24 flight and 6 non-flight computers) since the lack of spares has always been a significant problem." (p. 39)

      NASA Response: NASA is buying 26 flight general purpose computers (5 GPC's each for 4

Orbiters, and 6 spare GPC's). Additional spares will be ordered when sufficient data is available to predict attrition rate. The procurement of old GPC's was cancelled when the upgraded GPC was approved. There are adequate spare old GPC's in the present inventory.

c. Inertial Measurement Units

ASAP Comment: "The new instruments are lighter -- 120 pounds versus 175 pounds -- and they use less power." (p. 39)

NASA Response: The new IMU's will use more power than the present units.

E. Brakes and Nose-wheel Steering

1. ASAP Recommendations: "Standard use of nose-wheel steering is recommended, regardless of the type of brakes. The system performance should also be analyzed to permit increasing nose-wheel steering authority, as much as practicable, in order to maximize crosswind landing capability. The carbon brake design should be pursued as quickly as possible to replace current materials. The resulting configuration should provide manifold improvement in Orbiter landing ground roll control and stopping reliability. Further, the Panel is still hopeful that NASA will seek practical means of reducing Orbiter landing speed." (p. 9)

NASA Response: Standard use of nose-wheel steering has been adopted and demonstrated on landing at Edwards AFB. It is estimated that the flight qualified carbon brakes will be available by the third quarter of CY 1988. The design requirement for the carbon brakes is 82 million ft-lbs capability versus the 55.5 million ft-lbs capability for the existing beryllium brakes. We have examined means to lower the Orbiter landing speed. However, the modifications required to obtain significant reductions in speed would be major in nature and are not considered to be practical at this stage of the program.

2. Fact-Finding Results Concerning Brakes and Nose-wheel Steering

a. ASAP Comment: "However, 9 degrees maximum may not be enough. In the usual case, crosswinds are never steady in speed or direction ... with these considerations it would seem that the maximum nose wheel steering angle ought to be increased to 15-20 degrees to deal with high crosswinds, blown tires, inadvertent departure from the hard-surface runway, or a case where drift or skid exceeds the angular limits of the nose wheel. Will the nose wheel steering system allow for free-castoring if it goes to a hardover position, that is, a fail-safe, fail-operational condition?" (p. 40)

NASA Response: The Orbiter crosswind capability has been evaluated in simulations, and the nine degree limit has been found adequate to 20 knots with one blown tire. The system recovers in the castor mode from a hard over condition.

b. ASAP Comment: "There is concern by the STS management about the availability of resources to support the development of the carbon brakes." (p. 41)

NASA Response: Since the original concern, adquate resources (approximately $9 million) have been budgeted to fund development of the carbon brakes.

F. "(4) Landing Handling Qualities"

ASAP Comment: " ... it would behoove NASA to undertake such a research program (i.e. control augmentation devices or surfaces) with the view of furnishing timely information for future designs of the shuttle type, including possible flight tests of a research-type vehicle at either Ames or Langley Research Centers." (p. 41)

NASA Response: NASA has been funding research into advanced vehicles at the rate of approximately $1M per year. This activity is being conducted primarily at the Langley Research Center's Space Systems Division. The technical staff has published papers on the results of their studies.[1]

[1] Powell and Freeman, "Application of a Tip-Fin Controller to the Shuttle Orbiter for Improved yaw Control," Journal of Guidance, July-August 1982.

Powell and Freeman, "Aerodynamic Control of the Space Shuttle Orbiter with Tip-Fin Controllers," Journal of Spacecraft, Sept.-Oct. 1985.

Wilhite, Powell, Naftel, Phillips, "The Future Space Transportation Systems (FSTS) Study, 'Booster and Orbiter Configurations'," Astronautics and Aeronautics, June 1983.

NASA is currently involved with high-level trade studies of fundamental approaches to future space transportation concepts. More detailed studies of performance, payload capabilities, costs, etc. for the future concepts are to be undertaken. The hypersonic and landing characteristics are clearly two parameters of paramount importance to us, and these will be examined in great depth as the study activity progresses.

G. "(5) Automation"

ASAP Comment: "Automated landings, while still in the program, have not been demonstrated and are not in favor with the current pilot astronauts. They question the system's reliability and prefer a "hands-on" landing capability. However, it would appear that since landings at KSC are deemed mandatory to reduce the turnaround times between missions, the use of their automated system might well be needed to assure meeting the flights-per-year goal. An incongruity appears here in that the launch and ascent portion of the mission is already fully automated and been found to be extremely reliable throughout. The question that arises is: if the flight system for ascent is relied upon, then why not the flight systems for landing?" (pp. 41, 42)

NASA Response: The automated landing system for the Orbiter is available if needed but has not been demonstrated in flight as the panel observes. I believe, however, that a dependence on this system in order to increase the flight rate or to reduce the turnaround time should not be considered verified for routine operational use. The Shuttle Training Aircraft's (STA) activities have not demonstrated either consistent nor acceptable touchdown parameters while operating in the automatic mode. It has revealed, however, a limitation of the landing software to compensate for the ever changing and unpredictable environmental conditions, such as wind shears, high winds, etc., through which the Orbiter must fly. STA training with flight crews has shown that the astronaut pilot can make consistently better touchdowns using the "hands-on" operational mode. The added training time requirements for automatic landings would significantly increase the crew's training time because flight rules require that the crew be able to take over from the automatic mode after unplanned upsets, systems failures, or loss of control. Some of these take-over conditions can be verified in the Shuttle Mission Simulator (SMS), some in the STA; others, however, cannot be accurately demonstrated nor practiced. Our crews in training routinely fly "hands-on" approaches to touch down at facilities and runways without a microwave landing system (MLS). The MLS is required for an automatic landing. Any additional landing aid improves the crew's performance and confidence. We believe, based on NASA's success rate, our desire to maximize crew and training team capability, and to minimize the risk that we should not consider automatic landings as a factor to increase flight rate or turnaround capability.

H. Fuel Cells

Fact-Finding Results

ASAP Comment: "The bank of cells is fully redundant in a come-home emergency sense, but the mission power loads are high enough that there is not complete redundancy in a mission-power sense. This subject is worthy of review to assure the design of these accessories is, in fact, conservative." (p. 33)

NASA Response: The Fuel Cell Powerplant (FCP) improvement introduced during the flight program increased the number of cells from 64 to 96 in each of the three units. The 50% increase can provide more power for critical functions in the event of one or two failures. A power fault tolerance study now under way will determine the new margins for both ascent and entry. In addition, a new upgrade to be ready for flight resumption will improve reliability and safety. The changes include the elimination of end-cell heaters, which had numerous electrical components and the risk of a fail-on condition, and an expanded diagnostic capability to speed failure detection and isolation.

II. PROPULSION

A. Space Shuttle Main Engines (SSME)

1. ASAP Recommendations: "The recertification approach selected by NASA permits different parts of the engine to be 'certified' for different flight times. However, since most of the Phase II turbopump component improvements really only address degradation rates of critical components under nominal mission environments rather than increased stress level margins (the exceptions are the decreased High Pressure Fuel Turbine discharge temperatures -- 100° and a 7000 RPM improvement in synchronous whirl margin on the oxidizer turbopump), the Panel recommends that the engine be operated at power levels above 104% of Rated Power Level (RPL) only when mandatory. Also, when engine operation above 104% is necessary, the power level selected be only the value required for the particular mission and not taken all the way to 109% except when mandatory.

"The Phase II development and demonstration program should provide a data base for the modified turbopumps which can be used to estimate new Mean-Time-Before-Replacement criteria for the turbo-machinery. The hardware necessary to support this replacement rate should be made available in order to maintain the engine's new certification status and protect flight safety margins.

"We further recommend that the "precursor" (future) program improvements be supported at a level such that they can in fact be incorporated as soon as possible into the flight engines. In the long run, such expenditures will be cost effective as they result in more reliable flight engines with lower maintenance costs and a higher availability factor." (p. 11)

NASA Response: A power level of 104% RPL has been baselined (not to be exceeded except in emergency) by program direction.

New MTBR criteria have been established, and hardware requirements are covered by the proposed FY 1988 budget.

The precursor program will have to be delayed until the design and certification of critical items required for the first flight are accomplished. At that time (mid to-late 1988), NASA hopes to accomplish the testing of the precursor candidates.

2. Fact-Finding Results: "b. Space Shuttle Main Engine"

a. ASAP Comment: "Funding constraints in 1984, and continuing in 1985 and for the foreseeable future, have revised the planned program. . . . The Phase III part of the original program was eliminated and replaced by several other program elements. One of these, labeled Phase II-Plus, will develop and certify a new hot-gas manifold structure." (p. 42)

NASA Response: The program has been fully integrated and the 2-duct hot gas manifold (2+ program) will be certified along with the alternate high pressure turbopump in the early 1990's.

b. ASAP Comment: "Beyond these defined but limited tasks to improve known low-margin areas of the existing engine design, there is a new product improvement activity getting under way." (p. 43)

NASA Response: The alternate turbopump greatly improves the safety margin of the turbopump. This is achieved in part by increasing the margin of key components (heavier shaft). Use of new materials (single crystal turbine blades), and incorporation of instrumentation to provide data on turbopump health status.

c. ASAP Comment: ". . . component life limitations still exist in these areas and will continue to present replacement problems. Therefore, engine use at 109% of rated thrust should still be tightly constrained." (p. 44)

NASA Response: The 109% of rated power level capability is planned for use in Shuttle flights launched from the Vandenberg AFB site when it is reactivated. The 109% is required for early Air Force missions and such flights are not considered "routine." Until then 109% power level will be tightly constrained.

d. ASAP Comment: "However, the certification ground rules which permit replacements of various components such as turbopumps or blades, etc., during test series result in a somewhat questionable data base regarding true engine 'configuration' operating margins and valid Mean-Time-Between-Replacement values." (pp. 44, 45)

NASA Response: The quality of the pump design has created the program requirement to modify certification ground rules such that replacement of components is permissible prior to completion of the engine's rated life. This has been contrary to NASA's desires for a "clean" certification program, and consequently we approved in August 1986 the alternate pump program to provide a new, longer life pump with much higher safety margins. The desirable goal would be to perform limit testing to show margin, and this is under consideration. The philosophy, which has been adopted by the program, is to test for a given number of cycles and replace the flight motors after half of those cycles have been expended. That testing has revealed design deficiencies, and hence provision has been made for the procurement of additional pumps needed to maintain a safe operating factor on the low lifetime hardware. The same test margin for life deficient components is used as for the engine as a system. Hence, the impact to NASA is one of costs, through frequent component replacements, rather than one of safety.

e. ASAP Comment: "However, unless the new hardware is made available to support a more conservative Mean-Time-Before-Replacement schedule on the critical components currently showing wide scatter in lifetime, the "cannibalization" and "parts mixing" which now go on will seriously limit the value and effectiveness of this facility." (p. 45)

NASA Response: This was accomplished in the 1986-2 POP cycle.

B. Solid Rocket Boosters

1. ASAP Recommendations: "The Solid Rocket Booster holddown bolt calibration tests should be carefully examined at this time to aid in obtaining meaningful final test results. If the calibrated test results differ from that used in the Cycle-III analysis then the pre-launch and lift-off loads for the External Tank and Solid Rocket Booster will be incorrect. This could cause serious problems in meeting launch requirements." (p. 13)

NASA Response: The following provides a clarification of issues raised in the recommendations above:

a. The holddown bolts are load calibrated off-site before being installed in the holddown post. No problem exists with these strain gauges or with loads data accuracy of the holddown bolt. However, accurate bolt loads do not provide sufficient data for assessing SRB aft skirt and aft SRM segment loads experienced during SSME thrust buildup and pad abort; neither of the post loads provides data necessary to determine SRB/holddown post load interface initial conditions at the time of SRB pad release. These data are obtained from strain gauges located on the launch pad holddown posts; to date, calibration attempts have not yielded the desired accuracy.

b. The purpose of calibrating the holddown post strain gauges is to obtain accurate axial and lateral measured loads data for the transient events of SSME thrust buildup through vehicle release and on-pad shutdown to compare with design loads criteria. The calibration results are not used in the analyses in developing design loads or verification loads criteria.

As mentioned in item (a), attempts have been made to calibrate the holddown posts with sufficient accuracy to assess critical loads but without success. The posts were calibrated at the VAFB launch site in March 1985 by applying uniaxial loads to calibrate the strain gauges. Simultaneous lateral and axial loads were then applied to verify that the gauges would provide accurate data for loads simulating SSME thrust buildup. The gauges did not provide the desired accuracy. Subsequent to the VAFB calibration tests, a single post calibration test was conducted at KSC in the Launch Equipment Test Facility (LETF) with strains installed at different locations on the post than in the VAFB tests. This test was also unsuccessful. To date the post calibration objective has not been satisfied; however, the holddown post (HDP) strain calibration technique will be developed at KSC and then applied at VAFB. The HDP model used in the cycle-III analysis will then be compared with the measured calibration data.

2. ASAP Recommendations: "Continued analysis and further studies have to be conducted in order to fully understand the failure mode. Additional studies should continue to evaluate membrane/transition layups and coupon specimens. Until the issue can be resolved with a high level of

confidence, the Panel believes the FWC SRB's should not be used for STS launch. The Panel would like to be kept informed of the analysis results and of these upcoming tests." (p. 13)

Additional ASAP Comments Regarding SRB Structural Integrity

ASAP Comment: "Executive Summary" -- The ASAP notes a particular concern in the 'Executive Summary' with structural strength of the Filament Wound Case (FWC) for the uncertainty of the Solid Rocket Boosters (SRB's). Tests and analyses to date leave considerable questions as to the strength margins of safety in the transition areas between case segments. Until the issue can be resolved with a high level of confidence, the Panel believes the FWC SRB's should not be used for STS launch (and certainly not for the first launch from VLS)." (p. 3)

NASA Response: Coupon tests of the FWC transition have been completed utilizing specimens from the failed STA-2A test article, segments from the static fired DM-6 and DM-7 motors and from tag end mirror image transition sections wound in conjunction with VLS-3 aft segments. The failure mode of the coupons was compared to the failure mode of the full scale article by inspection, with good correlation. Detailed analytical models were developed of the coupon and the full scale segment transition. From these analytical models, critical stresses which support the failure theory and strength criteria were identified and also correlated to the measured failure load of the STA-2A test article. It is agreed that certification of the FWC for flight cannot be completed until further full scale tests which verify the structural margin are completed. During the FWC 140% compressive structural load test to simulate loads at SSME ignition, the AFT skirt failed at about 130%. Methods to structurally load the FWC segments to 140% are being evaluated. A test to failure of a full scale segment is also planned for the first half of 1987.

3. Fact-Finding Results of CY 85

a. ASAP Comment: "The FWC STA-2 (Structural-Test Article) was tested for prelaunch loads and failed at 118.4% of limit load. The failure mode was not properly identified and is receiving further study." (p. 46)

NASA Response: Prior to the STA-2A test failure during the prelaunch load test, the failure mode that resulted was unknown. This was due to the lack of very detailed analytical models of the membrane to joint transition region of the case, which would have identified areas of high stress concentrations. As a result of the subsequent failure investigation, the necessary detailed analytical models were developed. Coupon tests of specimens of the transition region, cut from full scale segments were also conducted. With the good correlation between the analytical models and coupon test results, and correlation to the failed test article, the failure mode is believed to be now well understood, with failure theory and strength criteria established. Verification of this work is planned with further full scale tests.

b. ASAP Comment: "Filament wound case DM-7 firing showed that at about 80 seconds there was significant thrust oscillation. This requires further analysis..." (p. 47)

NASA Response: The cause and evaluation of the thrust oscillations observed during the DM-7 static firing has progressed but is not yet fully resolved. The oscillations, which were between 2.5 and 3 psi, are believed to have resulted from frequency coupling between an inhibitor located on the propellant face at the end of each motor segment and the case. Substantiation of this theory by analysis has not been completed due to the work load impact of the Challenger accident. The effect of this oscillation on vehicle loads was conducted and found to be enveloped by the allowance already incorporated for thrust oscillations. The value observed for DM-7, however, cannot be considered a 3 sigma value and additional static firing data is needed for further verification. Before FWC-SRM flight, at least two additional static firings will be accomplished which will allow determination of maximum values for thrust oscillation, and the effect upon flight loads can then be reassessed.

c. ASAP Comment: "A search is under way for an insulation replacement since the use of asbestos is no longer legal. This is a real concern..."

NASA Response: Activities to eliminate the use of asbestos in Shuttle SRM materials have been under way for more than two years by JPL and Morton Thiokol (MTI). JPL has selected and evaluated in 40-lb. test motors, non-asbestos containing insulating materials and will evaluate the most promising in 48" test motors within a few months. MTI is conducting a similar program and several coordination meetings between MSFC, JPL, and MTI have been held for data comparison and planning. Results from the 48" motor tests will identify those materials for in-depth processing and bonding assessments. The overall schedule and development/quality plan for the replacement of the internal insulation and other asbestos containing materials in the shuttle SRM is being updated and is available.

C. External Tank

Fact-Finding Results

ASAP Comment: "However, any reduction in design margins must be carefully studied and understood. The possibility of shell buckling must be kept in mind..." (p. 48)

NASA Response: The above statement is true in all respects. However, there is no structural redesign planned for the ET.

III. STS OPERATIONS

A. Flight Crew Training

ASAP Recommendations: "NASA must commit the funds in a timely manner to ensure an adequately-sized fleet of training aircraft to meet the flight crew training needs, without reduction or compromise to the Orbiter flight training syllabus." (p. 10)

NASA Response: NASA agrees with the recommendation. The successful completion of modifications to a Gulfstream II aircraft in July 1986 increased the Shuttle Training Aircraft (STA) fleet to a total of three. In addition, a spare STA wing has been purchased and is undergoing modifications for scheduled availability in FY 1989. The fleet of aircraft currently budgeted will be capable of meeting the flight crew training needs over the next few years in view of the manifest reduction expected due to the Challenger accident. Plans are being formulated to purchase and modify an additional aircraft that may be available in FY 1989.

B. Logistics and Launch Processing

1. ASAP Recommendations:

a. "NASA management should monitor closely the effects of the recent reorganization at KSC to make sure that it has accelerated and simplified management of launch processing." (p. 14)

NASA Response: We are continuing to observe and evaluate the SPC's performance and the ability to accomplish launch processing operations safely and efficiently.

b. "NASA should examine the feasibility of developing data systems under management of the SPC, such as configuration management, that will centralize and augment KSC's operational launch capability." (p. 14)

NASA Response: It is NASA's intent that the SPC should be involved with the data systems for implementing configuration management and other functions to optimize launch activities.

c. "NASA should continue to give high priority to acquisition of spare parts and to upgrade the reliability (planned life) of hardware, especially items associated with the space shuttle main engine." (p. 15)

NASA Response: The POP 86-2 addressed this issue and funds an adequate supply of spares. The alternate turbopump program was awarded to Pratt & Whitney and will greatly improve the high pressure pump reliability because of increased margins in key components and the incorporation of instrumentation to provide data on turbopump health.

d. "NASA should explore whether better coordination could be achieved between those persons determining manifests for specific flights and those persons charged with launch processing. In some instances, the combination of payloads has exacerbated the launch processing sequence." (p. 15)

NASA Response: Planning and coordination are actively pursued at all NASA levels between manifesting persons and those charged with launch processing to optimize flows and at the same time satisfy customer relations.

e. "Facilities should be provided to minimize turnaround times of the Shuttle and Line Replaceable Units (LRUS).

- o Orbiter Maintenance and Refurbishment Facility (OMRF) building should be authorized.
- o LRU repair facilities should be provided at KSC for all units which can be properly and efficiently handled there." (p. 15)

NASA Response: An Orbiter Maintenance and Refurbishment Facility is currently under construction and is planned to be operational by late 1986 or early 1987. In addition an interim depot repair facility has been established offsite at KSC. This facility is operational and is currently certified to repair over 40% of the items identified for non OEM repairs (1460 items out of 3,457 total). The full up depot will be on line in 1991.

2. Fact-Finding Results: "e. Launch Sites/Vehicle Processing/Logistics"

a. "VAFB Launch Complex Development (VLS) Issues."

(1) ASAP Comment: "The Flight Readiness Firing (FRF) program will serve to resolve many remaining problems and add confidence in launch safety. Two major tasks still require resolution, namely, the system for ensuring safe burn-off of residual hydrogen in the SSME exhaust duct and the verification of actual launch mount loads on the pad, which are being pursued vigorously." (p. 49)

NASA Response: We are aware of the ASAP observation, and concur with the recommendations. During the approximate 2-year standdown resulting from 51-L, the Air Force will have the time to solve the SSME duct hydrogen burn-off problem and conduct the SRB special loads tests. This additional time will allow for more complete data reduction during test and for additional mods and tests required to assure that all problems are solved.

(2) ASAP Comment: "The Program organizational, staffing and personnel, planning, and training elements appear to be sound and providing the needed strengths to achieve program goals. The test program, including the FRF, appears thorough and one which will pay dividends in successful future launches. And, finally, the cooperative teamwork between the USAF and NASA at the VLS is highly evident and, the Panel believes, a great strength in the national space effort. There are two additional observations which the Panel would note: (1) the 7-day work week, success-oriented schedule, which carries certain risks; (2) over the long term of future launches at VLS, orderly success will depend, in large part, upon retention of a stable, experienced launch team. The Panel urges USAF consideration of a personnel assignment policy which will ensure that future capability." (p. 50)

NASA Response: This down time will also allow the Air Force to work other problems on a more leisure schedule than the success oriented 7 day/3 shifts workweek noted by the panel as a concern. We agree with the recommendation for the retention of a stable, experienced launch team. The NASA detailees are not permanent, and neither are the Air Force personnel. The government employees provide the data base and glue required to hold the contractor launch team together and assure a safe and successful launch operations process. We agree that the Air Force should review and address their personnel assignment policy as requested by the ASAP. They may decide to include more NASA involvement to ensure that safety concerns and issues are not overlooked in the future.

b. KSC Operations

(1) ASAP Comment: "Last year in its annual report the Panel noted that the Shuttle Processing Contractor (SPC) was struggling to handle the burden of work associated with each mission. Factors associated with these difficulties included: unplanned vehicle modifications, unexpected anomalies, shortage of spare parts, shortage of qualified technicians, heavy paperwork burden, planning and communication concerns, and some lack of hardware reliability. The past year has seen progress in resolving these problems but most of them are still present in some degree and will likely persist for the foreseeable future, thereby limiting the extent of "operational" status the STS is likely to achieve. Specifically:

"(a) SPC Performance. The SPC is improving its internal planning and operations through better communication within the SPC operation and with KSC and other NASA centers. Presence of SPC representatives at the centers has helped considerably. Workflow at the VAB and the pad seems under control. However, the Orbiter Processing Facility (OPF) capacity will have to be increased if the projected flight rate for 1987-1988 is to be achieved. Data systems to provide a common base of information around which to schedule the flow are still being developed, for example, all configuration management systems are outside the SPC's control and will remain so for the foreseeable future. Unplanned modifications now require only about 5% to 8% of the processing time, a considerable improvement; however, about 35% of the time is still devoted to responding to unplanned tests or change-outs resulting from flight concerns and anomalies." (p. 51)

NASA Response: SPC has made progress in improving Shuttle processing. NASA agrees that to accomplish higher flight rates, it is necessary to reduce work in the Orbiter Processing Facility. Emphasis has been made at all levels of NASA management that only essential tests, modifications and work should be performed from flight to flight. Unplanned modifications have been greatly reduced. Continued improvement in reliability of many elements of the Shuttle vehicle are necessary and being pursued in order to improve processing flow rates. Good progress to date with electronic "black box" maturity is demonstrated by the reduction from the 35% of processing formerly spent on unplanned tests and change-outs to currently about 20%.

(2) ASAP Comment: "(e) Flight rate. Given existing constraints -- hardware, spares, modifications, absence of data systems, manifesting difficulties -- the goal of 18 flights per year is not within reach at present. A more realistic goal is between 12 and 15 per year. The best composite time to date (best time at each facility, OPF, VAB, Pad) is 44 days. KSC hopes to reduce it to 35 days in the near term and, hopefully to 28 days eventually (goal). One fact is increasingly evident: sophisticated payloads result in long occupancy times in the OPF." (p. 52)

NASA Response: As a result of the 51-L accident, NASA is reviewing all resources with the goal of defining the date at which we can return to flight status and the rate at which we can fly in a reliable and safe manner. The concerns noted by the Panel are being addressed in this review.

IV. PAYLOAD INTERFACE STANDARDIZATION

ASAP Recommendations: "There will always be peculiar requirements for special payloads, but insofar as is feasible, there should be increasing effort to preparing and carrying payloads in a standardized fashion." (p. 16)

NASA Response: NASA agrees with the ASAP recommendation. The NSTS payload integration process provides a system to accommodate both complex and simple payloads. For example, two upper stage configurations have completed integration with the National Space Transportation System (NSTS). These are the PAM and IUS. Generic documentation has been generated for these upper stages, which the customer may use if his payload utilizes one of them. Because this documentation is already prepared, the customer has to provide only that information which is mission unique, thereby reducing the amount of time and effort required of the customer. These same measures will be incorporated for new upper stage configurations to facilitate the carrying of the greatest number of payloads in a standardized fashion.

V. SHUTTLE CENTAUR

ASAP Comment: "It is quite apparent that the problem of mating the successful Centaur (an unmanned design) with the manned Shuttle was underestimated by everyone. The extent of the changes to Centaur to be compatible with the redundancy and safety requirements of the manned Shuttle are such that new qualification and certification testing is required in many component and subsystem cases. This testing is occurring late in the program and may well be the most critical problem in meeting the schedule. The lateness, it turns out, is not so much a result of technical problems but rather of the initial decision to treat the Centaur as a payload, independent of the Shuttle. Much of the electronic hardware is late owing to problems with parts like the relays and in acquisition of hi-rel solid state devices (an endemic problem for small lot purchasers). This organizational posture inhibited or delayed the recognition of the magnitude of the system integration task posed by Shuttle-Centaur.

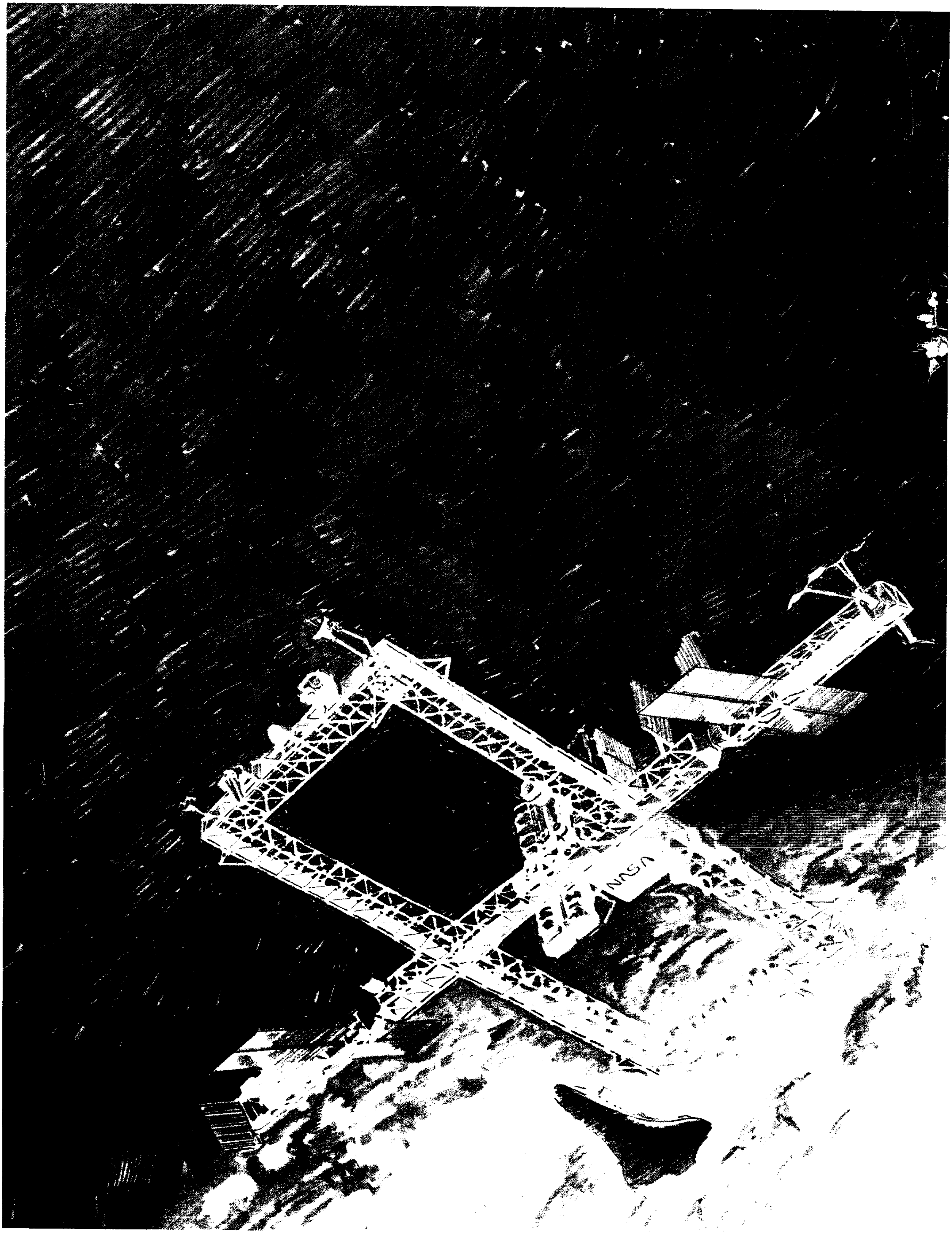
"The Panel has followed the technical progress of this program and while there are some current worries, they revolve more around the results of unfinished testing for certification rather than perceived real problems. Our concern really is: can the volume of outstanding work be done in time to meet the schedule? The program is aware of this and appropriate emphasis and the show stopper, if there is one, is the sheer magnitude of the work to be done and the lateness of component and system qualification and verification. This problem has been evidenced in previous reviews but should have subsided by now. It has not. Design changes are still being made, for instance some 20 changes in the ground launch system to shift its philosophy from fail safe to fail operational. This is a worthwhile goal and natural launch system evolution but should not burden the system -- if it does -- prior to Galileo and Ulysses deadlines.

"The system should realize that the old philosophy that technical perfection is more important than schedule with sufficient margin so that adequate technical performance can be obtained for fixed schedules. It is the difference between a development program and a transportation system. The case in point is that more than a few systems are to be verified or qualified as a result of the wet countdown on the pad. This simply does not allow any time for corrective measures should problems develop. Program management should prioritize the remaining work so that if necessary items essentially in the 'confirm for the record' class can be waived." (pp. 54-55)

NASA Response: Fully cognizant of the kinds of concerns expressed by the ASAP, I made the decision to terminate the Shuttle Centaur Program in June 1986. That was a very difficult decision to make, and it was only after a thorough review of all aspects of the program by all parties involved, including the Air Force, that the decision was made to cancel the program on the basis of overall safety considerations. The decision should not be interpreted, however, as total exclusion of the use of cryogenic stages as shuttle payloads on future flights.

A "Shuttle Centaur Alternative Trade Study" activity was initiated to examine the optional means of launching the critical planetary spacecraft: Magellan, Galileo, and Ulysses. Mr. Aller chaired an advisory group consisting of Dr. Rosen and Mr. Sade (Headquarters), Dr. Lyman (JPL), Mr. Baumann (GSFC), and Dr. Cook (DOD). This activity concluded with a presentation to me on November 4, 1986. As a consequence, NASA has baselined an IUS - STS launch capability for these payloads. Transportation of the IUS and other solid propellant motors has a proven safe track record aboard the STS.

James C. Fletcher
Administrator


NASA