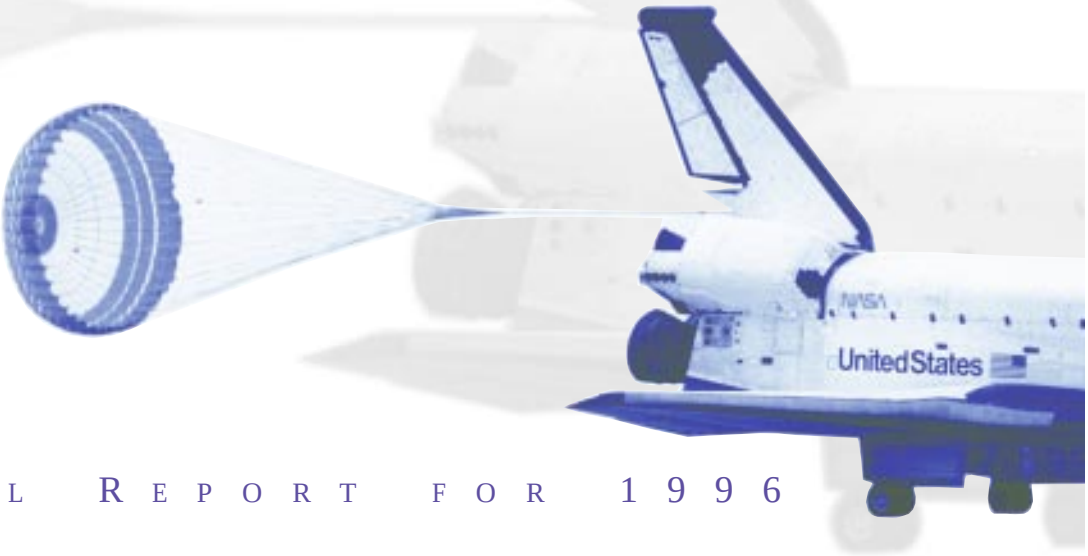
AEROSPACE SAFETY ADVISORY PANEL

National Aeronautics and
Space Administration



ANNUAL REPORT FOR 1996

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(NASA Authorization Act of 1968, Public Law 90-67, 42 U.S.C. 2477)

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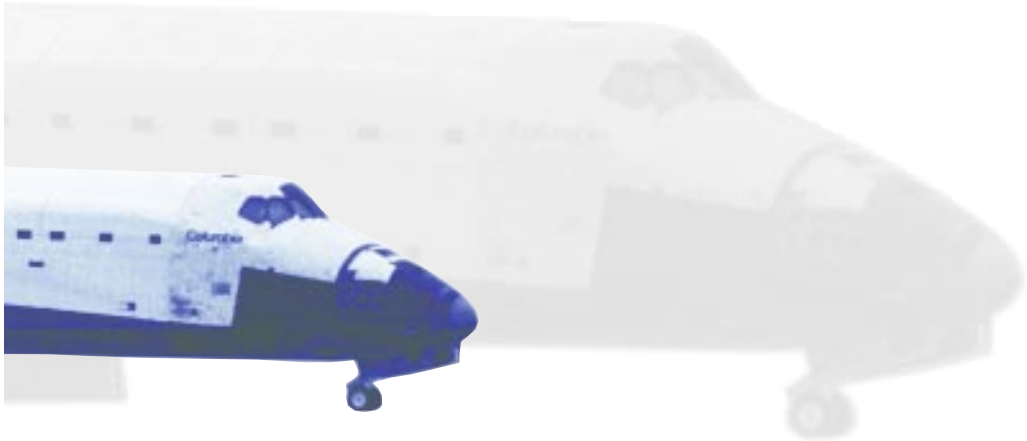

National Aeronautics and
Space Administration
Headquarters
Washington, DC 20546-0001

Reply to Attn of: Q-1

February 1997

Honorable Daniel S. Goldin
Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Mr. Goldin:

The Aerospace Safety Advisory Panel is pleased to present its annual report for calendar year 1996. This report provides findings, recommendations and supporting material regarding the Space Shuttle, the International Space Station, computer hardware/software, aeronautics programs and other NASA activities. The Panel requests that NASA respond only to Section II, "Findings and Recommendations."

This past year was one of great change for NASA, including implementation of the "Lead Center" concept, the continuation of downsizing and the initiation of the Space Flight Operations Contract (SFOC), all bold steps. At the request of the White House, you charged the Panel with the conduct of an overview study of the potential safety implications of these changes on the entire Space Shuttle operation. The report of that study was completed in November 1996.

The Panel's visits with NASA and its contractors confirmed that the commitment to "safety first" remains strongly in place. The fact that this guiding principle persists in an era of radical change is a tribute to the professionalism of all involved in the space program. Continuing this commitment to safety, however, depends heavily on the motivation and dedication of the individuals involved. Thus, as turnover and downsizing move forward, the Panel will monitor the continued support for safety in all aspects of Space Shuttle operations.

This year a major task facing NASA and its contractors will be the safe launch of the first element of the International Space Station. The Panel will review safety aspects of that program, the ongoing transition to SFOC, the impact of downsizing, manifests to support International Space Station assembly, Space Shuttle safety upgrades and the effectiveness of the communication networks within the system.

The Panel's activities this past year could not have been accomplished without the cooperation and extensive assistance of NASA and contractor personnel. The Panel takes this opportunity to thank them all.

Very truly yours,

Paul M. Johnstone
Chairman
Aerospace Safety Advisory Panel

National Aeronautics and
Space Administration

AEROSPACE SAFETY ADVISORY PANEL

ANNUAL REPORT FOR 1996

February 1997

Aerospace Safety Advisory Panel
Code Q-1
NASA Headquarters
Washington, DC 20546
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Table of Contents

Executive Summary **1**

I. Introduction **7**

II. Findings and Recommendations **13**

A. Space Shuttle Program 15
Operations / Processing 15
Orbiter 16
Space Shuttle Main Engine (SSME) 17
Reusable Solid Rocket Motor (RSRM) 18
External Tank (ET) 19
Logistics 20
B. International Space Station (ISS) 21
C. Computer Hardware / Software 23
D. Aeronautics 25
E. Other 26

III. Information in Support of Findings and Recommendations . . . **29**

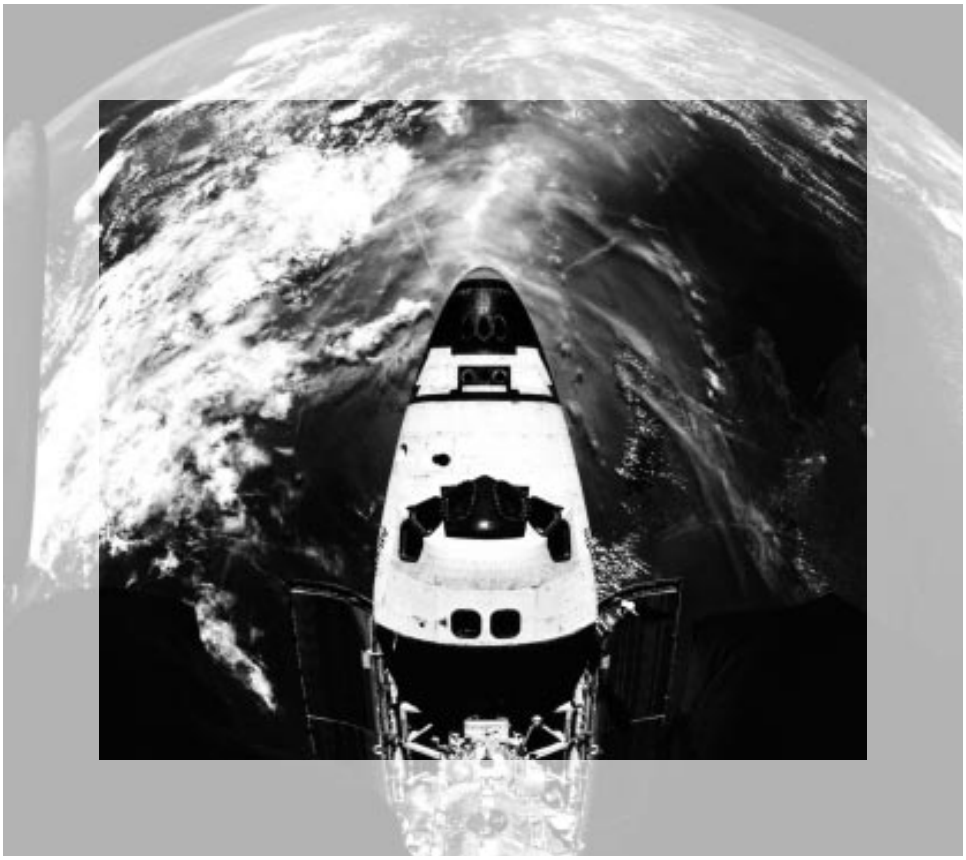
A. Space Shuttle Program 31
Operations / Processing 31
Orbiter 33
Space Shuttle Main Engine (SSME) 36
Reusable Solid Rocket Motor (RSRM) 38
External Tank (ET) 40
Logistics 42
B. International Space Station (ISS) 44
C. Computer Hardware / Software 48
D. Aeronautics 54
E. Other 56

IV. Appendices **59**

A. Aerospace Safety Advisory Panel Membership 61
B. NASA Response to February 1996 Annual Report 63
C. Aerospace Safety Advisory Panel Activities 97

Executive Summary

Executive Summary



Executive Summary

Executive Summary

Throughout the past year, the Aerospace Safety Advisory Panel (ASAP) examined the safety aspects of many of NASA's human flight programs. This resulted in 36 findings and associated recommendations covering the Space Shuttle and International Space Station programs, computer hardware/software, aeronautics, and other safety-related activities. Some of the highlights are discussed below.

The Space Shuttle program has begun the process of defining the modifications and upgrades that will enhance and prolong the viability of the system well into the next century. Once defined, these changes should be incorporated into the fleet as soon as possible. The Panel believes that any delay will have a negative impact on the opportunity for risk reduction and/or operational improvement. Maintaining the status quo might even increase risk if system reliability is decreased due to aging hardware.

One of the upgrades to the orbiter, the Multi-function Electronic Display System (MEDS), is off to a good start, but it will not reach its full potential until the information displayed takes full advantage of the capabilities of the system. The Panel believes that the Space Shuttle program should make a firm commitment to take advantage of the full range of safety and operational benefits inherent in the MEDS design.

The current Space Shuttle Main Engine (SSME) test program is designed to certify the Block II engine for use at 109% thrust level only for abort situations. As higher thrust levels reduce exposure to return-to-launch site abort modes, it would seem logical to demonstrate the highest thrust level to which the Block II engine can be certified. The Panel believes that the provision for use of the maximum capability of the SSME in an emergency situation is fully justified.

The Occupational Safety and Health Administration and state and local regulations may force obsolescence of the asbestos component and/or shutdown of the sole supplier of the asbestos-Nitrile Butadine Rubber (NBR) materials used in the Reusable Solid Rocket Motor (RSRM). Substitute materials that do not exhibit thermal and structural properties as good as, or better than, asbestos-NBR should not be flown in the RSRM. The Panel believes that NASA should apply for and be

granted whatever waivers are necessary to permit continued safe operation with what may be irreplaceable materials.

The structural design of the Super Light Weight Tank (SLWT) is a major source of concern to the Panel. Extensive discussions have improved the understanding of the design philosophy and the testing planned. It is clear that NASA recognizes the reasons for concern and has set up a rigorous series of tests of each tank leading to flight acceptance. The Panel emphasizes that these tests will be extremely critical. Safety of flight requires rigid adherence to the test processes.

While key indicators of logistics health are currently satisfactory, they are showing trends that project potential deterioration and problems. The Panel believes that it is not too early to begin detailed planning to forestall problems in the logistics area.

The International Space Station (ISS) assembly program is completely "success oriented." Schedule slips will be cumulative and have the potential to encourage shortcuts and omissions, which may very well impact safety.

While there has been great improvement in the software arena, the problems are by no means all solved. There are practices in the use of code generators that the Panel believes may be unsafe. Also, not all of the flight-critical software being developed are adequately verified and validated. While NASA has put considerable effort into defining the roles and missions of its various parts with respect to software safety, the picture is still far from clear. The Panel believes that there is still much important work to be done in this area.

I. Introduction

I. Introduction

The Aerospace Safety Advisory Panel (ASAP) maintained surveillance of much of NASA's human space flight and aeronautics programs throughout the past year. Emphasis was concentrated on those activities that have the greatest potential to impact safety. The Panel continued to monitor Space Shuttle launch activities, which included two dockings with the Russian Mir Space Station, a new time-in-space record for any U.S. astronaut, a new record length for a Space Shuttle mission, and a new duration record for any woman in space. The Panel is pleased to report that the few Space Shuttle anomalies during the past year were handled in an appropriate and professional manner.

The Panel continued to watch the transition process brought on by restructuring, downsizing, and the move to a single space flight operations contractor. The panel also began its surveillance of "third-tier contractors" and will expand that effort in 1997.

The magnitude and speed of the changes taking place within NASA also drew the interest of the White House, and in mid-year the Office of Science and Technology Policy (OSTP) on behalf of the President requested the Administrator to charge the Panel to undertake an across-the-board survey of the status of all the changes within NASA and their potential impact on the safety of Space Shuttle operations. The report, *Review of Issues Associated with Safe Operation and Management of the Space Shuttle Program* (available from the ASAP Office—Code Q-1 at NASA Headquarters), has been delivered to the Administrator and the OSTP. The Panel considers the report's recommendations to be supplementary to the findings and recommendations of this annual report. The Panel will continue its surveillance of this entire area.

A new topic section has been added to this report to emphasize the importance of computer hardware and software issues. Among these is the need for adequate and independent verification and validation of critical software.

There have been a number of changes to the makeup of the Panel this past year. Mr. Melvin Stone retired after more than 12 years of service to the Panel as a member and a consultant. Mr. Norman R. Parmet resigned after serving 14 years as a member; however, he will be retained as a consultant, thereby securing his experienced support to the Panel. Mr. Kenneth G. Englar, a Panel consultant and expert on structures, was appointed to fill the resulting vacancy. Vice Admiral

Bernard M. Kauderer, USN (Ret.), was selected as a consultant to the Panel for his vast experience in the management and operation of technically advanced, complex, and high-risk systems. A change also occurred in the NASA support function. Mr. Norman B. Starkey was selected to become the Executive Director to the Panel, and Mr. Frank L. Manning was named Technical Assistant specifically assigned to manage the coordination and publishing of the special White House study.

The balance of this report presents "Findings and Recommendations" (Section II), "Information in Support of Findings and Recommendations" (Section III), and Appendices (Section IV) describing the Panel membership, the NASA response to the February 1996 ASAP report, and a chronology of the Panel's activities during the reporting period.

II. Findings and Recommendations

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A. SPACE SHUTTLE PROGRAM

OPERATIONS/PROCESSING

Finding #1

One consequence of the implementation of the Space Flight Operations Contract (SFOC) is a reduction in opportunities for NASA personnel to maintain detailed, day-to-day work floor interfaces with their contractor counterparts both at space flight centers and major contractor facilities. This could compromise NASA's ability to carry out its assessment function.

Recommendation #1

In order to carry out its assessment role, NASA must maintain some physical presence on the work floor at the space flight centers and major contractor facilities. NASA must ensure that the people staffing these surveillance positions are and continue to be appropriately skilled, thoroughly knowledgeable about the Space Shuttle, and sufficiently experienced with both the subsystem they oversee and the total Space Shuttle system.

Finding #2

It is not clear how NASA Space Shuttle supervisory personnel will be trained and acquire the experience levels necessary to function effectively in senior management positions when the SFOC is fully implemented and the traditional learning ladder positions are staffed by the contractor.

Recommendation #2

NASA should develop and promulgate training and career paths leading to preparation and qualification as potential senior NASA Space Shuttle management.

Finding #3

No objective measure has yet been developed, or is likely possible, that can shed significant light on the impact of downsizing on the safety of Space Shuttle operations.

Recommendation #3
In the absence of a valid predictive safety metric, NASA should ensure that all functions affected by downsizing and necessary for safe operations are assigned to people who have the knowledge, skills, and time to carry them out.

Finding #4
Postflight discovery of a wrench and an equipment name plate in the forward skirt of one STS-79 Solid Rocket Booster (SRB) has heightened concern for the overall integrity of Space Shuttle processing quality assurance procedures.

Recommendation #4
NASA, in concert with the several Space Shuttle contractors, should conduct an in-depth review of Space Shuttle processing quality assurance procedures focused on creating a more formal, documented approach to accounting for tools and other material introduced to and removed from flight hardware work areas.

Finding #5
NASA plans to operate the Space Shuttle until at least 2012. This will require safety and operational upgrades to hardware, software, and logistics support.

Recommendation #5
NASA should complete Space Shuttle upgrades as soon as possible to take advantage of opportunities for earliest risk reduction and operational improvement.

Orbiter

Finding #6
The orbiter Reaction Control System (RCS) thruster valves continue to leak in flight. NASA has aggressively attacked this problem with some success. Procedural changes have improved thruster reliability, and the incidence of leakage has been reduced but not eliminated.

Recommendation #6
Continued attention must be focused on the elimination of the root causes of RCS valve leakage/failures.

Finding #7
A new gas generator valve module for the Improved Auxiliary Power Unit (IAPU) is currently entering the process of certification. When fully certified, the IAPU with this new valve is planned to be qualified for 75 hours of operation between scheduled teardowns and overhauls (in excess of 10 years at projected use rates).

Recommendation #7
Once certification is achieved for 75 hours of IAPU operation, NASA should establish a periodic inspection and test program to assure that IAPUs continue to perform in accordance with requirements throughout their service life.

Finding #8
The Space Shuttle is about to receive two major avionics upgrades—a triple redundant Global Positioning System (GPS) installation and the Multi-Function Electronic Display System (MEDS)—both of which require significant changes to the Primary Flight Software (PFS) and Backup Flight Software (BFS) systems.

Recommendation #8
The Space Shuttle program should ensure that both the GPS and MEDS software changes are thoroughly tested in the Shuttle Avionics Integration Laboratory (SAIL) using the normal and enhanced test protocols that have proved to be robust when testing major modifications.

Finding #9
The Multi-Function Electronic Display System (MEDS) in the orbiter is being implemented with display functions and formats that mimic the present electromechanical and cathode ray tube presentations. There are significant potential safety and operational benefits from enhancing the amount, type, and format of information shown on the MEDS displays.

Recommendation #9
The Space Shuttle program should commit to a significantly enhanced MEDS display as soon as possible. The MEDS advanced display working group or a similar multidisciplinary team should be tasked with identifying specific modifications and an associated timetable so that the opportunities inherent in MEDS can be realized.

SPACE SHUTTLE MAIN ENGINE (SSME)

Finding #10
The Block II SSME development program has proceeded well, except for the Alternate Turbopump Program High Pressure Fuel Turbopump (ATP HPFTP). The HPFTP has suffered significant failures in testing, which were traced to shortcomings in hardware design details. Corrective actions have been implemented on the HPFTP. Block II engine testing has resumed for this major safety improvement.

Recommendation #10
Continue the development and certification test programs as originally planned. Accumulate the specified test operating times for the modified ATP HPFTP, and employ the number of test pumps as per the original test plan.

Finding # 11

The schedule for the first flight of the Block II engine has slipped, from September 1997 to December 1997. This schedule is optimistic and contains no slack for future development problems. The schedule also requires continued availability of three test stands at the Stennis Space Center (SSC).

Recommendation #11

Maintain the full scope of the planned test programs. Assure the availability of test stand A-2 at SSC for as long as it is needed for the Block II engine test programs so that three test stands continue to be available.

Finding #12

The Block II engine will be certified for operation at 109% power level only for abort situations. Accordingly, the test program provides only limited cumulative test time at this thrust level.

Recommendation #12

After completion of the current planned Block II certification test program, conduct a certification extension test program that will demonstrate the highest thrust level for safe continuous operation achievable by the Block II configuration. This program should attempt to achieve at least the 109% power level.

REUSABLE SOLID ROCKET MOTOR (RSRM)

Finding #13

Changes in the Pressure Sensitive Adhesive (PSA) and the cleaning agent for the J-flap of the RSRM were driven by environmental regulations. The certification testing for these changes included a Flight Support Motor (FSM) firing without the application of side loads, a significant condition for RSRM field joints for which the J-flap plays a role.

Recommendation #13

Employ the application of side loads in all future RSRM FSM firings.

Finding #14

There are many material and process changes in work for the RSRM in response to both environmental regulations and obsolescence issues. A vital part of the certification program for these changes is the demonstration of the acceptability of the changes during an FSM firing. At present, FSM firings are scheduled at 2-year intervals instead of the 1-year or 18-month intervals previously used.

Recommendation #14

Considering the large number of changes in RSRM materials and processes and the

importance of proper simulation of operating conditions in any certification test program, NASA should re-evaluate its decision to have 2 years between FSM firings.

Finding #15

A substantial program effort is under way to eliminate the asbestos used in RSRM manufacture and replace it with more environmentally acceptable (i.e., "asbestos-free") materials. Although some of the materials tested to date meet specifications, they do not provide as high structural and thermal margins as the asbestos-containing materials.

Recommendation #15

To maintain flight safety, NASA should not eliminate the use of asbestos in RSRM manufacture. An environmental waiver should be obtained to continue its use in RSRM insulation, liners, inhibitors, and other motor parts in the event of future regulatory threat to the asbestos supplier.

EXTERNAL TANK (ET)

Finding #16

The 2195 aluminum-lithium alloy used in the tank walls and domes of the new Super Light Weight Tank (SLWT) has a lower fracture toughness at cryogenic temperatures than was anticipated in the design. To compensate for this potentially critical shortcoming, NASA has limited the pressure used in the full tank proof test and has recognized that acceptance of each SLWT for flight is highly dependent on far more stringent quality control of the materials and processes used to manufacture the SLWT than is required for the current external tanks.

Recommendation #16a

Assure that the acceptance tests of the 2195 material and the quality control procedures used in the manufacture of each SLWT continue to be sufficiently stringent, clearly specified, conscientiously adhered to, and their use unambiguously documented.

Recommendation #16b

The criticality of these quality control operations makes it mandatory for NASA to retain buyoff of the results of those fabrication operations and tests that are essential in determining SLWT safety.

Recommendation #16c

As quality control data on the size of flaws detected in 2195 aluminum-lithium material are collected, they should be used in an updated analysis of the SLWT structure, because it may permit the verifiable spread between flight limit stress and proof stress to be raised above that presently reported.

Logistics

Finding #17

Transition of logistics functions under Phase 1 of the Space Flight Operations Contract (SFOC) appears to be taking place smoothly. Key personnel are maintaining continuity in management techniques and processes.

Recommendation #17

Continue adherence to established systems, and make maximum use of the inherent capability of the incumbent personnel in the logistics systems.

Finding #18

Long-term projections suggest increasing cannibalization rates, component repair turnaround times, and loss of repair capability for the Space Shuttle logistics and support programs.

Recommendation #18

Take early remedial action to control this potential situation, such as maintaining sufficient spares and extending repair and overhaul capability.

Finding #19

Obsolescence of components and systems on the Space Shuttle is an increasing problem threatening critical spares availability.

Recommendation #19

Alternative components must be developed and certified, and, where necessary, systems must be redesigned to use available or adaptable units.

B. INTERNATIONAL SPACE STATION (ISS)

Finding #20

The schedules for ISS buildup are tight, and there is little, if any, schedule slack to accommodate late or unavailable hardware. Schedule and/or budget pressures could lead to deferring work to orbit or curtailing prelaunch testing.

Recommendation #20

ISS program plans for finishing and testing hardware before launch should not be compromised to meet either launch schedules or budgets.

Finding #21

The overall design philosophy for meteoroid and orbital debris (M/OD) mitigation has been agreed to, in principle, by the international partners. Much of the U.S. module shielding design is nearing completion. Nevertheless, there remains a finite probability that a penetrating collision will occur during the life of the ISS mission. The emphasis of the M/OD effort is therefore shifting to operations issues, such as caution and warning, damage control, and strategies for reaction to depressurization events.

Recommendation #21

Agreement with the international partners should be completed. Operational strategies and procedures for handling M/OD events should be developed and incorporated into ISS plans and schedules. Crew training programs to accommodate these strategies and procedures should be established.

Finding #22

The collision avoidance and maneuver process for evading meteoroids and orbital debris is complicated and not yet completely worked out for many of the scenarios likely to occur during the life of the ISS program.

Recommendation #22

The collision avoidance and maneuver process must be worked out in detail and documented in interagency memoranda and in agreements among the international partners.

Finding #23

Design of the Caution and Warning (C&W) system had been lagging behind that of other ISS systems. Priority has now been given to the system engineering effort that is required to resolve conflicting operational concepts and to finalize the design.

Recommendation #23

Continue to apply high-level system engineering attention to the expeditious resolution of C&W design philosophies and implementations.

Finding #24

The ISS has no requirement for sensing a toxic substance spill within a payload rack. ISS does require that toxic substances in payload racks be multiply contained.

Recommendation #24

The ISS should require payload providers to include, as part of their system design, detection and annunciation of any toxics they carry or could generate.

Finding #25

The ISS design does not include a requirement for a wireless communication system to maintain crew contact throughout the station. The present design requires a crew member to translate to a panel or connect a headset.

Recommendation #25

The ISS program should establish a requirement for "hands-free" communications with crew members to deal with situations such as injuries or meteorite/debris impacts in which it may be necessary to establish rapid contact.

Finding #26

The X-38 research vehicle program is a good approach for developing an ISS Crew Return Vehicle (CRV).

Recommendation #26

Any CRV resulting from the X-38 program should be capable of fulfilling the design reference missions that were developed by the Space Station Freedom program for an assured CRV.

C. COMPUTER HARDWARE/SOFTWARE

Finding #27

NASA's Agency-wide software safety policy allows projects latitude to tailor their software safety plan for safety-critical software. It does not, however, require projects to obtain center Safety and Mission Assurance (S&MA) approval of the tailored software safety plans nor does it require Verification and Validation (V&V) per se. While the software assurance standard does mention V&V, it does not require any independence of V&V for safety-critical software.

Recommendation #27a

NASA should require approval of a project's tailored software safety plan by both the center S&MA organization and by one administrative level higher than that making the request.

Recommendation #27b

NASA's software safety plan should require formal V&V of safety-critical software. Testing alone does not suffice.

Recommendation #27c

NASA should develop an explicit policy that requires independent V&V for safety-critical software.

Finding #28

NASA has put considerable effort into the reorganization of its software activities and has made significant progress. It does not yet, however, have a comprehensive, clear set of roles and responsibilities for various groups within the Agency with respect to software development, safety, V&V, and software process development.

Recommendation #28

NASA should ensure that there is a clear, universally well-understood, widely promulgated, and enforced NASA Policy Directive on the roles and responsibilities of its various organizations vis-à-vis software development and safety. Moreover, that Policy Directive should specify organizational roles and responsibilities solely on the basis of technical and administrative capability.

Finding #29

The use of the Matrix X autocode generator for ISS software can lead to serious problems if the generated code and Matrix X itself are not subjected to effective configuration control or the products are not subjected to unit-level V&V. These problems can be exacerbated if the code generated by Matrix X is modified by hand.

Recommendation #29

NASA should ensure that thorough IV&V is conducted on all code produced by Matrix X, including any hand-coded modifications made to it, and that there is adequate configuration control on the code generated by Matrix X.

Finding # 30

NASA does not have procedures in place for documenting the firmware that is placed in ISS components, particularly for devices that were grandfathered from Space Station Freedom.

Recommendation #30

NASA should ensure that all firmware code, particularly that grandfathered from Space Station Freedom, is properly documented and archived for future reference. Further, NASA should ensure that it retains the rights to such software.

Finding # 31

There has been a marked improvement in the software development process for the ISS.

Recommendation # 31

By no means have all problems been solved, and there is still much to be done. Continue the focused efforts.

D. AERONAUTICS

Finding #32

The well-planned consolidation of NASA flight research aircraft at the Dryden Flight Research Center has been put on hold by congressional mandates. This uncertain situation has prompted low morale and caused the loss of good people, which could well lead to flight safety problems.

Recommendation #32

The impasse between NASA intentions and congressional mandate must be resolved as soon as possible.

Finding #33

The fan blades on the 40' x 80' x 120' wind tunnel at the Ames Research Center developed cracks after only 2,000 hours of operation. To preclude shutting down the tunnel for the 1 year required to procure and install a new set of blades, it was decided to repair the old blades while waiting for delivery of the replacements. The repair includes wrapping the root section of the blades, which eliminates the ability to detect crack growth by visual inspection.

Recommendation #33

NASA should ensure that a suitable inspection program, including frequent checks using nondestructive evaluation methods, is implemented.

Finding #34

NASA's aeronautics research programs aimed at increasing aviation safety are having and will continue to have a significant positive impact on both military and civil flight operations. Several of these were in cooperation with other government agencies, such as the Federal Aviation Administration.

Recommendation #34

NASA should continue to pursue aeronautics research programs, particularly joint efforts with other agencies, that will increase the safety of air operations.

E. OTHER

Finding #35

The Space Shuttle program has experienced some difficulties when stable work processes were altered to counter obsolescence or meet new environmental requirements. The simultaneous change in pressure sensitive adhesive and cleaning wipe in the RSRMs to meet environmental regulations is one example.

Recommendation #35

The Space Shuttle program should not alter long-established and stable processes without defining and completing an adequate test program. If changes in stable and well-characterized safety-related hardware and processes are being driven by environmental requirements, NASA should consider seeking waivers of these requirements rather than altering a proven design.

Finding #36

While firefighting preparedness and training in NASA is generally adequate, further reductions in staffing and funding may compromise the ability to perform this vital safety function.

Recommendation #36

Continue to review firefighting at all NASA centers to ensure that funding, personnel, training, and adequacy of equipment are properly addressed.

III. Information in Support of Findings and Recommendations

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A. SPACE SHUTTLE PROGRAM

OPERATIONS/PROCESSING

Ref: Finding #1

NASA is currently involved in a transition to a Space Flight Operations Contract (SFOC) contractor and is simultaneously downsizing its work force. As a result, NASA personnel are being withdrawn from direct, "hands-on" engineering, technician, and inspection duties, initially on tasks deemed noncritical. The total responsibility for these tasks will be turned over to the SFOC contractor, United Space Alliance (USA).

The loss of many opportunities for day-to-day interactions by NASA personnel with their contractor counterparts and the actual systems will weaken a significant independent reporting path, which is only partially replaced by NASA surveillance activities. It will also remove a significant "training ground" for new NASA personnel at virtually all levels of the Space Shuttle organization.

NASA currently plans to retain a presence on the work floor and in contractor facilities. The Panel agrees with this basic approach but urges NASA to make sure that these liaison and surveillance positions are staffed with adequately trained and experienced people. This will maximize the quality of insight that NASA obtains and will maintain a "peer" relationship among NASA and contractor personnel.

Finding appropriate people for the required surveillance positions should not be difficult at this time. A problem could arise, however, with any successors to the incumbents who may not have the same depth of experience and working relationships on which to rely. The long-term maintenance of independent safety oversight will likely require NASA to develop and implement programs for critical skills retention and for the generation of direct Space Shuttle operating experience among NASA employees.

Ref: Finding #2

With the implementation of the SFOC, contractor personnel are assuming many roles and positions formerly used by NASA to train the senior managers of the future. Thus, NASA will no longer have the tools that create and maintain core Space Shuttle-related competencies in either the technical or the operational areas. While there will most certainly be a concomitant increase in the experience base of the SFOC, ultimate decision-making remains with NASA. The NASA people making these decisions must be trained and experienced. Program managers, certain engineering positions, and safety, launch, and mission control directors are typical of the many positions so affected. NASA should therefore develop and promulgate notional government career paths leading to preparation and qualification as potential senior NASA Space Shuttle managers.

Ref: Finding #3

The effect that downsizing can have on Space Shuttle flight safety has been an ongoing concern of the Panel. If the people who are downsized take with them the knowledge and expertise that have been significant contributors to Space Shuttle safety, that capability must be picked up by those who now carry out these functions. Paramount consideration must be given to assure that the necessary safety functions that these people performed have not been lost in the process of downsizing.

Not all factors that apply to the preservation of flight safety are subject to quantitative measure. Morale, thoroughness of analysis and review, and stability of policy are among these factors. These are best evaluated on a continuing and personal basis by the people who supervise or carry out the functions that have the potential for problems to arise.

While a metric for safety retention may not be feasible, there are still ways to obtain information for management decision-making. For example, interviews with the organizations affected by downsizing could show whether or not the safety functions previously performed have been satisfactorily picked up elsewhere. Such interviews could be extremely valuable in determining whether the functions, expertise, and folklore that resided with the people who have left have been satisfactorily transferred to the people who now carry the responsibility for the work that impacts flight safety.

Ref: Finding #4

The Space Shuttle fleet is aging, and the frequency of unplanned work has the potential to increase. Additional flights in support of the International Space Station (ISS) will create pressures to adhere to the schedule. Downsizing will erode the experience level of contractor workers and supervisors and cause a loss of institutional memory, especially in NASA personnel. In this environment, discipline can be easily lost unless there are well-established operating procedures on which workers and management can rely. This lack of discipline was likely a factor in the incident on

STS-79 in which a wrench was left in the forward skirt of one of the Solid Rocket Boosters.

To maintain safety in this turbulent period of transition and downsizing, formalized quality assurance procedures for tool and material control are needed. These procedures would partially compensate for a loss of experience and would minimize opportunities for error. Time invested in a disciplined approach up front would reduce time lost to rework and would enhance safety.

Ref: Finding #5

The *NASA Implementation Plan for the National Space Transportation Policy* includes flying the Space Shuttle until at least 2012. Flying the Space Shuttle until 2030 has even been discussed. If the current level of safety is to be maintained or enhanced while extending the Space Shuttle service life, system upgrades will be required. Some of these will compensate for obsolescence. Others will be needed to comply with environmental regulations. Still others will be warranted to take advantage of new technologies or better operational knowledge.

The Space Shuttle program has already begun the process of defining an upgrade program. Once identified, the upgrades should be included in the fleet as soon as possible. NASA should resist any temptation or pressure to stretch out the introduction of these enhancements. A significant opportunity for risk reduction and/or operational improvement will be lost if the planned improvements are delayed. Risk might even increase if system reliability decreased due to aging hardware.

ORBITER

Ref: Finding #6

The Reaction Control System (RCS) thruster valves are solenoid-activated, pilot-operated valves using the propellant as the working fluid. There are 76 of these valves in an orbiter ship set. The oxidizer thruster valves, in particular, have been the source of a large proportion of the in-flight anomalies experienced during recent Space Shuttle flights. There are two failure modes involved: either the thrusters leak or they do not operate at all. The malfunctions have been attributed to the oxidizer valves—specifically, the deposition of nitrates on the critical sealing surfaces within the valves. Leakage is caused by the nitrates forming between the pintle and its flat valve seat, which preclude proper seating of the pintle. Failure to operate is caused by the accumulation of the nitrates on the mating surfaces of the pilot piston and its stop. The nitrates act like an adhesive and bond the two flat mating surfaces, preventing pilot motion that would open the valve.

The potential deleterious effects of in-flight failures have been overcome by multiple redundancies in the RCS system, which permit the deactivation of the

malfunctioning thruster and the substitution of a "healthy" one. Normally, this is of little consequence but has to be avoided for rendezvous and Extra-Vehicular Activity (EVA) operations, which will greatly increase during ISS buildup and operation.

Generation of the nitrates is unavoidable and results from the chemical reactions involved in the propulsion combustion, as well as slow, long-term reactions between the oxidizer and the materials of the valve parts.

The valve design also contributes to the occurrence of failures because it relies on flat surface contact for sealing at the pintle/seat and at the piston/stop. It is an intricate assembly with small clearances. Also, the design of the pintle is such that when it seats, it traps oxidizer in the volume immediately above it, which leads to corrosion over time.

Consideration had been given to replacing the valves with a new design which would be "direct acting", that is, have the solenoid actually move the pintle directly for allowing or stopping flow. This approach was ultimately rejected because it was difficult to provide the required forces for valve operation and stay within allowable dimensions and power available. Also, the development and certification of such a valve would be very expensive.

A "tiger team" was formed to review and fix the RCS valve problems. Changes recommended included: operations improvements, better maintenance of valves, and design changes. NASA has already implemented a number of procedural steps at the Kennedy Space Center (KSC) to mitigate the deposition of nitrates. These include flushing the systems between uses, minimizing moisture intrusion, and increasing the thoroughness of filtration of the propellant during the loading of the supply tanks. Tightening the specifications to which the oxidizer is purchased (iron content is a particular concern) was considered, but it is believed that passing oxidizer through one or more molecular sieves at the launch pad prior to loading into the orbiter tanks will more effectively reduce iron and water content.

In addition to procedural changes, a study was conducted to determine whether the existing design could be modified to eliminate conditions conducive to the formation of the nitrates as well as improve the sealing effectiveness. It was found that by modifying three small parts, these objectives could be accomplished. The parts are the pintle, the pilot piston, and the valve seat. The pintle would be fluted so that when it is closed, it has paths to drain the volume above it that contained trapped oxidizer. Also, the sealing surfaces would be conical and the clearances adjusted so the pintle would be self-centering upon closure. The pilot piston sealing surface would also be conical.

The effectiveness of these proposed changes has been demonstrated in water flow tests using oversized clear plastic models of the changed parts. Tests using engineering models of the valve with the oxidizer will be conducted at White Sands in the near future. If these are successful, two flight valves will be modified to undergo a certification test program scheduled for completion in the last quarter of FY 97. This reworked

pilot-operated valve program is funded only through the certification of the test articles, and funds are not presently allocated to rework any additional flight hardware.

The programs being implemented to improve RCS valve reliability are commendable, but it is noted that the procedural changes may not eliminate the failures, although they have reduced their recent incidence. Continued emphasis should be focused on proving valve design changes, and a program should be outlined for implementation of these changes into the flight systems.

Ref: Finding #7

Once the Improved Auxiliary Power Unit (IAPU) is qualified to operate for 75 hours, its life span on an orbiter could be in excess of 10 years. This seems to be an extremely long period without the benefit of any inspection or verification that the IAPUs are meeting their performance goals. This is especially true because the units installed in the orbiters will be exposed to the corrosive effects of hydrazine during the long dormant periods when they are not flying.

Periodic visits to the shop and exploratory disassembly of the IAPUs appear appropriate to verify their performance and continued durability across this planned period. A periodic inspection and test program should be established to assure that the IAPUs continue to exhibit their desired operational characteristics across their entire life span. Such a maintenance program would also have the salutary effect of assuring that the manufacturer can maintain a core of technical skills to assure continuing technical support for the IAPU.

Ref: Finding #8

The Space Shuttle is about to receive two major avionics upgrades that involve significant changes to the Primary Flight Software (PFS) and Backup Flight Software (BFS) systems. The first of these changes to be implemented will be the Multi-Function Electronic Display System (MEDS). This is a “glass cockpit” for the orbiters, which will replace the current electromechanical instruments and cathode ray tube (CRT) displays. The second upgrade will be a triple redundant (“three string”) Global Positioning System (GPS) installation, which will replace the Tactical Air Navigation (TACAN) system for area navigation and the Microwave Scanning Beam Landing System (MSBLS) for approach and landing. GPS will also assist in on-orbit positioning.

These changes will require a new Space Shuttle software Operational Increment (OI) to support their unique features. Each of the first 25 OIs has received comprehensive testing in the Shuttle Avionics Integration Laboratory (SAIL) at the Johnson Space Center (JSC). This unique laboratory includes the characteristics of a flight simulator so that realistic crew inputs as well as prepared test scenarios can be used to validate Space Shuttle software. As experience in SAIL has been amassed, a robust test protocol has emerged that provides excellent assurance that

each successive OI can perform all of the functions it is intended to control in a valid and reliable manner.

In this time of budget pressures, personnel cutbacks, and the downsizing of facilities, there may be a temptation to curtail the admittedly costly SAIL testing of future OIs, particularly those associated with MEDS and GPS. While it is possible that the existing test protocols in SAIL are overly comprehensive, there is no evidence that a curtailed test protocol in SAIL can be effective in verifying and validating a new OI that includes a major change in capability. On the other hand, the approach to date has yielded Space Shuttle software that is largely free of major errors and safety defects. The Panel therefore believes that it would be shortsighted to reduce SAIL testing, particularly for major system changes, such as MEDS and GPS, that have extensive interactions with many other Space Shuttle subsystems.

Ref: Finding #9

MEDS is an integrated electronic display system that will replace the orbiter's electromechanical flight instruments, servo-driven status meters, and CRT displays with 11 identical full-color multifunction Liquid Crystal Displays (LCDs) in a "four string" fault tolerant architecture. The objectives of the MEDS program include improving safety, reducing aging and obsolescence problems, reducing weight and power consumption, providing for a transparent installation, and providing growth capability. The MEDS hardware consists of Multifunction Display Units, which house the normally black LCD glass, Integrated Display Processors, Analog-to-Digital Converters, and a MEDS Test Station.

MEDS in the orbiter is being implemented with display functions and formats that mimic the present electromechanical and CRT presentations. MEDS will not reach its full safety potential until the nature and quantity of information displayed are altered to take full advantage of the capabilities of the system. For example, more predictor information can be presented to the crew so that they have better anticipation of the future state of the vehicle. An advanced display working group has been formed and has begun exploring possibilities. This is a good start, but the Space Shuttle program has yet to make a firm commitment to take advantage of the full range of safety and operational benefits inherent in the MEDS design. The Panel believes that a significant opportunity for risk reduction is being delayed until a fully capable MEDS is defined and implemented.

Space Shuttle Main Engine (SSME)

Ref: Findings #10 through #12

The Block I engine entered routine use in the Shuttle Program during the current year and has performed excellently. Development of the Block II engine has been

proceeding quite well except for the Alternate Turbopump Program High Pressure Fuel Turbopump (ATP HPFTP), which has suffered a number of setbacks because of hardware failures during development testing.

The Block II engine improvements include a redesigned Low Pressure Oxidizer Turbopump (LPOTP), the Large Throat Main Combustion Chamber (LTMCC) with cast manifolds, and the ATP HPFTP. Both the LPOTP and the LTMCC have performed well during development testing. The LPOTP has met its performance requirements and demonstrated improved durability. The LTMCC has also performed well but has had difficulty meeting the specific impulse specification. Adjustments to the injector spray pattern and coolant flows are an attempt to remedy this condition.

In addition to these major new engine components, other reliability improvements are being incorporated into the Block II configuration. Among them are improved reliability pressure and temperature sensors. These should reduce the probability of sensor failures that could lead to launch aborts and/or in-flight engine shutdowns. Also improved are actuator bypass or “shuttle” valves that have been subject to galling and consequent actuator failure to move. Development and certification testing of sensors and valves have proceeded successfully and should be ready to support Block II certification without difficulty.

The ATP HPFTP development program has suffered a number of setbacks because of hardware failures during the year. After incorporating mechanical design changes to correct problems encountered during development tests in 1995, testing was resumed and was going well until late January 1996 when the ATP HPFTP suffered a significant turbine failure. Among the features that contributed to the failure were structurally inadequate second-stage turbine vane “hooks” and configuration details of the first-stage turbine blade outer gas seal, whose failure caused first-stage turbine blades to fail. The debris from this first-stage failure damaged second-stage blades.

Design changes to correct the HPFTP deficiencies were incorporated, the testing “clock” was returned to zero, and development testing restarted in May. After one unit had accumulated about 2,500 seconds of operation, it was subjected to a planned teardown inspection, during which both turbine blade airfoil and fir-tree attachment cracks were discovered. A second unit, under test at the same time, suffered a second-stage turbine blade failure, while operating at 111% power. This unit had accumulated about 3,000 seconds of operating time when this incident occurred. The loose blade caused damage to other blades of the second stage and some minor damage downstream of the turbine. Other blades of the second stage exhibited fir-tree cracks. An intensive and extensive investigation was instituted. Corrective actions involving many design changes to mechanical details to reduce stress concentration points were implemented. Cooling flow changes to reduce thermal stresses were also incorporated. Testing of the modified HPFTP configuration was started in October. The only planned significant design change not included in

the configuration in testing is a change to the cooling passage in the hollow, single crystal, second-stage blade.

The ATP HPFTP development test failures have resulted in slipping the first flight to December 1997. This is predicated on maintaining the prescribed certification and development test plans: "no problem" development and certification test programs and the ability to continue testing at the rapid pace exhibited most recently. This is highly optimistic. The schedule also depends on continued availability of the A-2 test stand at the Stennis Space Center so that three test stands are available. The A-2 test stand is planned for use in the engine testing for the Reusable Launch Vehicle program so a decision on priorities may be required in the future. In any event, it is imperative that the test plans be conducted as currently prescribed with the numbers of test specimens and operating times at specified thrust levels maintained. This includes substantial times at 109% and 111% power levels in both the development and certification programs.

The current test program is designed to certify the Block II engine for use at 109% only for abort situations. For each certification test cycle, which accumulates 5,500 seconds of operating time, about 31% is achieved at 109% power or greater. As higher thrust levels can reduce exposure to the Return-to-Launch-Site abort mode, it would be advantageous to demonstrate experimentally the highest thrust level to which the Block II engine can be certified. This could be accomplished during a certification extension test program and would define the safe, continuous operating thrust limits of the Block II engine.

REUSABLE SOLID ROCKET MOTOR (RSRM)

Ref: Findings #13 and #14

The recent experience on Space Shuttle flight STS-78 of hot gas blow-by past the J-flaps of the RSRM, which is attributed to the change of Pressure Sensitive Adhesive (PSA) and cleaning agent for the J-flap of the RSRM segment interfaces, underscores the importance of thorough testing of process and material changes and adherence to process requirements. There is some dispute about the intended function of the J-flap. The fact remains, however, that in all its use prior to the change of the PSA, it had functioned as a seal and had prevented incursion of hot combustion gases to the vicinity of the downstream capture feature "O" ring. The exact mechanism for the "blow-by" is not known at this time, but it is suspected that it occurred at RSRM ignition and may have been aided by the flexure of the RSRM joints during the ignition transient and stack "twang."

The change of the PSA and cleaning agent was certified by material property tests in the laboratory. Only the PSA was tested in a full-scale Flight Support Motor (FSM) firing. The FSM firing was with the motor in a horizontal position and did not

include applied side loads. This does not emulate the operating conditions of a flight motor, and therefore such a test does not constitute a complete verification of changes in the vicinity of the field joint.

There are considerable material and process changes in work to comply with environmental regulations or to counter obsolescence. It is therefore important that certification tests are conducted in as close to actual use conditions as possible. Certainly, during FSM firings, side loads representative of critical flight conditions should be applied.

FSM firings, which are used to certify changes in materials and processes used in the manufacture of the RSRM, are now scheduled at 2-year intervals. Formerly, they were scheduled at 1-year or, later, 18-month intervals. The change of interval was in response to budgetary pressures. Considering the number of pending changes, it would seem prudent for NASA to re-evaluate its decision to have a 2-year interval between FSM firings.

Ref: Finding #15

Recently, NASA has been concerned that OSHA and state and local regulations may force obsolescence of the asbestos component and/or shutdown of the sole source supplier of the RSRM asbestos-Nitrile Butadine Rubber (NBR) materials. To protect RSRM manufacturing capability against potential asbestos obsolescence, NASA has started an “asbestos-free” effort. The design goal of this effort is to achieve equivalent or better thermal performance than that provided by the asbestos materials, while maintaining current RSRM insulation thicknesses, so that there is no change to propellant loading/ballistic performance. After extensive screening, a Kevlar fiber-filled ethylene propylene diene monomer (KF-EPDM) formulation was selected. To date, this material has been tested in subscale motors and one static test motor (FSM-5) aft-end configuration. The latter test indicated that in the high impingement area of the aft dome, erosion of the Kevlar-filled insulation was higher than expected. Other subscale motor test results show that the Kevlar-filled material meets both thermal and structural safety factors. However, measured thermal margins were somewhat reduced from the current RSRM asbestos-NBR design. Structural margins, although within specification for the asbestos-NBR materials, were greatly reduced.

Materials that do not exhibit thermal and structural properties as good as, or better than, asbestos-NBR should not be substituted and flown in the RSRM. For example, a change in the propellant grain castable inhibitors to materials having reduced thermal and structural margins could adversely impact motor internal ballistics and durability. Although KF-EDPM is the insulation material successfully used in Castor IV motors and Titan IV Solid Rocket Motor Units (SRMUs), the latter experience cannot be extrapolated to Space Shuttle RSRMs because substantially different propellant formulations are used in the Castor IV/Titan IV SRMUs and RSRM motors. Therefore,

the test program of one development motor (PV-2) and two qualification motors (FSM-7 and FSM-8), which NASA is proposing to verify the performance of the "asbestos free" insulation materials, is inadequate. A full scale motor development and qualification test series is required.

The data base acquired by any reasonable test program would not begin to approach the presently well established data base on reliable, safe motor performance with asbestos-NBR materials. Therefore, because of the proven, unique thermal and structural properties of asbestos, its use in the RSRMs should be continued. A substantial data base exists supporting safe RSRM operations with the current motor design in which small amounts of asbestos fiber-filled NBR are used in formulations of the RSRM case, igniter, and nozzle flex boot thermal insulation, case and igniter liner and propellant grain castable inhibitors. These are safety critical insulation locations in the RSRM, and currently used materials have performed well without anomalies. Elimination of asbestos in RSRM manufacture has not been mandated to date, and it seems more prudent to request a waiver for its continued use, if necessary, than to accept the risk of jeopardizing flight safety inherent in any change.

EXTERNAL TANK (ET)

Ref: Finding #16

Fracture toughness is a significant design requirement in any structure (i.e., the structure's ability to function satisfactorily in the presence of small cracks). The design of the ET is based on the fracture toughness that the tank material has at the cryogenic temperatures it will experience in service. Because the tank proof test will be run at room temperature, the ratio of fracture toughness at cryogenic temperature to its corresponding toughness at room temperature is needed to extrapolate the proof test to the tank's in-flight operating conditions.

There is a contractual requirement that the ET structure withstand the presence of sharp cracks and other stress concentrations and that all major load-carrying structure be capable of surviving four mission load cycles in the presence of these cracks. The current Light Weight Tank, constructed of 2219 aluminum alloy, has demonstrated that it meets these design requirements. In designing the Super Light Weight Tank (SLWT), it was assumed that the empirically developed fracture toughness ratio for 2219 would also apply to the 2195 aluminum-lithium material of which the SLWT is made. In fact, however, the fracture toughness at cryogenic temperatures for 2195 has proved to be lower than assumed, particularly for the material gages used for the barrel sections of the SLWT.

The design of the SLWT limits the stresses that can be imposed on the liquid hydrogen (LH_2) tank during proof test, which is run at room temperature, to 0.955 times the flight limit (i.e., the design conditions for the tank). Furthermore, the

differential pressure across the aft dome of the LH_2 tank during proof test is limited to 38.2 psi, whereas flight design pressure is 40.0 psi. As a consequence, flight acceptance of the SLWT depends on successfully passing a series of tests consisting of:

1. Thorough inspection of raw material, using ultrasound and dye penetrant inspection methods to eliminate material with detectable flaws.
2. Rigorous testing of incoming plate and sheet to determine the fracture toughness at cryogenic temperature of that lot of material.
3. Dye penetrant inspection after forming.
4. X-ray inspection of welds, with increased attention paid to manual welds, crossing welds, and weld repairs.
5. Room temperature proof test of the tank with internal pressure in conjunction with applying external loads to the locations at which the orbiter and Solid Rocket Booster (SRB) are attached. This series of tests is used to determine the structural integrity of most of the welds and requires five different load conditions. Even so, some of the welds require additional x-ray inspection after proof test.
6. A room temperature "protoflight test" run on each tank to demonstrate stability during two critical flight conditions. One hundred fifteen percent of maximum flight loads are applied to the attach points for the orbiter and SRBs.

Successfully passing all these tests, coupled with analysis to show performance at cryogenic temperature, only demonstrates that barrel number 1 of the LH_2 tank at cryogenic temperature can accommodate stresses that may be as low as 2.9% above flight limit. This low value leaves little room for error.

Obviously, strict adherence to established procedures is required at every step of this process. Once successful, complacency cannot be tolerated in the production of subsequent tanks.

NASA is taking extra precautions to assure that errors in manufacture can be detected. For example:

1. Each sheet and plate of procured 2195 aluminum-lithium material is inspected by ultrasound at the vendor, where flaws as small as 0.047 inch can be detected, and a flaw of 0.078 inch is cause for rejection.
2. Before and after forming, the entire surface of each tank element is subjected to dye penetrant inspection, with two pairs of experienced and qualified eyes looking for flaws. Flaws as small as 0.086 inch have been shown to be detectable. Any detected flaw is cause for rejection.
3. All welds are x-rayed before proof test and selected welds after proof test. Unacceptable flaw growth is cause for weld repair and repeat of the proof test. After proof test, dye penetrant inspection is again performed in selected areas.

In addition, NASA has reviewed the quality assurance data that have been obtained on the material used to date and has found that the inspection procedures can find smaller flaws than had been used to predict fracture toughness of the SLWT structure. These data should be used in a revised analysis of the structure, because they will permit the verifiable spread between flight limit stress and proof stress to be raised above that presently reported. Better yet, there may well be enough improvement in the confidence in fracture toughness that higher tank pressure can be used in a revised proof test, thereby reducing the dependence on analysis to verify acceptance of the tank for flight.

Logistics

Ref: Findings #17 through #19

This has been a year of rather dynamic change and integration for the overall logistics functions with the advent of the Space Flight Operations Contract (SFOC). The actual integration process in the early months of Phase 1 of the SFOC appears to be proceeding smoothly, although there are still some concerns among shop floor-level personnel about permanency of employment. Management is working hard to dispel the "culture shock" of these changes. The actual process of integration of the main functions indicates that real efficiency gains can be made, and the working atmosphere appears to be very cooperative.

With respect to the actual logistics support functions, the performance appears to be generally very good. Continuity in management is providing the essential ingredient for stability. Program assessment using the principal five parameters of cannibalization, fill rates, zero balance, repair turnaround time, and pending loss of repair/spare capability projects the results to be excellent in the short term. In the long term, however, some of these parameters threaten departure from the "green" standard into "amber" and even into "red." Worries about future funding of spares/repair functions are influencing the latter category. Obsolescence concerns, especially as viewed in the 2012 or even to the 2030 time period, must be addressed more vigorously than they appear to be at present.

Obsolescence must be addressed in terms of providing more component repair and restoration capability in house, most probably by continued expansion of the NASA Shuttle Logistics Depot (NSLD) capabilities at Cocoa Beach. Where necessary, some system redesign must be contemplated in cases in which the original equipment manufacturer has terminated supply or manufacture. Obsolescence does not only concern component or unit supply, however, but also involves personnel training and skills availability. In particular, the future prospect for cannibalization is expected to worsen due partly to the backlog of repairable units awaiting action at the original equipment manufacturers and the NSLD. An unpleasant byproduct of this trend is a

noticeable increase in incidents and errors in maintenance functions as reported in a special section of the United Space Alliance's *Orbiter Logistics Supportability Assessment Report* for fiscal year 1996.

Overall, logistics systems for the Space Shuttle are managed by very competent personnel, and excellent continuity of key personnel has been achieved in the SFOC transition. Morale on the shop floor must be maintained by stability in management processes. The recruitment and retention of younger logistics personnel are essential to continue this success into the next century. Evolution of the Space Shuttle logistics system into a viable International Space Station logistics system is also contingent on achieving the foregoing.

B. INTERNATIONAL SPACE STATION (ISS)

Ref: Finding #20

Phase II of the ISS program has a relatively inflexible assembly sequence and depends on delivering the launch packages to orbit in their preplanned sequence. For example, one of the earliest launch packages is the Russian Service Module, which is needed before any subsequent stage can be launched. The development of the Russian-supplied Service Module has, however, been slipping for over a year. A launch delay of greater than 3 months will translate directly into overall ISS assembly delays. NASA has considered a contingency plan as drastic as replacing the Russian Service Module with a U.S.-built element.

Whether the ISS program elects to stay with the Russian-made Service Module or go to a U.S. alternative, the necessary design verification, test, and checkout of the module must not be compromised in an attempt to catch up on the schedule. There is precious little time on orbit to solve problems that should have been found and fixed before launch or to complete deferred work or testing. Moreover, the increased crew workload and curtailed training time available for these ad hoc operations could represent a safety problem.

Ref: Findings #21 and #22

Much has been accomplished in 1996 to mitigate the effects of meteoroids and orbital debris (M/OD) on the ISS. However, a number of issues remain.

A new model of the environment has been formulated, peer-reviewed by the scientific community and released for use. It shows that the amount of debris in the critical size range of 1 cm to 25 cm is lower than that on previous models by a factor of two. The new model is being incorporated into the BUMPER code, which is used to assess the vulnerability of various modules, taking into account the orbits, the orientation of surfaces relative to the velocity vector, shielding, and other pertinent factors of the design.

The design philosophy of shielding for smaller particles, maneuvering to avoid larger objects tracked by space surveillance agencies, and relying on the sparsity of objects of intermediate size has been articulated and accepted by all parties. All U.S., Japanese, and European Space Agency (ESA) modules will be launched with appropriate shields. The Russian Space Agency (RSA) has agreed, in principle, to the overall approach, but most Russian-built modules will have to be retrofitted with shields on orbit. Detailed memoranda of agreement are being worked out, and the process appears to be converging, but designs and planning dates do not yet seem firm.

Even when all modules are shielded to meet the requirements, the Probability of No Penetration (PNP) is low enough that some occasions of depressurization from debris penetration are to be expected over the probable life of the ISS mission. To plan for these contingencies, a Caution and Warning (C&W) Analysis and Integration Team

(AIT) has been formed, and coordinated efforts to provide for leak location instrumentation and methods have been initiated. Some notional designs of leak repair methods and tools have been undertaken by the Marshall Space Flight Center (MSFC) and by the RSA. In addition, a common strategy for dealing with depressurization is being worked out with the RSA, and a preliminary strategy document has been issued. These are all important efforts that should be encouraged.

M/OD collision avoidance, as presently implemented on the Space Shuttle program, is a complex operation involving several operational organizations in the Department of Defense (DoD) in addition to NASA. The details of the process for the ISS have yet to be worked out, specified, and documented, and it is not clear whether the accuracy of the prediction process will be sufficient to keep the false alarm rate low.

The M/OD avoidance process for the ISS will be more complicated than for the Space Shuttle because of the necessity to include the RSA in the communications and propulsion command loop. Further, there are periods of time—when the orbiter is docked to the ISS, for example—when the ISS engines cannot be fired to effect the avoidance maneuver. The course of actions that must be taken in these various situations needs to be jointly worked out, agreed to, and documented.

Ref: Finding #23

Although progress has been made in the design of the caution and warning system, many major decisions remain. Among these are: an auditory or visual locator for Personal Computer System (PCS) units in an alarm condition; strategies to implement remedial actions from the PCS keyboard; a localization scheme for depressurization events; and interfaces with the Environmental Control and Life Support System (ECLSS). As other International Space Station system designs are finalized, it will become increasingly difficult to influence their interrelationships with C&W. For example, the control of payload toxic hazards and the detection and annunciation of payload fire and power failure must be resolved. The division of responsibilities between C&W and ECLSS also must be further defined.

To date, a C&W team has been formed and charged with the responsibility of finalizing the design. This is a good start, but there is some catching up required. This team needs to be given sufficient priority so that their system engineering activities can have a timely influence on other ISS system designs.

Ref: Finding #24

Over the life of the ISS, numerous payloads and experiments from a wide variety of sources will be orbited. Some of these may include potentially toxic biological or chemical hazards as part of the experiment suite. Others may contain several basically benign substances that could produce a toxic substance if combined intentionally or unintentionally. Some of these toxic substances can be anticipated now. Others may not be identified for years as new experiments are defined.

The ISS design does not include any station-wide monitoring for the range of hazardous substances that might be present. It would be a daunting task to anticipate and accomplish detection of the many different toxic substances at the station or even module level. The ISS program has required payload developers to multiply contain any payload that contains hazardous materials. There is also a provision for enunciating an alarm on the caution and warning system at each payload rack. There is, however, no requirement for a payload supplier to provide such a warning signal.

The main area of concern is the absence of a requirement for payload suppliers to include sensing and annunciation of any toxic substances that their experiment contains or might produce. While toxic detection at the station or module level may not be possible, it is reasonable to accomplish at the rack level because the specific dangerous substances for a particular experiment will be known. Also, the baseline ISS design already includes facilities at each rack that would allow the annunciation of a toxic substance detection on the C&W system. It is therefore suggested that the ISS program require all payloads that contain or could produce toxic materials or substances to include detection of them at the rack level and annunciation of any detection to the ISS C&W system.

Ref: Finding #25

Space Station Freedom and ISS designers considered including a wireless intercom system so that crew members could maintain continuous, “hands-free” contact. This system was useful both as a convenience for nominal operations and as an important aid to locating and rescuing a crew member in trouble. The current design does not include such an intercom and has not replaced it with any other communications system with similar, two-way, hands-free capability. This could lead to increased risk under time-critical events, such as a crew injury or a meteoroid or debris penetration. When these events occur, it will be critical to locate all crew members quickly and accurately and to determine their condition. Because the affected crew member may be unable to translate to a communications panel and may not be connected to the ISS communications system by wire, location could be problematic and time consuming.

There would appear to be a significant safety risk associated with the unavailability of a “hands-free” communications capability in the ISS. Whether by wireless intercom or through two-way paging capability, the provision of this function would appear to be an important safety and operational consideration in the ISS. The Panel recommends that the ISS program examine alternative ways to maintain emergency and routine “hands-free” communications with all crew members and include an appropriate approach in the baseline ISS design.

Ref: Finding #26

NASA has previously delineated the design reference missions for a crew return vehicle as part of the Space Station Freedom program. They are: (1) the return of a

disabled crew member during a medical emergency; (2) the return of the entire crew after accidents or failure of station systems; and (3) the return of the entire crew during prolonged interruption of Space Shuttle launches.

The X-38 research vehicle program is a good approach for developing an ISS Crew Return Vehicle (CRV). Any CRV resulting from the X-38 program, however, should be capable of fulfilling the above-noted design reference missions.

C. COMPUTER HARDWARE/SOFTWARE

Ref: Finding #27

NASA has recently adopted an Agency-wide software safety policy. It defines different categories of software, including safety-critical software. For this latter category, a software safety plan is required, including hazard analyses and testing. This is a good, positive step. However, the policy allows a project manager to decide how to tailor a project's software safety plan without concurrence or approval from either center Safety and Mission Assurance (S&MA) or a higher management level. The policy may be tailored to a particular project by the project manager, with only *consultation* with the center's S&MA organization.

The notion of tailoring the plan to specific projects makes a great deal of sense because the top-level standard has only very general requirements, and greater detail is needed for specific projects or programs. The issue of concern is the manner of approving the tailoring that takes place, particularly in today's realm of limited budgets and high pressure to complete projects quickly. It could be tempting for program managers to adopt tailored plans that do not adequately incorporate safety mechanisms, or they might feel that this is the only way to complete their program within budget. There is nothing in the current standards and procedures to guard against this.

There is also no requirement for verification and validation (V&V) activities per se (much less *Independent* Verification and Validation—IV&V), only "testing." The document remains silent on who should do the testing or whether any independence of testing is required. From the document, it would seem that an engineer testing his or her own software could be considered satisfactory. It is thus possible for a program manager to perform only perfunctory testing of safety-critical software components with no independence of the tester from the developer (i.e., even less than the "embedded V&V" NASA frequently uses). In general, it is not necessary that the V&V activity be performed by a separate contractor, but at least some organization different from the developer needs to perform the V&V.

Ref: Finding #28

While there is a set of NASA software standards covering the topics of software safety, assurance, and inspection,* the roles of various components of the Agency with respect to these software policies are not yet clear. Moreover, there does not appear to be a consistent awareness, knowledge, and application of these standards.

The organization of software activities within NASA has been evolving rapidly over the past few years. Contributing significantly to this change is the development of

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* NSS 1740.13—Software Safety Standard; NASA-STD-2100-91—Software Documentation Standard; NASA-STD-2201-93—Software Assurance Standard; NASA-STD-2202-93—Software Formal Inspections Standard.

the NASA IV&V Facility at Fairmont, West Virginia ("Fairmont Facility"), and the designation of a Center of Excellence (COE) in Information Sciences for the Agency at the Ames Research Center. It is the evolution of the roles of these organizations, which is still ongoing, that both offers the potential for substantial improvements in the management of software-related activities throughout the Agency and raises the issue of the roles and responsibilities throughout NASA. The issues that arise in the evolution of change in these two parts of the Agency are representative of, and lead, those arising more broadly within NASA.

The Ames Research Center has been reorganized, and the Fairmont Facility placed, administratively, under the Ames Center of Excellence Office. As part of implementing this, the Deputy Associate Director for Information Technology at Ames has been appointed Director of the Fairmont Facility. However, there is still some potential confusion between Headquarters and Ames over the reporting chain for Fairmont. In contrast to reporting to Ames, the July 1996 Program Plan for the Fairmont Facility states that the Office of Safety and Mission Assurance at NASA Headquarters has *functional leadership* responsibility for that part of the Agency Software Plan that is to be conducted through Fairmont. This appears to be a dual reporting that could lead to confusion or difficulties in the operation of the Fairmont Facility. It is believed that this confusing situation will be rectified in the next update of the plan.

The situation is further confused by the fact that the Fairmont Facility Plan includes elements that reflect Agency-wide considerations. For example, according to the Plan, the NASA Chief Information Officer (CIO) is responsible for the Agency information technology policy. This raises questions about his role with respect to Ames and Fairmont.

The Plan also states that the Fairmont Facility has three program areas: (1) verification and validation; (2) assessment; and (3) the Agency Software Program. Within the V&V function, the Facility both performs V&V activities and conducts V&V research. Within the assessment area, it performs assessments and provides consultation. The Plan makes it clear that, within these first two areas, the Facility responsibility is as a service organization. It is less clear how the programs and centers are to be induced to bring their V&V and assessment work to Fairmont.

In the third area, the Agency Software Program, the role of Fairmont is not sufficiently clear. It is stated that the Fairmont Facility role in the Agency Software Program is one of assisting in the development and promulgation of the Agency Software Strategic Plan, as requested from other parts of the Agency. However, the Fairmont Facility Plan seems to go beyond that and contains words such as "ensure" and "establish," which have a strong connotation of implementation and enforcement. In Panel discussions with NASA personnel, it was stated emphatically that enforcing the policies was the responsibility of the center S&MA directors. In fact, it was said that they will be evaluated on how well they carry out this activity.

Nevertheless, this is far from clear in what is written in the Plan, and there is substantial potential for misunderstanding.

The Fairmont Plan also indicated that the Software Working Group (SWG), which is a body composed of representatives from most centers, is an *implementation vehicle* of the Agency. It was not entirely clear what "implementation" means in this case, but it appeared that the majority of the members of this group reported to the S&MA directors of their respective centers. Most likely, the SWG has only a coordination and intra-Agency communication role. However, this point should also be clarified.

Part of the strategy for the development of software safety technologies embedded in Fairmont's plan is to spread the work across the various NASA centers. In principle, this can engender interest and support in the advancement of software safety and Fairmont's role throughout the Agency. The Headquarters Office of Safety and Mission Assurance (OSMA) is funding this technology development with part of the funding it provides to Fairmont. In turn, a part of these funds go to the other centers to support their work. This appears to be a good way to initiate positive interactions between Fairmont and the other centers, although an eventual transition from OSMA funding to center and program funding has yet to be addressed. Twenty-four projects were funded in FY 96, each of modest size. The number of topical areas being covered was significantly larger than this, however, and most of the areas covered address major limitations on current software technology, requiring significant effort to advance current capabilities. While there was an indication that the centers may have been reporting everything on which they were working rather than just the activities being funded, there is a concern that the funded activities are being diluted through an imbalance in the breadth of coverage in comparison to the level of funding available. Moreover, the fact that the upper level reporting and management structure is still evolving could hamper the level of coordination and cooperation among the groups.

Another area of concern is the level of awareness of the evolving software safety activities and the utilization of existing standards at the various centers. At one center, while there were software quality assurance procedures in place for safety-critical software, these did not include formal code inspections or subsystem- or system-level testing. As with many other programs in NASA, the V&V functions were embedded within the organization, with a NASA person serving as test director. The personnel involved with this software professed no knowledge of the V&V activity at Fairmont. While they have subsequently made contact with the Fairmont Facility, this may be indicative of a lack of awareness of the Facility and its role across NASA.

In view of all of the above, it seems that there is still considerable uncertainty in software policy and responsibility. It does not seem that the Fairmont Facility is the complete answer to the Agency's software problems, as has sometimes been alluded

to in the past. It can play an important role, but direction needs to come from higher in the organization, and there needs to be further attention to the implementation aspect of the Agency Software Strategic Plan from outside of Fairmont. Some of the issues that need to be resolved are:

- Clarification of the role of the Agency Software Program referred to in the Fairmont Facility Plan vis-à-vis the existing software standards.
- Clear specification of roles, responsibilities, and authority among the CIO, the COE, the Fairmont Facility, and the centers with respect to software.
- A decision by NASA on the level of standards, policies, and procedures to be enforced and as a function of the kind of software development, including:
  - Defining precisely what levels of approval are required for determination of the applicability of standards, policies, and procedures, waivers of policy, acceptance of risk, or tailoring of plans to specific project needs.
  - Defining carefully what "software" is covered by each policy, guideline, or procedure and specifying the process by which it is decided whether a software item is included (i.e., what is the approval route?).
  - Clarifying what is required, at the Agency level, in terms of IV&V.
- An Agency decision on the mechanisms by which the resources of the Fairmont Facility are to be utilized by the centers and programs.
- A clear statement of the scope of activities of the Fairmont Facility consistent with its staffing level and funding.
- Development of a NASA Policy Directive that makes the role of Fairmont and Ames clear, together with complementary documents and programs that will help in making the centers and programs aware of Fairmont and how its resources can be utilized.

Ref: Finding #29

Matrix X is an autocode generator that takes higher level specifications of control functions and automatically generates application code—in the case of the International Space Station, Ada code (though the language is unrelated to the issue). The application code generated is not often used directly, however. Some product groups find it necessary to hand-code a few changes first. Three categories of issues arise: (1) problems arising when Matrix X, itself, is changed (which happens from time to time); (2) configuration management issues (e.g., making sure that all modules that have handcrafted changes are also revised when regenerated); and (3) problems with testing the Matrix X generated code.

If the Matrix X source code is re-processed for any reason—either an upgrade to Matrix X itself or a change to the source code—the code it generates must then be

revised by hand to reflect the changes that were made by hand originally. Redoing the hand-coded changes is complicated by the fact that the code regenerated by Matrix X will usually have different variable names than the previous version. This introduces a different kind of configuration management problem than normal and makes it much more difficult to find the areas of code that must be handcrafted, because the newly generated code may look different from the original.

The most important issue under debate is that the ISS program plans to do testing only of the higher level input specifications to Matrix X, as well as integration testing. They do not plan to conduct unit testing on the modules produced by Matrix X. Once again, software is being given less testing than hardware, where unit testing of all components is standard. The Panel believes that either handcrafting of Matrix X produced code should not be done or there should be unit testing on all modules produced by Matrix X.

Ref: Finding #30

The term software includes "firmware" and other embedded code, regardless of the physical means for executing it. From this perspective, there are other important issues to be considered. There are 38 unique firmware controllers currently planned for the International Space Station. Each is treated as a "hardware box"—that is, as a configured end item. Each has a separate heritage, with many designs and test results dating from Space Station Freedom. Those that were 70% or more complete are being "grandfathered" into the ISS without recompilation of the coding. Most of the source code for the firmware was written in higher level languages. There is no common, validated compiler used for the compilation of this firmware code, as there is for the data management system code being written for the ISS. It is argued that it is impractical to have a common compiler, and they must rely on testing of completed firmware for validation.

There has been little effort toward archiving the documentation on each set of grandfathered firmware. The ISS program could not identify who is responsible for archiving this information. This would make modification or development of replacement units difficult. It was noted that modification after first launch will be handled by returning the unit to the vendor. It is acknowledged that this may be a problem in the 20+ years of sustaining operation, but there is no budget at present to address this issue. The ISS may simply buy replacement boxes rather than upgrade what they have, and for that they do not need the source firmware code. Nevertheless, knowledge of the firmware code will be valuable, and possibly reduce costs, in the development of any replacement boxes. It could also be valuable for future analysis of system failures. Moreover, it is important to have complete documentation of the ISS.

It has also been noted that because many of the "boxes" containing firmware were developed by subcontractors, there is an issue of ownership of the firmware. It is not

clear that NASA would even have access to this code in all cases. Nevertheless, for NASA's future activities, it could be important that such access is available.

Ref: Finding #31

Last year, the Panel reported many problems regarding the ISS computer systems and software. We were pleased to see that considerable progress has been made on these. For example, last year it was reported that the 1553 databus had serious problems (e.g., that adding a workstation or even moving one could result in failure). This year, these issues have been resolved. Another issue facing the ISS last year was negative margins on memory and processor utilization. Positive memory and processor margins are now reported for all processors and memory.

Last year, there were questions about all of the government-furnished software being in compliance with DoD-STD-2167A. Now, the DoD-STD-2167A issue has been worked out and most, if not all, government-furnished software is in compliance. A major concern last year was that the software safety standards were not available to the developers. These have now been upgraded and integrated into the Prime Item Development Specification. As the developers were working in concert with those developing the safety standards, there was very little retrofitting that had to be done. One of the brighter points of last year, IV&V for the ISS, continues to move forward.

Overall, we believe the software is in much better shape than it was last year. There has been real progress in getting it under control, although there are still some problems. The big problem now, however, is that ISS software development is behind schedule and the product groups have to play catchup. We urge continuation of the progress over the past year and caution against cutting corners to achieve schedule.

D. AERONAUTICS

Ref: Finding #32

The consolidation of NASA aircraft at the Dryden Flight Research Center (DFRC) was started at the beginning of the year. This involved significant planning for transferring people and aircraft and hiring additional staff, as well as moving funds from other centers to DFRC. As a result of congressional action, NASA was first directed not to execute the consolidation. Later, the direction was changed to hold in abeyance the transfer of aircraft based east of the Mississippi (from Lewis, Langley, and Wallops) through FY 97. This situation has caused confusion, lowered morale, and departures among the personnel affected. The impasse between NASA intentions and the congressional mandates must be resolved as soon as possible.

The original plans for DFRC to accept and provide for the transferred aircraft and personnel were detailed and well organized. Related activities included: liaison with Edwards Air Force Base; the transfer of the Air Force C-17 hangar to NASA for use by the incoming aircraft; and the hiring of some new staff.

Ref: Finding #33

The 40' x 80' x 120' wind tunnel fan blades at the Ames Research Center were found to be cracked at the hub in 75 of the 90 blades. The blades were designed with a projected life of 20,000–30,000 hours and had accumulated only 2,000 hours running time when longitudinal cracks were discovered. The cracks were propagating very rapidly—3 inches during the 4.5 hours of running after the cracks were discovered. The source of the cracks is believed to be a failure to account fully for the dynamic effects associated with a change made in the tunnel turning vanes several years ago.

To preclude shutting down the tunnel for the one year required to procure and install a new set of blades, it was decided to repair the old blades while waiting for the delivery of the replacements. The repair includes wrapping the root section of the blades, which eliminates the ability to detect crack growth by visual inspection.

Because the repair will hamper the ability to inspect the fan blades visually, NASA should ensure that a suitable inspection program, including frequent checks using nondestructive evaluation methods, is implemented.

Ref: Finding #34

Several recent NASA programs have successfully transferred flight safety improvements to the aviation communities. Among these are flight test programs such as the wind shear detection efforts carried out by the Langley Research Center in cooperation with the Federal Aviation Administration (FAA) and the Propulsion Controlled Aircraft program at the Dryden Flight Research Center in cooperation with industry. Currently, NASA and the FAA are conducting a program to provide wake vortex protection in the form of prediction of occurrence and a set of rules to

be followed to prevent landing aircraft from encountering a hazardous wake vortex. Other programs, such as tire friction research and associated icing condition effects on aircraft stopping and heavy rain effects on aircraft wing lift, can provide a large increase in the safety of future air operations. NASA should continue to pursue aeronautics research programs, particularly joint efforts with other agencies, that will increase the safety of air operations.

E. OTHER

Ref: Finding #35

The Space Shuttle utilizes numerous materials and processes in the turnaround processing and preparation for launch. Some of these processes employ materials or solvents that are being phased out for environmental reasons or are becoming obsolete. Some elements of the Space Shuttle program have elected to change materials or processes to adhere to the Montreal Protocol, an international agreement for the reduction of ozone-depleting compounds and other volatiles, rather than seek a waiver. The RSRM project, in particular, sought and obtained a temporary waiver to postpone full implementation of the Montreal Protocol. However, that waiver was only granted under the condition that complete compliance would be forthcoming.

An example of an environmentally driven change was the Pressure Sensitive Adhesive (PSA) used in the J-flap of the segment interfaces of the RSRM and the solvent used in the joint cleaning process before application of the PSA. To avoid a waiver of the new environmental agreements, a new PSA was acquired and a solvent-based cleaning wipe was replaced with an aqueous-based joint cleaning process. The PSA was tested, but only in a single joint of a flight support motor (FSM). The old solvent cleaning wipe was used to prepare the FSM joint. Also, the FSM firing was made without any side load inputs, which would simulate dynamic flight loads.

The first flight of the RSRM with the new PSA and using the aqueous cleaner, produced unusually heavy sooting, and heat effects were found on insulation interfaces within the STS-78 field joints. After a thorough review, the sooting and heat were attributed to the inability of the new PSA to maintain the closure of the J-flap. As a result, the program resumed using the former PSA and joint cleaning process for STS-79 and subsequent flights. It is understood that NASA plans to seek an environmental waiver to continue their use.

The procedure used to qualify the changes in the PSA and cleaning processes for STS-78 was not effective. The actual two-part change *in toto* was never tested in a full-scale motor. The FSM test only examined the PSA without including the concurrent change to an aqueous cleaning approach. Also, the absence of side loads in the FSM test rendered it of questionable validity for qualifying the joint preparation. Moreover, the initial decision to alter a material and process that were performing well rather than seek a waiver of the Montreal Protocol was not prudent.

As a general rule, NASA should not change qualified and well-understood materials or processes if sources of supply can be maintained and the actual emission of banned substances is insignificant. It is in the best interests of safety to request a waiver of the Montreal Protocol in these instances. This will avoid eroding the safety of Space Shuttle operations by upsetting well-understood and adequately performing specifications.

On a broader level, the experience with the new J-flap preparation for STS-78 highlights a weakness in Space Shuttle change process control and testing. It was a mistake for the program to consider that it completely understood the role of the PSA and joint cleaning process in the maintenance of joint integrity without adequate testing and a model of how each facet contributed to the performance of the field joint. It was also inappropriate to test a configuration (new PSA and old cleaning method) that was not intended for flight. The test was also not sufficiently realistic because of the absence of side loads to simulate flight dynamics.

The Space Shuttle program should exercise greater scrutiny over the validity of proposed test methods for qualifying future materials and process changes. The program should require all qualification testing to emulate flight conditions as closely as possible. When such testing cannot be defined or accomplished or is economically prohibitive, and the change in question is not mandatory, it should be forgone if possible. If changes in stable and well-characterized safety-related hardware and processes are being driven by environmental requirements rather than obsolescence, NASA should consider seeking waivers of these requirements rather than altering a proved design.

Ref: Finding #36

As the NASA budget has been reduced and those reductions passed on to the individual centers, there has been a tendency to downsize firefighting personnel and defer equipment replacement and maintenance. Both the ASAP and NASA's Safety and Risk Management Division (Code QS) have determined that preparedness is generally adequate. While there have been no recent untoward incidents or injury due to fire, the nature of the business is that dollars must be spent before any problems develop, not after. A timely, thorough center-by-center review should be continued.

IV. Appendices

IV. Appendices

Appendix A

AEROSPACE SAFETY ADVISORY PANEL MEMBERSHIP

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MS. PATRICIA M. HARMAN
Staff Assistant
NASA Headquarters

MS. CATRINA L. MASON
Secretary
NASA Headquarters

Appendix B

NASA RESPONSE TO FEBRUARY 1996 ANNUAL REPORT*

SUMMARY

NASA responded on August 22, 1996, to the "Findings and Recommendations" from the February 1996 Annual Report. NASA's response to each report item is categorized by the Panel as "open, continuing, or closed." Open items are those on which the Panel differs with the NASA response in one or more respects. They are typically addressed by a new finding and recommendation in this report. Continuing items involve concerns that are an inherent part of NASA operations or have not progressed sufficiently to permit a final determination by the Panel. These will remain a focus of the Panel's activities during the next year. Items considered answered adequately are deemed closed.

Based on the Panel's review of the NASA response and the information gathered during the 1996 period, the Panel considers that the following is the status of the recommendations made in the 1996 report.

* NASA's response to the February 1996 ASAP Annual Report is, for the most part, written with only minor editorial corrections to make the text consistent with this year's report.

RECOMMENDATION

No.	*Subject*	*Status*
1	KSC government and contractor personnel and resources cutbacks	Continuing
2	Obsolescence of Space Shuttle components	Continuing
3	Return to launch site maneuver	Continuing
4	Range safety destruct system	Closed
5	Global Positioning System triple redundancy	Closed
6	Reaction Control System thruster valve leaks	Continuing
7	Alumina Enhanced-Thermal Barrier tiles with Toughened Uni-place Fibrous Insulation	Closed
8	Space Shuttle Main Engine prelaunch inspection and checkout	Closed
9	Block II engine certification program schedule pressures	Continuing
10	Space Shuttle flight safety	Closed
11	Flight Support Motors firing schedule	Closed
12	Super Light Weight Tank development	Closed
13	Pyrotechnic bolts on docking module	Closed
14	Reduce risk to ISS from meteoroids and orbital debris	Continuing
15	Caution and Warning system design for ISS	Continuing
16	English labels in Soyuz vehicles for crew rescue	Closed
17	Develop and deploy Crew Rescue Vehicle for ISS	Continuing
18	ISS data processing requirements	Closed
19	ISS computer system safety requirements and Integrated Product Teams	Closed
20	ISS lifetime computer architecture upgrades	Continuing
21	Verification and Validation activities for ISS flight software	Open
22	ISS software development processes and tools for certification	Continuing
23	ISS activities on Independent Verification and Validation	Closed
24	ISS computer-based training and virtual reality techniques	Closed
25	Develop plans for deorbit/decommission of intermediate ISS assembly configurations	Continuing
26	Extravehicular Mobility Unit improvement program	Closed
27	NASA microgravity research aircraft operations	Closed
28	Support for the wake vortex research program	Closed
29	Dryden Flight Research Center's Basic Operations Manual	Closed
30	Fatigue Countermeasures Program	Closed
31	Establish safety course for senior managers and major contractors	Closed
32	Top management involvement in safety aspects of planning for oversight of Space Flight Operations Contractor	Continuing
33	NASA involvement in what constitutes an out-of-family event	Continuing
34	Verification and Validation techniques for neural net control software	Continuing
35	Software assurance process	Continuing

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001

AUG 22 1996

Mr. Paul M. Johnstone
Chairman, Aerospace Safety Advisory Panel
24181 Old House Cove Road
St. Michaels, MD 21663

Dear Mr. Johnstone:

In accordance with your introductory letter to the February 1996 Aerospace Safety Advisory Panel (ASAP) Annual Report, enclosed is NASA's detailed response to Section II, "Findings and Recommendations."

The ASAP's efforts in assisting NASA to maintain the highest possible safety standards are commendable. Your recommendations are highly regarded and continue to play an important role in risk reduction in NASA programs.

We thank you and your Panel members for your valuable contributions. ASAP recommendations receive the full attention of NASA senior management. In particular, I expect that NASA's Office of Safety and Mission Assurance will track resolution of these issues as part of their role in independent assessment.

We welcome the continuance of this beneficial working relationship with the Panel.

Sincerely,

Daniel S. Goldin
Administrator

Enclosure

1996 Aerospace Safety Advisory Panel Report

Findings, Recommendations, and Responses

A. SPACE SHUTTLE PROGRAM

OPERATIONS

Finding #1

Cutbacks in government and contractor personnel and other resources at the Kennedy Space Center (KSC) and the planned transition of tasks from government to contractor workers will create a new mode of Space Shuttle operations. Those involved in day-to-day Shuttle operations and management are in the best position to determine how to maintain the stated program priorities—fly safely, meet the manifest, and reduce costs, in that order.

Recommendation #1

Additional reductions in staff and operations functions should be accomplished cautiously and with appropriate inputs from the KSC NASA/contractor team itself.

NASA Response to Recommendation #1

KSC operations continue to focus on the program goals of flying safely, meeting the manifest, and reducing costs, with flying safely being paramount. Teamwork between NASA and its contractors has enabled us to meet program challenges in the past, and we will rely on that same teamwork to meet the challenges of the Space Flight Operations Contract (SFOC) transition. Reductions in personnel will be proportional to requirement reductions as opposed to budget reductions. Requirements reductions which will reduce work content should come from the program as well as efficiencies which are originated at KSC. KSC plans to use a phased methodology to control change and risk. In a partnering relationship, NASA and United Space Alliance (USA) will jointly plan change, implement change, then stabilize and assess the results before making further changes. “Partnering” provides NASA visibility and management insight into the transition process and ensures desired levels of safety and quality are maintained. By implementing a disciplined transfer of mature systems, proven procedures, and experienced personnel into SFOC, we feel that we can accomplish a seamless transition without disturbing the infrastructure that has made this program such a success.

Finding #2

Obsolescence of Space Shuttle components is a serious operational problem with the potential to impact safety. Many original equipment manufacturers are discontinuing support of their components. NASA is, therefore, faced with increasing logistics and supply problems.

Recommendation #2

NASA should support augmenting the current comprehensive logistics and supply system so that it is capable of meeting Space Shuttle program needs in spite of increasing obsolescence.

NASA Response to Recommendation #2

NASA concurs with the finding that current tracking and control systems are providing timely information to deal with logistics problems. With regards to the specific need for better visibility into the subject of obsolescence, it was with that concern in mind that the Safety and Obsolescence (S&O) activity was established as a process for identifying and responding to trends indicative of aging and to identify areas where replacement parts may no longer be available.

The S&O process baselined in NSTS 08198 provides a rigorous prioritization approach which factors in the criticality of the systems and nonsafety related risks involved with Shuttle flight and ground processing hardware. This process identifies the most serious problems and generates data used to support requests to program management for correction of the identified concerns.

Finding #3

The Return to Launch Site (RTLS) abort maneuver is one of the highest risk off-nominal Space Shuttle flight procedures. A Space Shuttle Main Engine (SSME) shutdown leading to an intact abort is more likely than a catastrophic engine failure. Exposure of an ascending Space Shuttle to the risk of performing the demanding RTLS maneuver might be significantly minimized by operating the Block II SSME at higher thrust levels at appropriate times. Certification of alternative Space Shuttle landing approaches for use during contingency aborts and installation of Global Positioning System (GPS) could also contribute to the minimization of RTLS risk (see Finding #5).

Recommendation #3

NASA should pursue with vigorous efforts to minimize Space Shuttle exposure to the RTLS maneuver through all available means.

NASA Response to Recommendation #3

NASA has and will continue to increase the reliability of the hardware to decrease the probability of any abort and to make operational trades to balance the risks between the available abort modes. The RTLS abort mode is fully certified and has been a requirement throughout the design and certification of the vehicle. Options

to improve abort capability, such as increased SSME throttling or utilization of GPS to increase operating flexibility, are continually evaluated.

A decision for certifying the Block II SSME intact throttle to 109 percent is scheduled for late 1996. Routinely operating at higher thrust settings may add additional risk, which needs to be evaluated versus RTLS exposure. A review of the GPS implementation schedule is under way. Single-string GPS is in development for three vehicles to gather flight test experience. Software development for three-string GPS is also currently in work. As development and flight testing continues, the GPS contribution to minimizing RTLS risk will be assessed. While the RTLS intact abort mode is certified and is considered to be acceptable, however, improvements to decrease the risks of RTLS will continue to be evaluated. Each flight is designed to meet RTLS constraints, and operational considerations are continually reviewed to ensure that the proper trades are being made to balance risks.

While many alternatives have been considered, none can eliminate the requirement for RTLS capability, and, to date, all are predicted to have risk greater than that associated with the current certified abort modes.

Finding #4

The Range Safety System (RSS) destruct charges have been removed from the liquid hydrogen tank of the External Tank (ET). The risk studies which supported this removal also suggested that the RSS charges had to be retained on the Liquid Oxygen (LOX) tank of the ET. It is preferable to omit as much ordnance as possible from flight vehicles to reduce the possibility of inadvertent activation.

Recommendation #4

Studies supporting the need for the RSS destruct system on the LOX tank should be updated in light of the current state of knowledge, operating experience, and the introduction of the new Super Lightweight Tank (SLWT) to determine if it is now acceptable to remove the ordnance.

NASA Response to Recommendation #4

Studies have been completed, and the Space Shuttle program has formally eliminated the requirement for an ET RSS and approved removal of ET RSS hardware. Deactivation of the system is planned with a phased implementation of hardware removal on tanks that culminates in a total removal by ET-96. RSS hardware removal may begin as early as ET-87. The first SLWT (ET-96) will not have any RSS hardware installed, thus increasing the Shuttle safety by removing the possibility of inadvertent activation of the tank destruct system.

ORBITER

Finding #5

The Orbiter and its landing sites continue to be configured with obsolescent terminal navigation systems. The existing Tactical Air Control and Navigation (TACAN) system and the Microwave Scanning Beam Landing System (MSBLS) are increasingly difficult to maintain, vulnerable, and expensive. Continued reliance on them limits landing options in the event of a contingency abort. Replacement of TACAN and MSBLS with now-available precise positioning GPS in a triple redundant configuration would ameliorate and most likely solve these problems.

Recommendation #5

Accelerate the installation of a triple redundant precise positioning service GPS in all Orbiters.

NASA Response to Recommendation #5

The Space Shuttle orbiter project is accelerating the first installation of three-string GPS to the orbiter maintenance down period (OMDP) scheduled for OV-104 in 1998. This improves the date for the last TACAN flight by 2 years, from 2002 to 2000. The FY 1998 OMDP is the earliest date that can be accommodated by hardware design, certification, and flight software development. Software development and hardware installation during the OMDP are the pacing items in bringing the three-string system on line. The requirements to install the wiring, antenna, and control panel modifications for the three-string system have been estimated to be approximately 5,000 man-hours of work on each vehicle. Implementing any change of this size during a vehicle flow in the KSC Orbiter Processing Facility would create prohibitive launch flow impacts, thus relegating the change to OMDP.

The single-string system now being implemented for OV-103, -104, and -105 is essential to verifying GPS performance. Plans to thoroughly evaluate and certify the GPS as the primary Shuttle navigational system are being prepared. The additions to GPS flight software necessary to support just the single-string system require the single largest software change since the initial development of the Space Shuttle program. The additional changes to go from single-string to the operational three-string system will be approximately the same size. Production of this software is being given the highest priority.

The backup flight software system (BFS) will support the single string-system on STS-79. Primary flight software for the Shuttle is developed in operational increments. GPS software was originally considered for OI-26 in 1994; however, it was necessary to give priority to software associated with payload performance enhancements that enable construction of the International Space Station. A special OI-26B was created to add single-string GPS capability to the primary flight software. OI-27 will be devoted to the three-string system. Meanwhile, NASA is considering utilizing single-string GPS data for additional risk reduction for contingency aborts and emergency de-orbits.

Software and hardware improvements and supporting certification will allow for first flight of the three-string GPS in January 1999 on STS-96. The Space Shuttle program continues to investigate upgrades that will minimize the risks of contingency abort modes.

Finding #6

Orbiter Reaction Control System (RCS) oxidizer thruster valve leaks are occurring with increasing frequency. More recently, RCS fuel thruster valve leaks have also been observed. Because isolation of leaking thrusters can be implemented by manifold shutoff and thruster redundancy is provided, leaking thrusters have not been considered a serious safety hazard. RCS leaks in the vicinity of rendezvous targets such as Mir and the International Space Station (ISS) could, indeed, be a serious safety hazard.

Recommendation #6

Do what is necessary to eliminate the RCS thruster valve leaks now and in the future.

NASA Response to Recommendation #6

A comprehensive program to improve thruster reliability and eliminate RCS thruster leaks has been put in place. The majority of oxidizer valve leaks are attributed to the long-term accumulation of nitrates that form in the presence of moisture. The changes fall into three categories: operations improvements, improved maintenance of valves, and design changes. Changes in the way turnaround operations are performed consist of emphasizing the maintenance of the RCS propellant system in a hard-filled/wetted state, improved thermal conditioning to keep the thrusters always above the minimum temperature, and reduction of moisture intrusion into the system. These principles have been incorporated into written procedures at KSC and are currently in use. In addition, a molecular sieve is being implemented at the launch pad to reduce the residual iron and water in the RCS oxidizer.

Periodic flushing of thruster and valve passages to remove accumulations of nitrates has been implemented. The thruster flushing essentially returns the thruster to an as-new condition in terms of nitrate accumulation. Thruster flushing has been performed at each OMDP beginning with OV-103 in July 1995. Subsequent intervals for flushing are planned at every other orbiter maintenance down period (OMDP), subject to change based on evolving failure rates from nitrate accumulation.

Two design approaches to achieve a more reliable valve have been evaluated, and one has been chosen for implementation. The first design solution proposed was to abandon the current pilot operated valve (POV) in favor of a direct acting valve (DAV). In addition to technical problems involving reliability of required bellows, it was determined that removing and replacing all the oxidizer valves in the fleet was cost prohibitive. It was determined that the cost-effective approach could be achieved by replacing certain internal parts of the existing valve with redesigned parts on an attrition basis. The redesigned parts modify the areas of the current valve

that have been shown to be sensitive to nitrate contamination. Examples of design changes are reduction of seal surface contact area, adoption of a conical seal geometry, and a stronger spring with more valve closing capability.

In summary, a comprehensive, cost-effective program to improve thruster reliability and minimize leaks has been defined and is in various stages of implementation. The effectivity of various elements of the program will be carefully monitored and the program adjusted according to results.

Finding #7

The use of Alumina Enhanced-Thermal Barrier (AETB) tiles with Toughened Uniplace Fibrous Insulation (TUFI) coating on the Orbiter has the potential to enhance safety and reduce life cycle cost.

Recommendation #7

NASA should make a thorough study of the potential use of the AETB/TUFI tiles to determine whether it is cost effective to qualify the tiles for flight.

NASA Response to Recommendation #7

The use of AETB tiles with the TUFI has been considered extensively in the last year for use on the Shuttle.

AETB/TUFI tiles have been flown as technology demonstrations in support of the X-33 program. These tiles were installed on the lower body flap and base heat shield of the orbiter. Tiles with density of 12 pounds/cubic foot were attached to the body flap. Those attached to the base heat shield had a density of 8 pounds/cubic foot.

The use of TUFI coating with the FRCI-12 substrate has been identified as a practical option for certain damage prone areas of the orbiter. Certification of this combination for multiple flights will be relatively inexpensive because of similarity between the current coating and TUFI. However, the weight of FRCI-12 with the TUFI coating excludes its use for large area applications. Weight is a critical parameter as the Space Shuttle program strives for performance improvements in support of Space Station assembly flights.

The AETB-12 tile substrate, which is the most mature AETB material, offers few benefits over the current certified FRCI-12. The AETB-8 shows some promise as it would be weight competitive with the LI-900 configuration. Development of AETB-8 technology continues, but it is not in production. Studies will be performed to determine whether it is cost effective to certify and implement this tile configuration. These studies will determine whether the lower maintenance costs would provide an adequate payback.

Space Shuttle Main Engine (SSME)

Finding #8

The SSME has performed well in flight during this year. While some launches were delayed because of problems or anomalies discovered during prelaunch inspections and checkout or development engine test firings at the Stennis Space Center (SSC), such issues were thoroughly and rapidly investigated and resolved.

Recommendation #8

Continue the practice of thorough and disciplined adherence to inspection and checkout of engines prior to commitment to flight as well as prompt and thorough resolution of any anomalies discovered.

NASA Response to Recommendation #8

A disciplined adherence to procedures and a commitment to complete resolution of all anomalies will be maintained.

Finding #9

The Block II engine, in near-final configuration, re-entered development testing in mid-October 1995. Testing of what had been expected to be the final configuration was begun later that month. The High Pressure Fuel Turbopump (HPFTP) was a principal cause of the late restart of testing primarily because of slips in obtaining some redesigned turbopump components. The remaining time to achieve the scheduled first flight of the Block II configuration is very tight and allows for little, if any, problem correction during development and certification testing. The improved ruggedness and reliability of this version of the SSME is critical to the assembly and operation of the ISS.

Recommendation #9

Do not let schedule pressure curtail the planned development and certification program.

NASA Response to Recommendation #9

The Space Shuttle program and the SSME project are committed to completing the development and certification program of the Block II engine. Current planning supports the utilization of the Block II SSME for ISS missions, but the Shuttle has adequate performance with Block I engines for the initial Space Station flights.

Reusable Solid Rocket Motor (RSRM)

Finding #10

Postflight inspection of recovered RSRMs from STS-71 and STS-70 identified gas paths leading to primary O-ring heat erosion in joint #3 of the RSRM nozzles. Heat

erosion in this joint could compromise Space Shuttle mission safety. NASA stopped all launches until the anomaly was resolved and corrective repairs made.

Recommendation #10
NASA should continue to investigate and resolve all potential Space Shuttle flight safety problems in this same forthright manner.

NASA Response to Recommendation #10
NASA concurs. Anomalies that could compromise Space Shuttle mission safety will be resolved before subsequent Shuttle launches.

Finding #11
The schedule for firings of Flight Support Motors (FSMs) for evaluating changes made to the RSRM has been stretched out. Now, accelerating obsolescence and new environmental regulations have increased the need for the data supplied by FSM firings.

Recommendation #11
Do not further stretch out FSM firings.

NASA Response to Recommendation #11
NASA concurs with the finding and, based on current funding profiles, plans to abide by the schedule associated with FSM firings.

EXTERNAL TANK (ET)

Finding #12
The development of the Super Lightweight Tank (SLWT) using aluminum-lithium (Al-Li) material entails several unresolved technical issues. These include a low fracture toughness ratio and problems in large-scale joint welding. There are also critical structural integrity tests that are behind schedule. Resolution of these issues could impact the delivery of the SLWT.

Recommendation #12
Satisfactory resolution of these issues must be achieved prior to SLWT flight.

NASA Response to Recommendation #12
NASA recognizes the concerns expressed in the findings and recommendations for this item. Appropriate efforts and planning have been implemented within the SLWT project to focus the needed resources on development of resolutions to the issues noted and support delivery of ET-96 to meet the International Space Station first element launch in December 1997. Progress/changes that address these issues since the last Aerospace Safety Advisory Panel review follow.

Simulated service testing of plate material has replaced fracture toughness ratio testing to ensure mission life capability. Simulated service testing subjects the material to its actual usage environment and simulates four missions following a proof test. Simulated service testing is believed to be most representative of the actual material usage and takes advantage of the cryogenic enhancement.

Changes have been developed and implemented for an improved welding process; the test article has been completed and delivered; and 70 percent of the first flight article welds have been successfully completed. Significant welding issues have been addressed and overcome.

All major structural component tests have been completed. Anomalies from three of the tests are currently being addressed. Resolution plans for these anomalies support delivery of a flight-worthy SLWT on schedule.

The aluminum-lithium lightweight tank structural test article (ALTA) has successfully passed proof test and is installed into the test stand at the Marshall Space Flight Center (MFSC) for stability testing. The ALTA testing is on schedule and is planned to be completed in time to support the third quarter 1996 proof testing of the SLWT-1 LH_2 tank. Testing and analysis of ALTA will provide validation of analytical methods and approaches to be used on SLWT, confirm stability allowables and methodology for LH_2 tank barrels and LO_2 aft dome, and also provide confirmation of full-scale fabrication processes for gores, chords, and LH_2 tank barrels.

B. INTERNATIONAL SPACE STATION

SHUTTLE/MIR

Finding #13

STS-74 delivered a Russian-built docking module to Mir, which will be used for multiple Shuttle/Mir dockings prior to ISS assembly. This docking module and one designed for use on the ISS use Russian-manufactured pyrotechnic bolts. These bolts cannot be certified to NASA standards because of the absence of adequate information from the manufacturer. They also do not meet the NASA design requirement that pyro bolts be hermetically sealed. The development of a replacement American pyro bolt has been put on hold because its design may violate the proprietary rights of the original Russian manufacturer.

Recommendation #13

Continue to pursue the options of having the Russian manufacturer modify the existing pyro bolt design to include a hermetic seal and the possibility of using the American-designed pyro bolt as a substitute.

NASA Response to Recommendation #13

The International Space Station, through the Docking System Integrated Product Team, is ensuring that the pyro bolts for the ISS mechanisms will meet ISS requirements. At this time, the possibility of an American-designed pyro bolt substitute is not being considered. A new hermetically sealed bolt is under development by RSC-Energia and will be introduced into the program to support the ISS mission 3A and subsequent ISS missions. The pyro bolt will be certified for 33 missions and a 15-year lifetime for each orbiter mechanism and will be required to meet all ISS requirements including the 10^{-6} cc/sec He leak rate.

The current Russian pyro bolt design will be used for all Mir missions through Mir-9 and performance requirements are being verified through the Mir certification process. Certification has been completed for flights through Mir-7 (STS-86). Although not hermetically sealed, these bolts have exhibited leak rates of from 10^{-2} to 10^{-7} cc/sec He, and to date all bolts have performed acceptably. Negotiations have been completed to certify the current pyro bolts for four additional missions, which will cover Mir-8, Mir-9, and two additional contingency Mir missions. Certification testing for the four additional missions is in progress and will be completed in the fall of 1996.

INTERNATIONAL SPACE STATION

Finding #14

Over the life of the ISS mission, there is a risk of some meteoroid or orbital debris penetration. While there is an awareness of the need for mitigation of the potential

for debris penetration of habitable and critical modules, planning and implementation of damage control and repair methods are lagging.

Recommendation #14
Continue to work hard to reduce the risk of penetration of inhabited modules by meteoroids or orbital debris. Implement damage detection, localization and isolation, or repair measures to reduce the risk of life- or mission-threatening impacts.

NASA Response to Recommendation #14
"Preventing the Hazard" has been and always will be both NASA and Boeing's top priority with regard to the threat posed by the meteoroid and orbital debris environments. However, we have recognized the need for dealing with damaging impacts when they occur and have taken active steps in these areas over the last 2 years to be prepared to deal with these events.

We are currently evaluating a concept proposed by RSC-Energia for a leak detection and location system that could be installed on the Space Station on orbit.

Boeing added an engineer experienced in the meteoroid and orbital debris area to the ISS staff, with the module hole repair process as one of his assigned areas of responsibility.

Shielding has recently been added to key Thermal Control System (TCS) lines to help assure mission success by prevention of early TCS leaks.

Shrouding is under consideration for addition to the truss segments, primarily for thermal reasons, but has a secondary driver of reducing M/OD impact effects.

We continue to be actively involved in attempting to better understand penetration and impact effects, with work being performed by both Marshall Space Flight Center (MSFC) and Johnson Space Center (JSC) hypervelocity impact specialists to more efficiently prevent or mitigate impact effects.

Finding #15
The Caution and Warning (C&W) system design for the ISS has not kept pace with the station's level of development due to cost constraints, among other reasons. As a result, the ability to develop a maximally effective safety system design that detects and localizes hazards and provides the information needed for damage control may be compromised.

Recommendation #15
The C&W system should not be unnecessarily constrained by other ISS design decisions or cost limitations. It is a vital part of the total safety environment of the ISS and deserves more detailed and timely design emphasis.

NASA Response to Recommendation #15
The Space Station Program Office (SSPO) Station Management and Control

(SMC) team agrees that Caution and Warning (C&W) is a vital part of the total safety environment. The architecture of the ISS C&W system was designed on a functional basis. The functional requirements were developed by the SMC team and allocated to the appropriate design teams. The SMC team is responsible for the integration of common C&W events and has continually worked with the design teams and the Safety, Operations, and Crew Office to ensure consistent definition of C&W events. The Prime Architecture teams are responsible for ensuring the proper development of the design in accordance with the allocated requirements.

The SSPO takes exception to the statement that the C&W design is not keeping pace with the Station development. Imposed constraints from the Freedom program required existing designs to be utilized in many areas; thus these designs have been quite stable. In the areas that required design work, these designs have progressed on schedule.

The imposed constraints, necessary or unnecessary, were brought forward as part of the ISS baseline, based on managerial decisions from the Freedom program. The program has accepted these constraints and designed a C&W architecture that is acceptable to crew personnel representing this area. The above-mentioned requirements are for alerting the crew. The remaining area needing discussion is the response to the events. The SMC team is responsible for the requirements for autonomous response. These requirements have been allocated to the appropriate design team and have been reviewed through the design cycle by the SMC team as well as the Prime Architecture teams. The nonautonomous responses are allocated to the operations community (crew/ground). (See "Background Information" in Attachment 1 for a discussion of hazard localization.)

Finding #16

The decision by the ISS program to use two Soyuz vehicles for crew rescue during the early years of deployment involves at least two significant limitations. The first is the exclusion of approximately 28% of the crew population due to anthropometric constraints. A second and more tractable issue is the acceptance by the program of Russian language placards on displays and controls. Under pressure, rudimentary training in the Russian language has the potential to break down and increase the probability of errors.

Recommendation #16

There is little that can be done about the inherent limitations of the Soyuz design such as the crew size constraints until Soyuz is modified or replaced with a fully capable rescue vehicle design. The inclusion of some simple placards to provide English labeling would seem warranted given the emergency climate in which a rescue vehicle will be used.

NASA Response to Recommendation #16

Plans are being jointly developed to provide the appropriate level of training (Russian language and Soyuz operations) for non-Russians. Negotiations are also

progressing toward anthropometric modifications. We, therefore, believe that the risk abatement plans are in place to address these concerns.

Currently, the ISS program is planning to use Soyuz-TM spacecraft for crew rotation and crew rescue capability. Factors such as Soyuz orbital lifetime, assembly sequence, logistics requirements, crew training, and crew rotation indicate that up to 10 to 12 Soyuz spacecraft may be required to support ISS crew rotation and crew rescue capability through Assembly Complete. This assumes a baseline ISS crew of three. Additional ISS crew members during this phase would require more Soyuz spacecraft.

The Soyuz-TM anthropometric limits may only include approximately 20 to 40 percent of the astronaut corps. Negotiations are under way to initiate a Soyuz modification program that will change anthropometric limits so that up to 70 to 90 percent of the astronaut corps will be accommodated.

The experience of astronauts participating in the Phase 1 (Shuttle-Mir) program has shown that it is easier to learn the Cyrillic acronyms than to develop transliterated or phonetic nomenclature. This symbolic system is analogous to the NASA Shuttle Flight Data File (procedures and nomenclature). The current concept for ISS Soyuz operations is that a Russian cosmonaut will serve as the designated Soyuz Commander, operating the vehicle within the established Soyuz operating system and communicating in the Russian language with MCC-M if necessary. The other two crew members, who may be non-Russian, will have sufficient basic language skills to use the acronyms on the panel, along with a dual-language Flight Data File, and will be trained to the skills necessary to assist the Commander and accomplish the mission. In a scenario involving an incapacitated Commander, we choose not to assume additional risk (i.e., incapacitated crew member = incapacitated Russian), but we are assuming that the skill levels of non-Russians are sufficient to operate the automated return functions of the Soyuz.

The Soyuz panels are very limited on availability of space for additional labeling. Smaller typeface may be a safety issue, with readability compromised during dynamic phases of flight. The electronic displays would require software changes that affect the vehicle's command and telemetry interaction with existing Space Station and ground control infrastructure.

Finding #17

The use of Soyuz as the Crew Rescue Vehicle (CRV) for the ISS provides only an interim capability. Maximally effective crew rescue capabilities can only be attained through the development and deployment of a special-purpose CRV.

Recommendation #17

A new, fully capable CRV should be developed and deployed as soon as possible.

NASA Response to Recommendation #17

NASA concurs with this recommendation and has an active in-house technology program in progress to produce a vehicle that will satisfy the Station requirements for a crew return vehicle. The experimental CRV (X-CRV) project has adopted the external shape of the X-23/X-24A lifting body developed by NASA and the USAF. The cross-range capability of the lifting body increases landing opportunities and reduces the time a returning crew must stay on orbit for emergency returns. The lifting body entry trajectory also reduces the g-levels that the crew sees (considered a significant factor for deconditioned crew members). The inherently poor low-speed flying characteristics of the lifting body are addressed by the use of a deployable parafoil to provide a fully automated slow-speed, low-impact landing.

Significant milestones and activities to date for the X-CRV project have involved design and analysis of the vehicle configuration, internal arrangements, structural layout, systems definition, aerodynamic and aerothermal analyses, and trajectory design. This design and analysis activity has been supplemented by test programs conducted at Johnson Space Center (JSC), Dryden Flight Research Center (DFRC), and other locations. Test activity to date has included subscale vehicle drop tests with a controllable parafoil, KC-135 flight testing of the guidance/navigation package, and full-scale parafoil tests with a KC-130 pallet loaded to produce the proper wing loading. Test benches of major vehicle subsystems are in buildup to allow system performance assessment and development of flight control and systems management software.

Full-scale “boilerplate” vehicles are being constructed under contract for use in further drop tests from a B-52 aircraft. These tests will study parafoil deployment and flight and landing characteristics and provide limited vehicle free-flight data. A fully functional, flight-capable vehicle will be designed, fabricated, and outfitted at JSC. This vehicle will be used for extensive ground test and systems checkout and may be flown in an unmanned test flight.

This project is directed toward providing the earliest feasible replacement for the Soyuz TM emergency return vehicle.

During the ISS assembly time period, the Soyuz TM will serve as the emergency return vehicle for the onboard Station crew. Currently, approximately 20 to 40 percent of the U.S. astronauts meet size limits imposed for the Soyuz TM spacecraft. As a short-term solution to the problem of the crew size limitations for the Soyuz TM, NASA is pursuing modifications to the crew seats and other interior hardware, which will allow a larger number of U.S. crew to fit within the Soyuz Descent Module. The proposed modifications could raise the number of U.S. astronauts to the 70 to 90 percent level. Modifications proposed by RSC-Energia will require 3 years to complete and thus could be completed as early as mid-1999. Funding for these changes will be by a modification to contract NAS 15-10110 and will specifically designate funds for the Soyuz TM design changes.

Finding #18

There are important ISS data processing items for which there are no written requirements. For example, it appears that there is no formal requirement that any specific portion of the computational system, software included, be operational at any stage of ISS assembly.

Recommendation #18

NASA should review ISS top-level requirements, and their flowdown, and add specific requirements where necessary to assure the correct, staged assembly of the station and its computer and software systems.

NASA Response to Recommendation #18

The ISS program is identifying stage unique requirements and will incorporate them in the specifications. Each stage is assessed to ensure it is safe, survivable, and able to be assembled.

Figure 1: Vehicle Requirements Documentation Cube

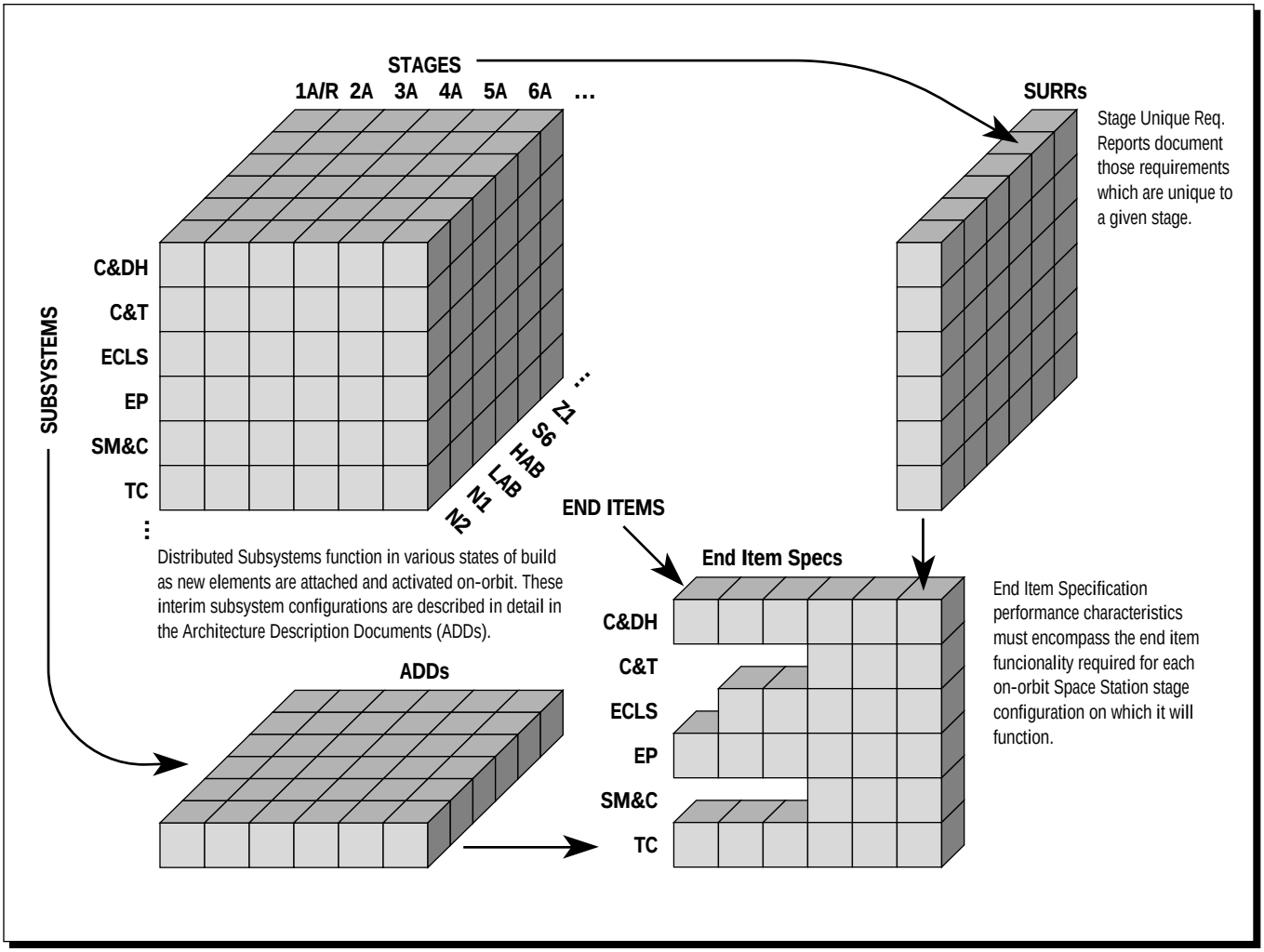

Figure 1

The functions required for each stage are identified in the Stage Functional Allocation Matrix. These functions may be implemented in hardware and software (see Figures 1 and 2).

The Assembly Implementation Requirements Document (AIRD) development process, in conjunction with the Design Analysis Cycle and Flight by Flight Reviews, identifies all of the necessary requirements (unique, partial, and assembly complete) for each stage. AIRD requirements that drive the design of hardware/software end items are captured in the end item development specifications, or an appropriate workaround is identified (e.g., flight support equipment, on-orbit support equipment, operational procedures).

The Stage Unique Requirements Report (SURR) documents the unique and partial requirements for each stage of the ISS assembly sequence. The SURR for a particular stage contains information such as: the interface definition between end items on that stage; the functional allocation matrix, summarizing the allocation of minimum functional capability required; stage unique requirements and the unique requirements necessary to support assembly, but not required upon assembly completion; partial stage requirements (those requirements that are a subset of an assembly complete requirement); the list of capabilities requiring fault detection, isolation, and

Figure 2: AIRD/SURR Development

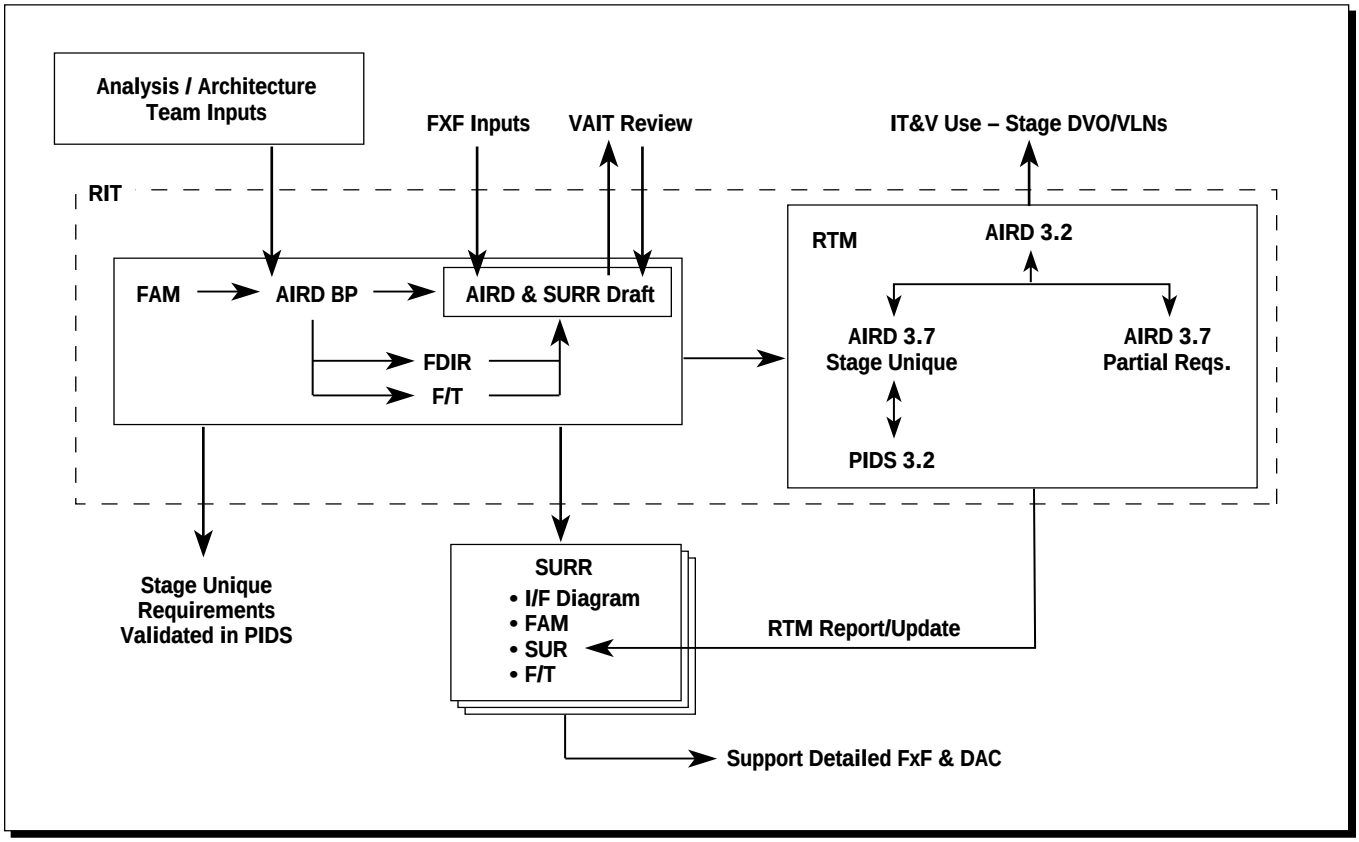

Figure 2

ensurance that this stage can be assembled, sustained, and safe until the next stage arrives; the failure tolerance requirements necessary to ensure that this stage can be assembled, sustained, and safe until the next stage arrives; and the operational constraints and vehicle limitations at this stage.

Finding #19

ISS computer system safety requirements, both hardware and software, have not been available in a timely manner to the product development teams. This is a matter of considerable concern. Also, the safety function of the Integrated Product Teams (IPTs) for computer system development appears less than totally effective.

Recommendation #19

NASA should review its computer system safety requirements and the integration of safety personnel into its IPTs to ensure that requirements are in place before they are needed and that safety activities are given proper coverage.

NASA Response to Recommendation #19

NASA has reviewed its computer system safety requirements and is now implementing those requirements. NASA has also integrated safety personnel into ISS IPTs. The Computer Safety Working Group of the Safety IPT has been formed to ensure that computer safety issues are resolved and that safety activities are given proper coverage.

The computer safety requirements developed at the end of the Freedom program were placed into section 3.7 of the system specification (SSP 41000) in December 1994. These formed the basis for the requirements that were developed with Integrated Product Team (IPT) representation and support beginning in January 1995 and culminating in SSP 50038B.

Although the process for implementing a new set of safety requirements seems lengthy, the task is now at completion and is entered in the formal CM process.

Finding #20

While the ISS computer architecture has been simplified considerably, there are still areas in which problems exist. The planned lifetime of the station will almost certainly require upgrades to various computer and avionics components, but there are no current plans for defining and managing upgrades.

Recommendation #20

NASA should have plans in place to test the robustness of the ISS computer architecture to ensure reserve memory and computing capacity throughout the station's lifetime and to provide an upgrade path for critical computer system components.

NASA Response to Recommendation #20

NASA has established computer resource allocation requirements within the USOS Segment Specification to save CPU and memory resources for operational growth

within the current architecture. Plans for defining and managing computer upgrades are addressed in the Program Sustaining Engineering Plan, which is in draft review. While there is no current plan for upgrade, components of the Multiplexer/Demultiplexers (MDMs) can be changed out to provide additional capability, or new processors with 1553 connectivity can replace existing MDMs.

Finding #21

Much of the testing for ISS software is based on the use of simulators for various components. If the simulations are not correct, errors in the flight software could go undetected. The simulators are not subject to the same level of Verification and Validation (V&V) as the flight software. The V&V of the simulators is "by use," which means that the principal validation of the simulations occurs at the same time that the simulations are being used to perform V&V on the flight software.

Recommendation #21

NASA should employ methods for more thoroughly verifying and validating the simulation models used in V&V activities for ISS flight software.

NASA Response to Recommendation #21

The Prime Contractor proposed the verification of simulations "by use," a method that was successfully employed on previous Boeing contracts. This method was accepted by the program to lower cost and schedule risk. This method varies from the traditional approach in that there is no formal verification of the simulation prior to verification of the flight software, but both are verified at the same time. The intent is to apply the same thoroughness to the verification of the simulation with the "by use" method as would be applied in the traditional software development approach. In addition, the recent Vehicle reorganization ensures appropriate testing of hardware and software outside of the Software Verification Facility as part of the verification process.

Finding #22

It is not at all apparent that there are adequate and consistent controls on the software development tools that are in use for creating ISS software. For example, software being developed for Multiplexer/Demultiplexers (MDMs) will be written in Ada and compiled using a certified compiler, while software for other device controllers may be written in a variety of languages and compiled with even an uncertified compiler. Also, a commercial code generator is being used beyond its intended domain.

Recommendation #22

NASA should immediately review all of its software development processes and tools to ensure a consistent and adequate level of certification.

NASA Response to Recommendation #22

NASA has worked with the Prime Contractor in reviewing the software development processes and tools being used on the program. NASA will continue to review software

development as part of its ongoing task to assure that the Government receives the best software products, given the cost and schedule restrictions that have been placed on the program. Specifically, a Software Control Board has been established to control software development, and NASA engineers will participate in Prime/Product Group design and test readiness reviews. Also, a specific hardware/software integration task has been focused on the Vehicle organization as part of a recent reorganization.

Finding #23

Initial ISS activities on Independent Verification and Validation (IV&V) of software appear to be following a logical and reasonable approach. The approach of bringing up issues at the lowest reasonable level and escalating up the chain of command as necessary is well advised and has been and should continue to be effective.

Recommendation #23

NASA should build upon the good start that has been made in the ISS IV&V effort.

NASA Response to Recommendation #23

NASA concurs. Safety and Mission Assurance (S&MA) works closely with the Independent Assessment Panel (IAP) in review of IV&V activity. NASA S&MA reviews all IV&V recommendations with IAP to determine whether the ISS program needs a special presentation on the issue/concern. NASA has continued to use IV&V in reviewing and providing recommendations in Space Station software activities.

NASA currently has a request for proposals out that will consolidate NASA-wide IV&V activities for the Agency. NASA has designated the Software IV&V Facility, Fairmont, West Virginia, as the Center of Excellence for software IV&V across the Agency. As the Agency focal point for software improvement and software IV&V, this facility acts as a catalyst to foster a heightened awareness of cost-effectively applied software in NASA's systems engineering program.

Finding#24

The reduction in full around-the-clock support from the Mission Control Center, the likelihood of unanticipated safety situations to which the crew must respond, and the extended mission durations suggest that the ISS strategy of deploying comprehensive on-orbit training resources using both computer-based training (CBT) and virtual reality (VR) techniques is appropriate.

Recommendation #24

The ISS should continue its excellent strategy of using both CBT and VR training on orbit. In addition, an effective on-call system to ensure the rapid response of mission support personnel on the ground should be developed.

NASA Response to Recommendation #24

We agree that there needs to be an effective plan to have people on call, and we plan to have a plan in place when the time comes. We have on-call plans for our Shuttle

missions today. It is too early to define specific plans, because we have not yet defined what our team rotation is going to be. We will also continue to develop CBT and VR training techniques to enhance both training on the ground and on-orbit training. For example, we are currently cofunding VR development activities with the Shuttle program within the Engineering Directorate at JSC.

Because of the unique continuous operations of the station (versus Shuttle limited flight duration), and due in part to an austere operations budget, the ISS program has significantly revised our plan for ISS MCC support as compared to the Shuttle. The team sizes have been reduced, and full manning is not planned around the clock. We believe there is justification for this reduction based on the ISS systems redundancies, safing procedures/concepts, and sufficient time to address failures (as compared with the Shuttle, which has the time-critical ascent and entry phases). We are also very aware that crew training must take a different approach from the traditional Shuttle training model. Because of the long duration of on-orbit time, and because some of the training will have to be accomplished at the international partner facilities, there will sometimes be a long time between training for an event and the actual event on orbit. Therefore, the ISS is assessing strategies for comprehensive on-orbit training using both CBT and VR techniques.

Finding #25

The currently proposed method for deorbiting/decommissioning the ISS at the end of its useful life entails a controlled, targeted reentry with surviving debris falling into a remote ocean area. The analysis and planning are based on having a fully assembled station and do not take into account deorbiting any of the possible configurations prior to completion.

Recommendation #25

NASA should develop plans for deorbit/decommission of intermediate ISS assembly configurations.

NASA Response to Recommendation #25

The planned concept for a controlled deorbit of the ISS at the end of its useful life may be applied to the intermediate assembly stages as well. The assembly complete configuration represents the most challenging configuration to deorbit because it has the highest mass and requires the most propellant and longest thruster burn times; however, analyses of the deorbit of intermediate stages is currently in progress.

Finding #26

Current ISS plans include extensive Extravehicular Activity (EVA). As a result, NASA has planned an improvement program for the existing Extravehicular Mobility Unit (EMU) or spacesuit.

Recommendation #26

Continue to support the EMU improvement program to ensure that the EMU can meet the increased EVA requirements.

NASA Response to Recommendation #26

NASA agrees that the EMU is a critical item for the assembly and maintenance of the ISS. EMU improvements have been and are being incorporated, including improved thermal protection for the astronaut and increased time between required maintenance activities. These improvements have been designed to increase the already significant capabilities and reliability of the EMU for its use on the ISS. NASA will continue to use EVA's during upcoming Space Shuttle missions to demonstrate EMU enhancements and new EVA procedures. The new hardware and procedures will be incorporated into training and flight plans and will help to ensure the EMU's successful support of the ISS program. NASA is also developing an interoperable EVA capability, including common foot restraints and common tethers, that will allow crew members in Russian Orlans (spacesuits) to perform tasks on U.S. elements and vice versa for contingency scenarios.

Prior to the STS-61 HST Servicing Mission 1, an EVA Detailed Test Objective demonstrated that in certain orbiter attitudes, an EVA astronaut can become unacceptably cold. Some hardware and procedural changes were implemented for STS-61 to solve that mission's needs. However, development of further improvements were determined to be needed for the harsher Space Station environment. Additionally, the new logistics requirements for the ISS program, including the increased frequency of EVAs and the fact that the EMUs would stay in orbit for longer periods of time and for a greater number of EVAs, required other improvements. The improvements under consideration include a number of thermal protection enhancements, making spacesuit sizing adjustments able to be performed on orbit, making EMU life support components more modular and removable on orbit, and increasing the maximum time allowed between maintenance activities. When possible, EMU enhancements are being demonstrated on Shuttle missions prior to their use on the Space Station.

Additionally, NASA has consolidated the Agency's EVA management and activities by establishing the EVA Project Office at the Johnson Space Center. The ISS program is committed to support that organization. The strength and leverage that the EVA Project Office can bring to bear will enhance our overall EVA capability.

C. AERONAUTICS

Finding #27

Congress has drafted legislation directing the privatization of the NASA microgravity research aircraft. No in-depth study has been completed on the safety ramifications of the transfer of the Johnson Space Center (JSC) KC-135 or Lewis Research Center (LeRC) DC-9 microgravity aircraft to commercial operation.

Recommendation #27

For reasons of safety, do not transfer any NASA microgravity research aircraft operations to a commercial provider until ongoing studies can assess the attendant safety issues. If economic or other reasons dictate that the aircraft must be transferred and time does not permit waiting for study results, then microgravity aircraft operations should be suspended until they can be certified safe under the aegis of the new operators.

NASA Response to Recommendation #27

NASA concurs that no transfer of NASA microgravity research aircraft, or any other aircraft, should occur until all safety issues have been identified and resolved.

Finding #28

Langley Research Center has commenced a joint Federal Aviation Administration (FAA)/NASA program to amass data that can be used to formulate operational procedures for avoiding or minimizing the effects of flying into aircraft-generated wake vortices. This program has begun to shed light on an important area of flight dynamics suspected of having contributed to aircraft mishaps.

Recommendation #28

The wake vortex research program should be strongly supported, and whenever meaningful data are derived, these data should be exported to the National Transportation Safety Board (NTSB), the FAA, and the entire spectrum of commercial, military, and general aviation.

NASA Response to Recommendation #28

It is NASA's intention to continue strong support for, and to provide the widest possible distribution of information derived from, the joint NASA/Federal Aviation Administration (FAA) wake vortex program. One of the program's prime objectives is to develop data useful to the FAA, the National Transportation Safety Board, as well as commercial, military, and general aviation so that those entities can formulate procedures to avoid and minimize the effects of aircraft-generated wake vortices.

Finding #29

The Dryden Flight Research Center's Basic Operations Manual (BOM) describes a proactive attitude toward safety that is exemplary and worthy of emulation throughout NASA.

Recommendation #29

Other centers and NASA contractors could profit from the use of the Dryden BOM as a model.

NASA Response to Recommendation #29

NASA agrees that the Dryden Flight Research Center's Basic Operations Manual (BOM) describes a proactive attitude toward safety that is exemplary and worthy of emulation throughout NASA. The Dryden BOM was installed on the Internet 2 years ago and can be accessed from the Dryden home page. This will ensure its availability to other NASA centers and contractors for use as a model in developing or improving their own operations documentation.

D. OTHER

Finding #30

NASA researchers have examined the impact of fatigue and circadian disruption on pilots and shift workers and developed a Fatigue Countermeasures Program. Material developed by the Fatigue Countermeasures Program is now in widespread use at airlines and elsewhere. Tens of thousands have received training and guidance on effective ways to manage fatigue through symptom identification and scheduling/behavioral, physiological, pharmacological, and technological countermeasures.

Recommendation #30

Methods for fatigue identification and material on effective fatigue countermeasures should be incorporated in training, including that for astronauts, flight crews, ground crews, and mission controllers. These groups are often forced to vary their work-hours and could therefore benefit from the information now widely being used throughout the transportation industry.

NASA Response to Recommendation #30

NASA agrees with the recommendation that a comprehensive fatigue countermeasures program for astronauts, flight crews, ground crews, and mission controllers must be identified and included in training for these groups. To accomplish this, we will obtain and evaluate the fatigue countermeasures program developed by the Ames Research Center (ARC) for its operational suitability and applicability for the aforementioned groups. NASA is currently evaluating flight-suitable methods of assessing and managing fatigue and countermeasures to promote restful sleep that will be integrated into the NASA Fatigue Countermeasures Program. The Behavior and Performance Integrated Project Team of the Space Medicine Program is charged with identifying and implementing a suitable fatigue countermeasures program for astronauts and ground support crews. We perceive that elements of the ARC program, along with specific methods developed at JSC, will constitute the comprehensive operational fatigue countermeasures program.

Finding #31

The Senior Managers Safety Course conceived and conducted by JSC is an outstanding overview of philosophies, techniques, and attitudes essential to a successful safety program.

Recommendation #31

A safety course for senior managers similar to the one conducted at JSC should be established at other NASA centers and Headquarters. Consideration should also be given to exporting the course to major NASA contractors and including its elements in managerial training programs.

NASA Response to Recommendation #31

The Senior Managers Safety Course conducted at JSC has become the benchmark at NASA for establishing enhanced safety awareness at the Center Director level. The Associate Administrator for Safety and Mission Assurance coordinated and promoted the awareness course during presentations on April 9–11, 1996, in Houston, Texas, to NASA Center Directors, senior managers, and senior safety, reliability, maintainability, and quality assurance personnel. Attendees highly praised the course and recommended enhancing senior participation by request of the NASA Deputy Administrator. The Deputy Administrator will invite all Center Directors to a second presentation at JSC in the fall of 1996. The goal will be to transport this course using the "train the trainer" concept to each participating NASA center, with the objective of keeping safety and mission success foremost in every NASA operation.

Finding #32

NASA's ongoing reorganization and the intention to pass responsibility for Space Shuttle operations to a single Space Flight Operations Contractor (SFOC) have potential safety implications. To this point, other than an effect on morale at KSC due to uncertainty, no significant problems have surfaced.

Recommendation #32

NASA leadership and top management should continue active and detailed involvement in the safety aspects of planning for and oversight of the NASA reorganization in general and Space Shuttle operations in particular.

NASA Response to Recommendation #32

NASA's top priority throughout the restructuring process and implementation of the SFOC has been, and will continue to be, maintenance of safety. Safety considerations are currently embedded in the program management processes and will remain so. To help assure this, the Associate Administrator for Safety and Mission Assurance (S&MA) at NASA Headquarters has formed a Human Exploration and Development of Space (HEDS) Assurance Board, which includes in its membership the S&MA Directors of JSC, MSFC, KSC, and SSC and the Shuttle S&MA Technical Manager's Representative (TMR) from the Program Office. The HEDS Assurance Board charter is to monitor program safety implementation and provide guidance through transition to the SFOC.

The Lead Center Director (LCD) at JSC has established the position of Associate Director (Technical) with responsibility for overseeing program safety and providing recommendations to the Center Director. (Astronaut John Young currently occupies this position.) The LCD receives weekly SFOC implementation status from the Program Manager as well as monthly program issues reports, which are shared with the Associate Administrator for Space Flight.

Additionally, the Program Manager provides status briefings to the OSF Management Council (the Associate Administrator for Safety and Mission Assurance is a member) quarterly or as requested.

The implementation of Space Shuttle program streamlining and the SFOC is, therefore, receiving top-level management visibility and guidance on a routine basis. Even so, NASA is being extremely careful in implementing the SFOC. For example, particular attention is being paid to safety considerations at KSC, where the flight hardware will be processed by the SFOC. There, NASA will be instituting an extensive audit, surveillance, and independent assessment of SFOC processing activities that are required to be compliant with existing NASA-approved processes. The KSC management team will be retained as an integral part of the program management structure and will maintain insight into SFOC launch, landing, logistics, and S&MA activities. This team will continue to play a major role in Flight Readiness Review (FRR) activities with full membership on the FRR Board. Finally, we believe execution with the incumbent operations support contractors for the SFOC provides maximum assurance of continuation of safe operations.

Finding #33

The plan for Space Shuttle restructuring and downsizing provides that NASA personnel will be involved in the resolution of any off-nominal events that are beyond the operating experience base or "out-of-family." This places extreme importance on the development and implementation of the definition of an out-of-family situation.

Recommendation #33

NASA personnel with direct Space Shuttle operations experience should be involved not only in the derivation of the definition of out-of-family but also in the day-to-day decisions on what constitutes an out-of-family event.

NASA Response to Recommendation #33:

The Space Shuttle program management plans to maintain full capability for identifying, evaluating, and resolving all anomalous performance of Space Shuttle systems. To support this objective, the program has developed general definitions of "In-Family" and "Out-of-Family" characteristics for all Shuttle systems and processes, which will serve as performance classification criteria. NASA will use its most experienced and skilled personnel to develop detailed definitions and data bases. With the implementation of the Space Flight Operations Contract (SFOC), the program is transferring responsibility for routine operations activities to the contractor, which will be accountable for classifying performance as either "In-Family" or "Out-of-Family" per the definitions and consistent with well-defined systems and processes performance data bases. The SFOC contractor will be required to report and interface with NASA on a daily basis to ensure that appropriate data are exchanged to identify "Out-of-Family" issues. Additionally, NASA will perform audit and surveillance of the operation using

NASA technical and operations experts. Metrics will be developed that will support the identification of "Out-of Family" issues as well as the health of the processes.

For evaluating those issues reported as "Out-of-Family," the program will retain a core team of NASA experts in each area (e.g., KSC ground operations, JSC flight operations, orbiter, flight software, etc.) that will be capable of performing independent assessment of issues and making recommendations to the Program Manager. In this approach, the Program Manager requires these NASA experts to concur in "Out-of-Family" resolutions.

Finding #34

New propulsion control modes utilizing neural nets are under development. The use of neural nets raises questions of how such control software are to be verified and validated for flight operations. There may be a technology/certification mismatch at present.

Recommendation #34

The Ames Research Center in its capacity as designated Center of Excellence for information systems technology should undertake the research and technology necessary to provide NASA with appropriate V&V techniques for neural net control software.

NASA Response to Recommendation #34

NASA is developing propulsion control modes utilizing neural networks. We have initiated research into the development of methods and processes that will allow us to qualify the software used in the operation of these networks for flight. Our initial effort will be focused on qualifying the neural network software for flight in one of our testbed aircraft. NASA is also working with the FAA to identify research needed to support certification across a broad range of technologies. This is clearly a new technology that requires innovative methods for certification. We have also detailed a full-time employee to work at the FAA to coordinate matters concerning aircraft and systems certification.

Finding #35

While hardware typically gets adequate coverage from the Safety and Mission Assurance organizations at the NASA centers, there is evidence that software does not.

Recommendation #35

The Headquarters Office of Safety and Mission Assurance should examine the depth of the software assurance process at each of the centers and promulgate NASA-wide standards for adequate coverage.

NASA Response to Recommendation #35

NASA agrees with the importance of this recommendation. The NASA Software Assurance Standard (NASA-STD-2201-93) promulgates commonality and provides

direction on what activities are to be performed for software assurance across the Agency. The NASA Software Safety Standard (NSS 1740.13) was added to the Safety Standards series in 1996. The addition of the software safety standard and guidebook will assist projects to plan and budget for software safety as software increases in criticality and importance in NASA systems.

The generation of requirements for the Shuttle and the International Space Station (ISS) programs predates the issuance of the NASA Software Assurance and Safety Standards. The process used in past developments and in changes to an operational system, such as the Shuttle, imposes demanding mission safety assurance standards on the software process. The process of verification, testing, and certification of flight software, within NASA, has been subjected to a rigorous set of standards, configuration control, and testing. The process used, including standards, configuration control, verification, and certification, is the result of 30 years of space flight and is documented in JSC documents, contractor documents, and STS 07700, System Requirements Specification.

NASA is using, for the ISS development, primarily Department of Defense (DOD) Standards in acquisition, review, and development of software. These standards are: DOD-STD-2167A, Defense System Software Development, and DOD-STD-2168, Defense System Software Quality Program. The emphasis of DOD-STD-2167A is on activities to be performed during software engineering, with the activities more oriented toward managing the software development effort. The requirements of DOD-STD-2168 affect all aspects of the software development effort, including the software engineering methods, products, and testing. For example, within contract NAS15-10000 (NASA's contract with Boeing for the International Space Station) section C, 1.3.2-5 reads "Integrate and build software for the U.S. On-Orbit Segment and MBF in accordance with DOD-STD-2167A (as tailored by the Software Development Plan) and the Software Standards and Procedures Specification." In addition, SSP 41173 (Space Station Quality Assurance Requirements) paragraph 4.0, Software Quality Assurance reads "Software Quality Assurance shall be in accordance with DOD-STD-2168, and the following additions. . . ." International Space Station software safety requirements are defined in SSP 50038B, Computer Based Control System Safety Requirements.

The Functional Management Review (FMR) activity, begun at NASA in 1994, governs the process by which management processes are reviewed and validated. Important to the review process are corporate-level spot checks to ensure that center implementation of OSMA policies are valid. Recently, the Safety and Mission Assurance (S&MA) FMR and spot check processes have been further augmented by the Process Verification (PV) initiative. This initiative is being defined to examine the adequacy of selected S&MA processes and the associated expertise available at each center S&MA organization for performing these processes.

One such process to be verified is the software assurance process as it is applied at the center with respect to NASA-STD-2201-93. Process Verification will provide the Agency the confidence that proper skills and personnel exist to adequately perform software assurance for each center. Software assurance has a high priority to be verified within the first year of the PV initiative.

ATTACHMENT 1
BACKGROUND INFORMATION

Background Information for Topic #15:

It is stated in various paragraphs* that localization of events is either not possible or done at a minimal level. This comment can be addressed either globally or specifically. On a global level, localization is performed to the highest degree possible given current design constraints, hold-over Freedom architectures directed for implementation on the ISS, and cost benefit decisions made within the ISS program. Specifically addressing the three emergencies—Fire, Rapid Decompression, and Toxic Spill—it becomes an argument of personal choice and belief structure. While it is true that a fire event cannot be localized to the "box" level, it is believed that the current "fire control zone" concept provides adequate isolation for suppression and avoidance techniques. Each rack deemed a credible fire risk is provided a smoke sensor, and other areas such as standoffs and end cones are protected by area smoke detectors. This protection scheme has undergone in-depth review by design, safety, and crew communities.

Toxic spill localization has never been designed into the Station architecture. It has been the long-standing position of both the Freedom and ISS communities that the annunciation of toxic spills will be manually initiated by the crew, and as such no remote localization capabilities have been put in place. It is true that no automated means exist to detect toxic spills.

The localization of rapid decompression event involves either a hull penetration or leak of some type. Localization of this event is currently possible only with manual crew procedures and strictly enforced hatch protocols. The current design supports this operation and provides safe localization of reasonably sized penetrations. The crew office has accepted this design and has already developed this manual crew procedure. The old Freedom design did include an automated system to determine module penetration location via triangulation of high-frequency sound associated with escaping gas. This system was referred to as the HISS system and was deleted mid-duration of the Freedom program due to budget constraints and concern over the system design.

More detail on Fire Detection and Suppression (FDS), toxic spills, and rapid decompression should be obtained from the Life Support AIT, which maintains the requirements for safing of these hazards. The SMC AIT controls the requirements for fault detection, isolation, and safing for all other events, as well as annunciation requirements (audio and textual) throughout the Station.

The Portable Computer System (PCS) use in C&W localization was alluded to being nonexistent and should be "explored again." The PCS does indeed experience Single

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* Reference: Section III, Information in Support of Findings and Recommendations, ASAP Annual Report, February 1996.

Event Upsets (SEUs) and is deemed a criticality 3 device, but it is still being used to enhance current C&W system functionality.

The PCS is being designed to provide a textual interface to C&W messages, logs, and ancillary data used for localization. The Common Display Development Team (CDDT) has designed display navigation schemes and dedicated displays to aid in failure (also known as C&W) localization and description. The SMC team is providing detailed lists of C&W event identifiers (Program Unique Identifier or PUI) through the User Interface Requirements Document (UIRD). The C&W panels and Audio system meets all criticality 1 requirements for annunciation, while the PCS serves to enhance the overall design and provides a more palatable crew interface. The criticality of SEUs should be tempered by the fact that at Assembly Complete, the ISS will contain a total of 15 PCSs with the capability for 8 core PCSs and 5 payload PCSs to be operating at any given time. It is reasonable to assume that the crew can rapidly locate an operational PCS given these numbers and the low probability of multiple, simultaneous SEUs. It is the SMC team's position that the PCS is being utilized appropriately for C&W annunciation and event localization.

Appendix C

AEROSPACE SAFETY ADVISORY PANEL ACTIVITIES JANUARY–DECEMBER 1996

JANUARY

18 Panel Annual Report Editing Committee Meeting at Headquarters
31 Space Shuttle Operations Discussions with NASA Alumni League at Headquarters

FEBRUARY

5–7 Kennedy Space Center Restructuring and Morale Briefing and Discussions
21 Aerospace Safety Advisory Panel Meeting with Administrator
29 Aerospace Safety Advisory Panel Annual Meeting at Headquarters

MARCH

12–13 Intercenter Aircraft Operations Panel Meeting at Kennedy Space Center
26 Software Review at Independent Verification and Validation (IV&V) Facility, Fairmont
26–28 International Space Station IDR2A Outbriefing at Johnson Space Center
27 Software Security Briefing and IV&V Review with Associate Administrator for Safety and Mission Assurance at Headquarters

APRIL

1–3 National Research Council Committee Meeting on Space Station Meteoroid/Debris Risk Management at Johnson Space Center
8 Space Shuttle Discussions with Associate Administrator for Space Flight at Headquarters
9–10 Aeronautics Safety and Software Briefings at Ames Research Center
17 Subcommittee on Space and Aeronautics Hearing, “The Fiscal Year 1997 NASA Authorization,” Washington, DC
17–18 Integrated Logistics Panel Meeting at Marshall Space Flight Center
17–18 International Space Station Quarterly Reviews at Rocketdyne and McDonnell Douglas

May

7	Software Review at Johnson Space Center
8	Review of Space Shuttle Main Engine Testing and Fuel Pump Certification at Stennis Space Center
9	Review of Super Light Weight Tank Development at Michoud Assembly Facility
14–16	Kennedy Space Center Operations Review
21	Review of Improved Auxiliary Power Unit program at Sundstrand
29	Discussions with Associate Administrator for Safety and Mission Assurance

June

12	Space Shuttle Program Review Planning Meeting at Headquarters
18–20	STS-78 Prelaunch Review and Launch
20	Space Shuttle Program Review Discussions with Inspector General
	Space Shuttle Program Review Discussions with Office of Space Flight

July

10–11	Review of Solid Rocket Booster Safety Program at Thiokol
15	Intercenter Aircraft Operations Panel Meeting at Headquarters
18	Space Shuttle SFOC Planning Meeting at Headquarters
24	Panel Plenary Session at Headquarters
25	Office of Space Flight Space Shuttle Program Briefing at Headquarters
	Space Shuttle Program Discussions with Administrator at Headquarters
	Space Shuttle Program Discussions with Office of Science and Technology Policy in Washington
30	Panel Steering Committee Meeting re Space Shuttle Program Review

August

1	Review of Aeronautics Safety Programs at Langley Research Center
6–8	Panel Plenary Session and Review of Space Shuttle and Space Station Programs at Johnson Space Center
14	Lead Center Concept Discussions with Office of Space Flight
16	Multiplexer-Demultiplexer Program at Honeywell Review
21–23	Kennedy Space Center Operations Review
27	Downsizing Discussions with Office of Space Flight and Associate Administrator for Headquarters Operations
27–28	Caution and Warning Briefing and Independent Safety Oversight Discussions at Johnson Space Center

29 STS-79 Flight Readiness Review
Independent Safety Oversight Discussions at Stennis Space Center and Michoud Assembly Facility

September

6 Independent Safety Oversight Discussions at Marshall Space Flight Center
10 Downsizing Discussions with Marshall Space Flight Center
11 Lead Center Concept Discussions at Marshall Space Flight Center
16 Panel Plenary Session at Lancaster, CA
17–18 Aeronautics Safety Program Review at Dryden Flight Research Center
18 Space Shuttle Main Engine and Aerospike Engine Safety Program Reviews at Rocketdyne
19 Space Shuttle Orbiter Safety Review at Rockwell
25 Space Shuttle Program Discussions with NASA Alumni League
30 Software Team Review at Fairmont IV&V Facility

October

7 Plenary Session in Huntsville, AL
8 Review of Solid Rocket Booster, Reusable Solid Rocket Motor, Space Shuttle Main Engine, External Tank/Super Light Weight Tank Programs at Marshall Space Flight Center
9 Review of Safety and Mission Assurance and Reusable Launch Vehicle Programs at Marshall Space Flight Center
10 Review of International Space Station Program at Marshall Space Flight Center
22 Panel Editorial Committee Meeting

November

19–21 Plenary Session and Preparation and Review of Annual Report
25–26 Review of the Super Light Weight Tank Program at Michoud Assembly Facility

December

3–4 Editorial Committee Meeting
16–17 Editorial Committee Meeting
17 Telecon with Johnson Space Center and Reusable Solid Rocket Motor