E. OTHER

Ref: Finding #29
The Simplified Aid for EVA Rescue (SAFER) is a small maneuvering unit intended to fit at the bottom of the Portable Life Support System (PLSS) of an EVA astronaut. Its design purpose is to permit an astronaut who becomes untethered from the Space Station or a Space Shuttle to return safely. This potential problem is not considered great for a free flying Shuttle since it can maneuver immediately to retrieve an astronaut who is drifting away. It can be serious, however, if the Space Shuttle is attached to the Space Station or another satellite and is not free to maneuver quickly.

In addition to astronaut rescue, there are also contingency situations which cannot be resolved at present because an EVA astronaut is unable to maneuver to the source of the problem. For example, if there were an indication that an ET umbilical door on the Orbiter had failed to close, the crew would have no way to perform a visual inspection to confirm the validity of the warning.

Since SAFER was designed primarily for rescue, it does not include the degree of redundancy typical of human-rated flight systems. It was reasoned that a single string system would be adequate for rescue objectives. However, this lack of redundancy appears to have deterred NASA from expanding the use of SAFER to the contingency situations in which it can be a significant benefit.

Five flight units have been ordered. Three of these will be deployed on the Mir and Space Station. The two remaining units are to be flown on the Space Shuttle only when an EVA is planned. This deployment strategy does not make full use of the safety benefits of flying SAFER. Given that a problem has occurred such as an indication of an unlatched ET door or the suspicion of tile damage, it would likely be an acceptable risk to employ a SAFER unit to inspect or correct the situation. In general, if there is the possibility of a corrective or confirmatory action to increase flight safety, the small additional risk arising from the lack of redundancy in SAFER can be tolerated.

Based on these considerations, it would appear reasonable to carry one or two SAFER units on all Space Shuttle missions once the flight units are available. These units are relatively light weight and have minimal logistics requirements. They stow in the airlock on the PLSS, so they do not require any Orbiter modifications. The availability of the SAFERs will provide mission planners with a significant increase in flexibility to handle contingencies which might arise. The only exception to the general deployment of the SAFERs would arise on those missions which are severely weight limited and do not have any planned EVAs. NASA should examine the logistics and costs associated with a more widespread use of SAFER, and, if necessary, procure additional flight units to support an expanded role for SAFER.

Ref: Finding #30
Over the past several years, NASA has received recommendations from the General Accounting Office, the ASAP and the National Research Council among others stating that the agency needed to give greater attention to potential software problems. Early in the year, NASA established a Software Process Action Team (SPAT) to review and develop plans for addressing the plethora of software concerns that have been raised. The problem with the initial implementation of the SPAT was that several of the NASA organizations involved in software development were permitted to bypass participation.

The SPAT has been addressing a broad range of important software and process issues, including:

- software development processes
- software management processes
- training of developers and managers in software technology
- software acquisition processes
- the mandating of processes
- the role of a lead center in software management
- roles, responsibilities and reporting structure of the Software Working Group
- inclusion of people with a software background in the Systems Engineering Process Activity
- access to launch software of purchased launch vehicles in view of the Commercial Launch Act.

It is important that the SPAT focus on the level of recommendation that can lead to useful work and not get mired in excess detail. It is better to focus at this stage on what needs to be done rather than a formula for doing it.

The SPAT was charged with producing a comprehensive report after a small number of meetings. In retrospect, there may be too much in the task statement for the time allowed. NASA should ensure that computer software issues are given high priority throughout the agency and that those addressing these issues are given the support needed to produce adequate ways of dealing with them. The creation of the SPAT was an important initial step toward dealing with complex safety critical problems, but more needs to be done. In particular, all affected groups should be required to participate in these activities.

Ref: Finding # 31
There were several in-flight and ground-based episodes in which astronauts developed adverse reactions to substances used in human experiments. Although within the anticipated outcomes of the experiments, these events raise a concern with regard to the particular needs of protecting human subjects in a space flight environment. An aspect of the problem appears to be that there is insufficient independent oversight within NASA of the safety of human experiments. The researchers all submit their protocols to a standard Institutional Review Board (IRB) process. This is a good step, but it is a peer review and the IRB members may not necessarily be knowledgeable about the unique aspects of human experimentation aboard a spacecraft. Since NASA has the Office of Safety and Mission Assurance (OSMA) and it has responsibility for incident investigations, it would seem appropriate for OSMA to become involved in at least two areas related to human experimentation. First, OSMA could establish a review process to augment the standard IRB. Second, it could ensure that the Shuttle and Space Station systems requirements provide sufficient equipment, staffing and training to deal appropriately with any problems which might be experienced. Together with the standard IRB, the OSMA review would add significant breadth to the oversight of the safety of human experiments.

Ref: Finding #32
The ASAP has maintained a continuing interest in the Aviation Safety Reporting System (ASRS) since ASRS was established in 1975. In that year, the FAA asked NASA to develop and operate the system, acting as a neutral third-party between aviation operating personnel and the FAA. The ASRS was designed to receive voluntary reports of unsafe occurrences and hazardous situations, process, analyze, and interpret these reports, and disseminate findings and recommendations to the aviation community. The program is well managed,

extremely well-accepted by the aviation community, and the system has contributed to aviation safety by reporting insights and advisories that otherwise might be suppressed or lost through a highly-structured regulatory process. The value of the system has been confirmed repeatedly by operating and management personnel.

A recent report on the ASRS by a study team from the National Academy of Public Administration (NAPA) provided a thorough and complimentary review of ASRS (*A Review of the Aviation Safety Reporting System*, NAPA-August 1994). Given the many benefits of ASRS identified by NAPA, NASA and the FAA should restore the full capability of analysis, interpretation, and dissemination of the ASRS and promote electronic dissemination and expanded educational outreach.

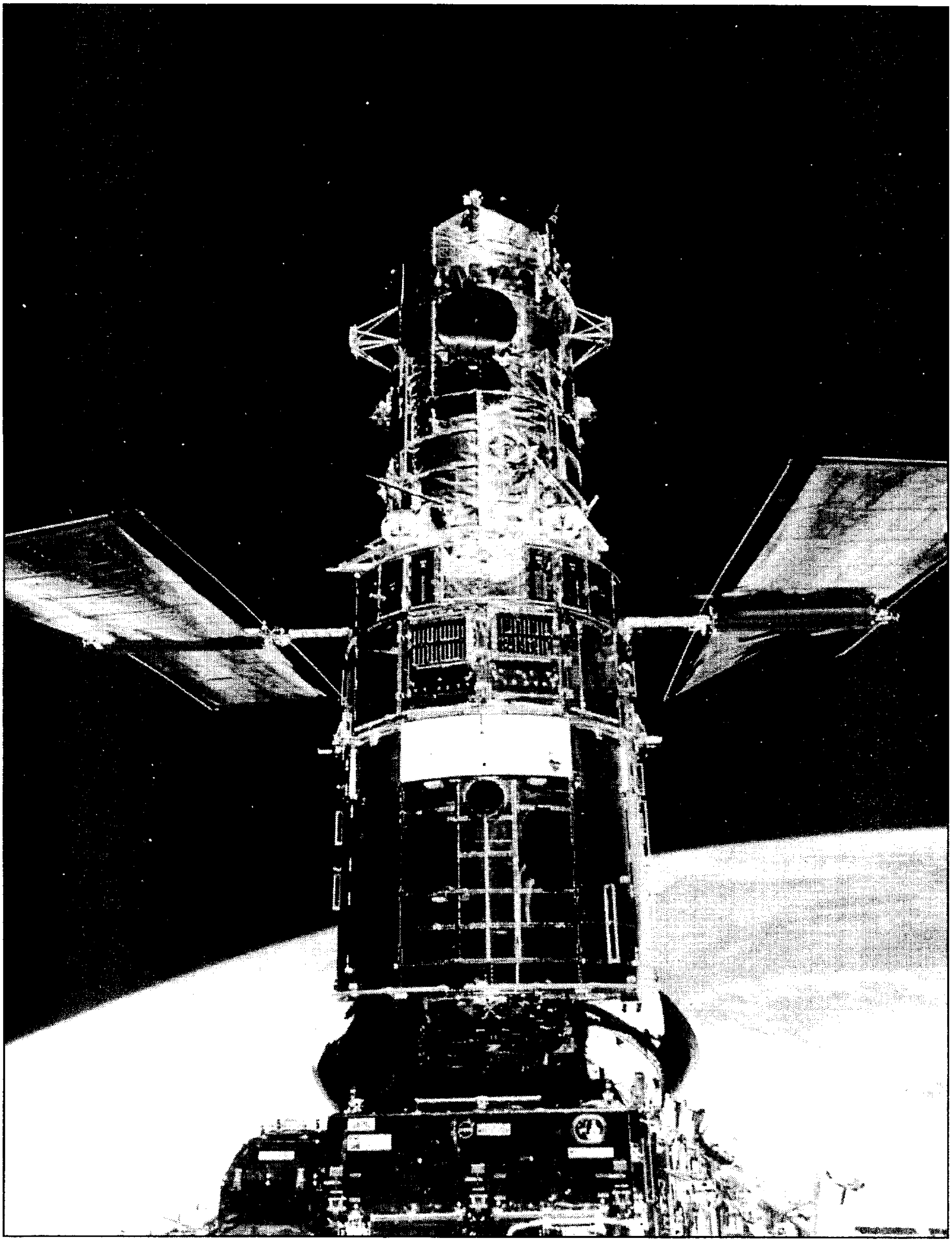
Ref: Finding #33

NASA's predecessor organization, the NACA, in establishing its research agenda, benefitted from the advice of experts drawn from industry, the government and academia through an advisory committee structure. One such committee, the Committee on Aircraft Operations, provided advice in problem areas relating to meteorology, fire prevention, noise and flight safety. A similar panel was eliminated during a period when NASA was required to reduce the number of its advisory committees. This has created a void in the input NASA receives to define its aeronautical and flight safety research programs which should be filled. It may be possible to obtain the needed advice through the restructuring of the existing committee structure.

Ref: Finding #34

In previous reports, the Panel has questioned the commitment of the entire NASA/contractor team to the practice and principles of Total Quality Management (TQM). Whatever misgivings which may have once prevailed are now assuaged and the Panel is convinced that NASA and its contractors do, indeed, have TQM programs worthy of emulation by others both in and out of government.

IV. APPENDICES



APPENDIX A

NASA AEROSPACE SAFETY ADVISORY PANEL MEMBERSHIP

CHAIRMAN

MR. NORMAN R. PARMET
Aerospace Consultant
Former Vice President, Engineering
Trans World Airlines

DEPUTY CHAIRMAN

MR. PAUL M. JOHNSTONE
Consultant, Former Senior Vice
President, Operations Services
Eastern Airlines, Inc.

MEMBERS

MR. RICHARD D. BLOMBERG
President
Dunlap and Associates, Inc.

MS. YVONNE C. BRILL
Aerospace Consultant
Former Space Segment Engineer
INMARSAT

VADM ROBERT F. DUNN, USN (RET)
Aerospace Consultant/Author
Former Deputy Chief of Naval
Operations Air Warfare, Pentagon

DR. GEORGE J. GLEGHORN
Aerospace Consultant
Former Vice President & Chief Engineer
Space & Technology Group, TRW, Inc.

DR. NORRIS J. KRONE
President
University Research Foundation

MR. MELVIN STONE
Aerospace Consultant
Former Director of Structures
McDonnell Douglas Corporation

DR. RICHARD A. VOLZ
Head, Department of
Computer Sciences
Texas A&M University

CONSULTANTS

MR. CHARLES J. DONLAN
Aerospace Consultant
Former Deputy Director
NASA Langley Research Center

MR. JOHN A. GORHAM
Aerospace Engineering
Gorham Associates

DR. SEYMOUR C. HIMMEL
Aerospace Consultant
Former Associate Director
NASA Lewis Research Center

MR. JOHN F. MCDONALD
Former Vice President
Technical Services
TigerAir, Inc.

DR. JOHN G. STEWART
Director
Consortium of Research Institutions

DR. WALTER C. WILLIAMS
Aerospace Consultant
Former NASA Chief Engineer

EX-OFFICIO MEMBER

MR. FREDERICK D. GREGORY
Associate Administrator for
Safety and Mission Assurance
NASA Headquarters

STAFF

MR. FRANK L. MANNING
Executive Director
NASA Headquarters

MS. PATRICIA M. HARMAN
Staff Assistant
NASA Headquarters

APPENDIX B

NASA RESPONSE TO MARCH 1994 ANNUAL REPORT

SUMMARY

NASA responded on July 1, 1994 to the "Findings and Recommendations" from the March 1994 Annual Report. NASA's response to each report item was 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 1994 period, the Panel considers that the following is the status of the recommendations made in the 1994 Report.

	RECOMMENDATION	
NUMBER	SUBJECT	STATUS
1	U.S. and Russian Space Program safety concerns	CONTINUING
2	Impact of space debris on long-duration missions	CONTINUING
3	Space Station structural dynamics in collision-avoidance maneuvering	CONTINUING
4	Space Station Crew Rescue	CONTINUING
5	KSC Continuous Improvement	CLOSED
6	Impact on safety as a result of cost reductions at KSC	CONTINUING
7	KSC Space Shuttle processing problems due to human factors	CLOSED
8	KSC Structured Surveillance Program	CLOSED
9	Thermal damage to OV-103 elevon tiles	CLOSED
10	Development of improved tiles	CLOSED
11	Multipurpose Electronic Display System	CONTINUING
12	Improved Auxiliary Power Unit	CLOSED
13	Autoland	OPEN
14	Space Shuttle Main Engines (SSME)	CLOSED
15	High Pressure Fuel Turbopump (HPFTP)	CLOSED
16	SSME Block II development	CLOSED
17	Engine Sensors	CONTINUING
18	SSME health monitoring system	CONTINUING
19	Solid Rocket Motor Aft Skirt Stress	CONTINUING
20	Redesigned Solid Rocket Motor (RSRM) forward casing crack	CLOSED
21	Use of Advanced Solid Rocket Motor design features in the RSRM	CLOSED
22	Monitoring chamber pressure in RSRMs	CLOSED
23	Super Light Weight External Tank	CONTINUING
24	Integrated Logistics Panel Support to entire logistics program	CLOSED
25	Vision 2000 effects on logistics program	CLOSED
26	Just-In-Time manufacturing and shelf stocking concept	CLOSED
27	Main logistics system performance	CLOSED
28	Dryden Flight Research Center (DFRC) range safety policy and system	CLOSED
29	DFRC Flight Safety and Mission Assurance Organization	CLOSED
30	X-31 aircraft stability	CLOSED
31	Agencywide policy and process for software	CONTINUING
32	Space Human Factors Engineering Program	CONTINUING
33	Total Quality Management principles and practices	CLOSED

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

JUL 1 1994

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

Dear Mr. Parmet:

In accordance with your introductory letter to the March 1994 Aerospace Safety Advisory Panel (ASAP) Annual Report, enclosed is NASA's detailed response to Section II, "Findings and Recommendations."

The ASAP's commitment to assist NASA in maintaining the highest possible safety standards is commendable. Your recommendations play an important role in risk reduction in NASA programs and are greatly appreciated.

We thank you and your Panel members for your valuable contributions. ASAP recommendations are highly regarded and receive the full attention of NASA senior management. We look forward to working with you.

Sincerely,

Daniel S Goldin

Daniel S. Goldin
Administrator

Enclosure

1994 AEROSPACE SAFETY ADVISORY PANEL REPORT FINDINGS AND RECOMMENDATIONS

A. SPACE STATION PROGRAM

Finding #1: Joint U.S. and Russian space programs, including the Space Station, are now underway. Potential safety concerns arising from these collaborative efforts have not yet been completely defined or addressed.

Recommendation #1: Safety requirements for the joint programs should be established from a thorough understanding of the underlying policies of design, test, and review in use by each country. Timely total systems analyses should be conducted to ensure adequate safety of components and interfaces as well as overall system safety.

NASA Response: Safety concerns will be addressed by obtaining agreement from both NASA and the Russian Space Agency (RSA) on a common set of technical safety requirements and a review process.

The technical safety requirements for the Russian Segment Specification are intended to be the same as those being imposed on the other international partners. Of the 122 identified safety requirements, 92 have agreement, 15 have pending agreement, and 15 are still under negotiation. Presently, the Russians do not implement a safety review process similar to NASA's. The NASA safety review process is based on hazards analyses at the subsystem, system, and integrated levels. The closest equivalent in the Russian process is a review of "off-nominal" situations. Negotiations are in process to evaluate the Russian off-nominal situation process for compatibility with hazards analyses and to ensure that appropriate steps are implemented to address hazards with Russian hardware. The latest draft of the NASA/Russian memorandum of understanding provides for a NASA/Russian safety review process in Article 10, Safety and Mission Assurance.

Finding #2: Much good work has been done to assess the impact of space debris on the long-duration mission of the Space Station, and significant accomplishments have been made in developing shielding to protect the Station. However, there is still insufficient information on the probability that penetrations will have a catastrophic effect.

Recommendation #2: To support effective risk management, NASA should continue its emphasis on space debris problems, including a better characterization of the risk of catastrophic failures and an assessment of the capability to add shielding on orbit.

NASA Response: The international Space Station program is continuing to place strong emphasis on understanding, characterizing, and mitigating the risks associated with meteoroids and orbital debris. A Meteoroid/Debris Analysis and Integration Team (M/D AIT) consisting of NASA, contractor, and international partner technical experts is active and reports directly to the Vehicle Analysis and Integration Team.

The M/D AIT comprehensive strategy for managing M/D risks consists of a three-part approach; protection, avoidance, and risk abatement. Protection systems (state-of-the-art shielding) are baselined to prevent penetrations of critical elements for particles that are sized less than 1 cm. Collision-avoidance procedures will be implemented to protect the Station from the threat of larger, (typically greater than 10 cm) ground-trackable particles. The midrange size particles will be handled by a series of risk-abatement approaches that will be established initially and evaluated continually. These approaches are being pursued to characterize the risks of impacts of midrange (1 to 10 cm) particles and to increase the effectiveness of the protection offered by shielding and collision avoidance.

Risk abatement approaches with the goal of increasing protection system performance under consideration include: reduction of environmental model uncertainties, enhanced hypervelocity test and penetration analysis techniques, on-orbit shield augmentation capabilities, and alternate altitude strategies. Approaches that may increase collision avoidance effectiveness include enhanced radar capabilities and flight operations techniques. Finally, approaches being pursued to characterize and minimize the residual risks include; definition and assessment of critical items and the probability of catastrophic failures, advanced analysis of critical crack and fracture mechanics, crew training and operations techniques, and repair and replacement procedures.

Finding #3: Consideration is being given to maneuvering the Space Station to avoid larger debris that are capable of being tracked. Such maneuvers raise concerns about Station structural dynamics, disruption of the microgravity environment, and the ability of existing or planned systems to provide adequate debris tracking data.

Recommendation #3: Before adopting any maneuvering option, care must be taken to ensure that the dynamics of operation, including their effects on hardware, e.g., solar and radiator panels, and their influence on microgravity experiment operations, are considered. Realistic evaluation must also be made of the ability of ground-based and on-orbit systems to support maneuvering options with adequate debris tracking.

NASA Response: A collision-avoidance maneuver is, in practice, the same as a reboost maneuver. There are no concerns related exclusively to a reboost maneuver due to structural dynamic effects since all Space Station systems are being designed to handle a reboost; therefore, a known collision-avoidance maneuver will, likewise, present no structural problems.

However, a short-notice collision-avoidance maneuver could require a maneuver without being in the preferred configuration (i.e., solar panels, remote manipulator system). The operational procedures to ensure structural integrity and afford the capability for collision-avoidance on short notice continue to be worked.

The microgravity (micro-g) environment would be interrupted during an avoidance maneuver. However, the Space Station is not always required to be in a microgravity environment. The current microgravity requirement is for 180 days/year, subdivided into no less than 30-day periods. Current analysis shows that the Space Station could actually exceed the requirement by two additional 30-day periods. Therefore, if a maneuver must occur, and a micro-g period is disrupted, the margin of two micro-g periods can be used for "recovery."

Ground-based tracking of space debris is provided by the U.S. Space Command, not NASA. Their systems have the ability to track debris particles as small as approximately 10 cm.

Finding #4: Present plans for rescue of Space Station personnel are not fully defined and may prove unsatisfactory without more precise and detailed planning, including necessary training and restrictions on the Station population.

Recommendation #4: NASA should reexamine current plans to ensure that they meet the required safety criteria. If they do not, priority should be given to the protocols necessary to ensure rescue of the entire Station crew if the Station must be evacuated.

NASA Response: The Space Station program is planning for the rescue of the entire crew in case of medical emergencies, Space Station evacuation, or interruption in Shuttle operations. Currently, the Space Station program plans to use Russian Soyuz spacecraft to perform this function during the assembly phase. This spacecraft has been proven over many years in supporting the Mir station. American astronauts will be fully trained in the use of Soyuz, and restrictions on its use by our astronauts are fully understood. Replacement of the Soyuz after the year 2002 is being considered by either a modified Soyuz or an American-built Crew Transfer Vehicle.

B. SPACE SHUTTLE PROGRAM

LAUNCH AND LANDING

Finding #5: The organization and management of Space Shuttle launch operations at Kennedy Space Center (KSC) continue to benefit from a "continuous improvement process" managed by the Shuttle Processing Contractor (SPC). Greater employee involvement, better communications, strengthened employee training and the use of task teams, process improvement teams, and a management steering committee have been major factors in this improvement.

Recommendation #5: A strong commitment to achieving "continuous improvement," despite budget cutbacks, should be maintained, at the same time recognizing the paramount priority of safety.

NASA Response: The SPC continues its deep commitment to Continuous Improvement (CI) with over 550 active process improvement teams and 86 percent of their 6,600-person workforce trained in the principles and precepts of CI. The underlying theme of all SPC initiatives is their pledge for the highest level of performance at the lowest possible cost with absolute dedication to safety and quality.

Finding #6: More than 1,200 positions have been eliminated by the SPC since September 1991 with only about 22 percent being achieved through involuntary separations. Present reductions have been achieved without an apparent adverse effect on the safety of launch processing. A comparable further reduction has been called for by the end of FY 1995. These additional reductions cannot likely be made without a higher probability of impacting safety.

Recommendation #6: KSC and SPC management must be vigilant and vocal in avoiding any unacceptable impacts on safety as a result of cost reductions planned for FY 1995 and beyond.

NASA Response: KSC and SPC management are firmly committed to the precept that safety will not be compromised as a result of cost reductions. Procedures for processing a safe space vehicle have been established and are strictly followed. These procedures are revised only after a thorough review by technical and safety personnel to ensure that safety will not be compromised. Schedule times are flexible; safety requirements are not. As the cost reductions continue, KSC is committed to processing only the number of vehicles that can be completed safely within available resources.

Finding #7: Several Space Shuttle processing problems at KSC have been attributed to human factors issues. KSC has recently formed a human factors task force to address these problems.

Recommendation #7: KSC should ensure that the human factors task force includes individuals with training and experience in the field. Specific assistance should be sought from appropriate research centers and technology groups within NASA.

NASA Response: The Management Steering Committee, chaired by the KSC Launch Director, established a CI team to support the Incident Error Review Board (IERB) in assessing human-error factors. This team reviewed the human-factors aspects of the Freon Coolant Loop Number 1 Pump Package incident on OV-105/STS-61 and made nine specific recommendations concerning the incident. A tenth recommendation addressed the need for the team to obtain training in human factors principles.

The CI Human Factors Team has since received training on human factors from the Battelle Memorial Institute in a seminar conducted at KSC. Some team members attended a class on incident investigation taught by The Central Florida Chapter of the National Safety Council. The team has subsequently added a new member with extensive experience in human factors from Analex Space Systems, Inc. The team will continue to pursue additional human factors training.

Finding #8: KSC has developed a Structured Surveillance Program with the objectives of decreasing overall process flow time, increasing "first-time quality," and reducing cost. The program approach involves reducing the reliance on inspections for assuring quality. Structured Surveillance also is proving valuable as a tool for the effective deployment of quality assurance resources.

Recommendation #8: The Structured Surveillance program should be continued and cautiously expanded.

NASA Response: KSC has improved structured surveillance data elements, data collection methods, and metrics for the entire program at KSC (both Government and contractor) and has discussed these improvements with the Panel. To ensure effective implementation of the Government application of the structured surveillance program, the leadership of this effort has been moved up to the directors of the two implementing organizations. These directors co-chair a newly formed control board that manages the generation and modification of the policies, procedures, and training necessary for full implementation of structured surveillance.

ORBITER

Finding #9: Thermal damage was noted on the STS-56 (OV-103) elevon tiles. The slumping of the tiles indicated that the tile surface reached a temperature of approximately 1,000° F. A temperature of this magnitude suggests that the temper and strength of the underlying aluminum structure could have been affected.

Recommendation #9: NASA should initiate an analysis to determine the temperature profile of the underlying aluminum structure of the elevons and its possible consequences on the strength of the Orbiter structure.

NASA Response: On STS-56 (OV-103), an alternate forward elevon schedule (part of Center of Gravity Expansion Activities, Detailed Test Objective (DTO) 251) was flown. This was the maximum-up schedule (12 degrees up) ever flown. There was some tile slumping (caused by temperatures exceeding 1500 degrees F) at the center hinge location, but detailed postflight vehicle inspection confirmed that the aluminum structure was neither damaged nor subjected to unacceptable temperatures. Positive Margins-of-Safety have been verified subsequently through thermal design analysis. A redesign has been certified and is currently being installed on all four vehicles. This new design will allow a full-up (16 degrees) elevon without overheating of the underlying structure. Prior to incorporation of this modification, the elevon schedule had been constrained to 7 degrees up.

Finding #10: The Shuttle tiles have provided effective heat protection. However, the surface of the tiles is easily damaged and their shrinkage and distortion properties are not as low as desired. A new tile formulation with superior characteristics and possibly lower density is being explored.

Recommendation #10: NASA is encouraged to support the development of thermal protection tiles with improved mechanical properties and lower density than the current Shuttle tiles.

NASA Response: NASA is considering several improvements to the Tile Protective System (TPS). On STS-51 (OV-105), a tougher tile coating on Fiber Reinforced Composite Insulation (FRCI-12) tiles was flown as a DTO on a few door tiles on the base heatshield. There were no hits on these tiles. However, the DTO will be flown a number of times to obtain a good evaluation of the improvement expected from this coating. This tougher coating will enhance turnaround activities by minimizing tile replacement due to coating damage.

Finding #11: NASA has made excellent progress on the engineering of the Multipurpose Electronic Display System (MEDS) for retrofitting Orbiter displays. However, there is no formal program to identify and include the safety advantages possible from a fully exploited MEDS.

Recommendation #11: A thorough review of the performance and safety improvements possible from a completely developed MEDS should be conducted based on crew inputs to system designers and researchers. A definitive plan should be developed to determine the schedule/cost implications of such improvements, and, if warranted, implementation should be scheduled as soon as possible.

NASA Response: The MEDS, when operational, will provide a foundation for potential upgrades and enhancements to the current crew displays that will improve safety. The initial MEDS program must be on line in a timely manner to replace aging electro-mechanical devices. The flight crew, mission operations, engineering, training, and safety, reliability, and quality assurance program personnel have all agreed that the "transparency" achieved by designing enhanced displays similar in function and appearance to the current displays is the optimum solution initially. By designing similar but enhanced displays, the impacts for a mixed fleet while MEDS is being installed are minimized in the areas of training and flight software. There is only one single-motion base simulator, therefore, crews training for MEDS or non-MEDS equipped vehicles will be able to train on displays that are similar to those they will use in flight. Similar display formats do not require any changes to the existing flight software. Once trainers and laboratories are equipped with MEDS, the test beds will be in place to evaluate display upgrades.

The next phase of the total orbiter displays-and-controls update activities will be to achieve a world-class state-of-the-art system by expanding the total complement to digital electronics replacing current wiring and switches as practical. Planning for this phase is beginning, but the exact implementation schedule will be dependent on funding availability as well as future human-tended spacecraft planning.

Finding #12: The Improved Auxiliary Power Unit (IAPU) has experienced problems that have impacted Space Shuttle processing and logistics.

Recommendation #12: A new focus on increasing the reliability of the total IAPU system should be initiated and supported until the identified problems are solved.

NASA Response: To improve Auxiliary Power Unit (APU) reliability, a continuous improvement program has been underway since the STS 51-L accident. Results from this program include the completion of an IAPU "upgrade" project (which eliminated injector tube corrosion, exhaust housing cracking, and some Criticality 1 concerns), a new design for the turbine wheel, an improved APU controller and fuel isolation valve, and the more reliable "Path a" Gas Generator Valve Module (GGVM). These changes have resulted in a greatly reduced rate of APU in-flight anomalies and fewer delays to the Shuttle processing and logistics support activities. Elements of the continuous improvement program not yet complete, but now underway include development of an entirely new GGVM, certification of a new material for the fuel pump thermal isolator, and development of more vibration-resistant thermostats. As the new GGVM is incorporated in the fleet, the APU should be totally certified for its planned 75-hour life capability.

Finding #13: In its response to the Panel's last Annual Report, NASA indicated that "The program is reviewing the operational flight rules pertaining to Autoland, we have budgeted upgrades in software and hardware to improve the Autoland functionality, the life sciences organization is collecting physiological data and developing countermeasures to ensure adequate crew performance as the mission duration increases. We are confident with using Autoland in a contingency mode, but do not plan to demonstrate Autoland until a firm requirement mandates a demonstration."

Recommendation #13: The focus of Autoland should not be exclusively on long-duration missions. NASA should formulate a complete set of operational procedures needed for emergency use of Autoland, taking into account a full range of operational scenarios and equipment modifications that might be beneficial. These include upgrades to the

Microwave Scanning Beam Landing System (MSBLS) receiver group, and installation and certification of Global Positioning System (GPS) capability.

NASA Response: It is agreed that the Autoland system should not be focused just on long-duration missions. Currently, mission planning requirements do not include missions longer than approximately 18 days, including the Space Station program. The entry systems requirements including piloting techniques are continuously assessed for improvements. Autoland backup capabilities as well as heading alignment cone piloting enhancements are being developed and will be incorporated as we continue to implement the flight program. MSBLS/GPS type systems are being considered and will be brought on line as improvements are practical.

No specific training or procedures are required for the emergency use of Autoland, as the only manual tasks required of the crew in an Autoland scenario (e.g., deploying landing gear, postlanding braking, air data probe deployment, and navigation sensor data incorporation) are identical to those performed in a manual landing. Present flight rules define orbiter and landing-site equipment that must be functioning to perform an Autoland landing. The decision to engage Autoland in a contingency is left to the commander's discretion to protect the safety of the crew. Exact flight rules to define all Autoland engagement criteria exceed the number of failure cases addressed by the current flight rules. A program to expand these criteria would require large resource commitments to develop and is not currently in the planning.

SPACE SHUTTLE MAIN ENGINES (SSME)

Finding #14: The SSME has performed well in flight but has been the cause of launch delays and on-pad launch aborts that were primarily attributable to manufacturing control problems.

Recommendation #14: Continue to implement the corrective actions developed by the NASA and Rocketdyne manufacturing process review teams and devise techniques for detecting and/or precluding recurrence of the types of problems identified.

NASA Response: The process audit teams and the NASA and Rocketdyne incident investigation teams have both identified process improvements which either have been or will be incorporated into all areas of the engine program. These process improvements will improve detection and preclude the recurrence of manufacturing control problems in any of our new or recycled hardware and substantially reduce the likelihood of associated problems leading to launch delays or launch pad aborts.

Finding #15: "Sheetmetal" cracks in the Phase II (current) High Pressure Fuel Turbopump (HPFTP) have become more frequent and are larger than previously experienced. This has led to the imposition of a 4,250-second operating time limit and a reduction of allowable crack size by a factor of four. Congress has delayed the funding for restarting the development of the alternate HPFTP. This new turbopump design should eliminate the cracking problem.

Recommendation #15: Restart the development and certification of the alternate HPFTP immediately.

NASA Response: NASA fully agrees with the recommendation to restart the alternate HPFTP immediately. Congressional authority to restart the program was received on April 14, 1994. The Space Shuttle program (SSP) is proceeding with the restart. The alternate HPFTP will be incorporated into the Block II SSME configuration with first flight scheduled for September 1997.

Finding #16: The approved parts of the engine component improvement programs, now organized into block changes, are progressing well. The Block I grouping will enter formal certification testing by mid-1994. Progress in the Block II effort is, however, hampered by the delay in restarting the alternate HPFTP development effort.

Recommendation #16: Continue efforts to complete ***all*** of the Block II development as soon as possible.

NASA Response: NASA fully agrees with this recommendation and is firmly committed to developing and implementing all of the SSME safety improvements, including the Alternate HPFTP and the Large Throat Main Combustion Chamber. Upon completion of these modifications, a significant reduction in Shuttle operational risk will be realized. Initiation of full-scale development testing is currently planned for mid-1995, with first-flight capability scheduled for September 1997.

Finding #17: Engine sensor failures have become more frequent and are a source of increased risk of launch delays, on-pad aborts, or potential unwarranted engine shutdown in flight.

Recommendation #17: Undertake a program to secure or develop and certify improved, more reliable engine condition sensors.

NASA Response: Improved hot gas temperature-sensing instrumentation is undergoing development testing and is planned for the first flight in FY 1995. A two-step improvement process for pressure and flow measuring instrumentation is also under way. As a first step, a new screening selection process has been developed for immediate implementation to improve sensor quality control. The second step, redesigning and improving sensors, is being implemented as these improvements become available.

Finding #18: The SSME health monitoring system comprising the engine controller and its algorithms, software, and sensors is old technology. The controller's limited computational capacity precludes incorporation of more state-of-the-art algorithms and decision rules. As a result, the probabilities of either shutting down a healthy engine or failing to detect an engine anomaly are higher than necessary.

Recommendation #18: The SSME program should undertake a comprehensive effort to improve the capability and reliability of the SSME health monitoring system. Such a program should include not only improved sensors but also a more capable controller and advanced algorithms.

NASA Response: NASA agrees that the development and implementation of an advanced health monitoring system for the SSME is potentially worth pursuing. A system currently being considered would incorporate more processing capability in an upgraded controller and allow the utilization of advanced health monitoring software algorithms. With an improved system of this nature, the probability of shutting down a healthy engine would be reduced while the probability of preventing a catastrophic failure would be increased. NASA is reviewing proposals that would certify and implement this new capability into the Block II SSME configuration.

SOLID ROCKET MOTORS

Finding #19: A segment of an aft skirt will be used to test the effectiveness of an external bracket modification in reducing the overall bending stress of the skirt. The validity of using an 11-inch-wide test specimen to determine the effectiveness of the bracket is yet to be demonstrated.

Recommendation #19: NASA should evaluate the first specimen test results to see if the strains in the weld area duplicate the strains found when a full aft skirt was tested in the Static Test Article-3 (STA-3) test. If not, another test approach should be pursued.

NASA Response: Tests on three of the four aft skirt test specimens have been completed. The baseline test article (TA-1), which represents the current aft skirt configuration, has been subjected to 100 percent of the developed load case. Based on a thorough evaluation of the TA-1 test data and correlation of the data with STA-3 test results, it is clear that the weld area strain field developed in the TA-1 test article correlates well with the strain field in this same area on the STA-3 aft skirt. This correlation confirms the validity of the test approach being used.

The second test article (TA-4) was also in the baseline configuration and was subjected to a maximum load of 70 percent of the developed load case. This article utilized the photoelastic method for determining the strain field as opposed to using the typical strain gage method used on all other articles in this test program. This test verified that the STA-3 strain field could be duplicated on two separate articles within acceptable limits and that no high strain areas were overlooked during the analytical study of the test article response.

The third test article (TA-2), which has an external bracket for the reduction of strain in critical weld region, was subjected to 205 percent of the developed load case with no structural anomalies occurring. Comparisons of the baseline configuration article (TA-1) and the bracketed configuration article (TA-2) were made at 100 percent loads. This comparison demonstrated that there was approximately a 50 percent reduction in the average weld strain in the critical weld region.

The baseline configuration article (TA-1) was tested to failure during June 1994. This test defined the weld failure strain for the TA-1 article. Test data obtained from this test is being compared to the results of the 205 percent TA-2 test and the STA-3 test to develop a comparative assessment of the benefit gained by the addition of the external bracket modification. If this assessment does not reveal adequate stress reduction, additional testing may be indicated.

__Finding #20:__ A small crack was found in the inner wall of a forward Redesigned Solid Rocket Motor (RSRM) casing used for STS-54. Although slightly above the specified minimum detectable size, it was well within the acceptable limits for safe flight. This was the first time that a crack had been found in a forward segment, although cracks have previously been detected in other segments. The crack occurred during the manufacturing heat treatment process because of an inclusion in the parent material.

__Recommendation #20:__ The X-ray and magnetic particle inspection program criteria should be re-evaluated to assess their ability to detect cracks of the size found.

__NASA Response:__ A single crack was detected during standard refurbishment of the forward segment flown on STS-54. The subsequent investigation determined that an inclusion introduced into the metal during the manufacturing process caused the crack to form during heat treatment of the cylinder. The segment had been flown four times prior to detection of the crack. Prior to each of these flights, the cylinder was proof tested, which demonstrated safe life (4 mission cycles) in the membrane region where this crack was found.

All areas of the RSRM metal hardware (case, nozzle, igniter) have been reevaluated with respect to critical flaw size and whether proof test, magnetic particle inspection or other nondestructive evaluation methods are required to demonstrate compliance to safe life requirements. As a part of this reevaluation, an RSRM hardware configuration specific magnetic particle inspection probability of detection (POD) study was completed. Prior to this study, crack detection threshold limits were based on industry standards. This RSRM magnetic particle inspection POD study incorporated RSRM specific geometries, physical access, gauss levels, surface finishes, potential flaw types, inspection times, and multiple operators. The results demonstrated that, in the areas of the RSRM hardware upon which magnetic particle inspection is solely relies, the detectable flaw size is smaller than the critical flaw size. Proof test is the method of choice used to demonstrate safe life in the case membrane region, not magnetic particle inspection.

X-ray inspection is not used for crack detection in RSRM metal hardware. Magnetic particle inspection capability has been reevaluated and, as a result of an RSRM hardware configuration specific POD study, detection capability versus location is well characterized. In those areas that rely solely on magnetic particle inspection, the detectable flaw size is smaller than the critical flaw size.

__Finding #21:__ The Advanced Solid Rocket Motor (ASRM) project has been canceled. Some elements from the ASRM development have possible reliability and/or performance benefits if they were applied to the RSRM.

Recommendation #21: Examine the potential applicability and cost-effectiveness of including selected ASRM design features in the RSRM.

NASA Response: The RSRM project has continued to consider ASRM design attributes, as motivated by RSRM flight results, performance goals, obsolescence issues, and cost enhancements. Examples of these are the RSRM project's ongoing initiative to replace metal parts vapor degrease cleaning with an aqueous process and the ongoing initiative to remove asbestos from the primary RSRM insulation material. Both of these obsolescence replacement activities have drawn from previous ASRM activity.

There are numerous ASRM design attributes for potential consideration for future adoption in the RSRM. These include, in part, propellant formulation (hydroxyl-terminated polybutadiene), sealing system designs, pressure vessel design and materials, some attributes of the nozzle design, and some manufacturing process automation, such as insulation strip winding and Real Time Radiography (RTR) for nozzle and case inspections. At present, the RSRM project is considering incorporation of the previous ASRM RTR system into the RSRM hardware verification process and the use of ASRM manufacturing equipment for nozzle fabrication. Based on collective consideration of the implementation cost impacts and RSRM flight demonstrated hardware performance, no requirements have been established to pursue the ASRM sealing system, pressure vessel, or nozzle design attributes. However, future justifications in these areas are possible based on continuing RSRM flight evaluation or increased Shuttle program performance requirements.

Finding #22: A chamber pressure excursion of 13 psi (equivalent to a thrust perturbation of 54,000 pounds) occurred in one of the RSRMs of STS-54 at 67 seconds of motor operation. A thorough investigation of the phenomenon was initiated and found that the most probable cause was the expulsion of a "slug" of liquid slag (aluminum oxide) generated during normal propellant combustion. Analyses showed that, even under statistical worst-case conditions, the safety of the Shuttle system is not compromised by such perturbations. Some testing and analyses are still scheduled to complete the investigation.

Recommendation #22: Complete and document the investigation, and continue the established practice of monitoring chamber pressures and examining possible remedial actions.

NASA Response: The RSRM project has concluded its investigation and has determined that the generic cause of chamber pressure excursions is the periodic expulsion of liquid slag (aluminum oxide). Slag is produced during normal propellant combustion and is temporarily accumulated in the aft end of the nozzle prior to being "dumped" through the nozzle. The RSRM project has implemented the recommendations set forth by the Panel and has established a program to continue to evaluate multiple parameters that could affect the pressure perturbations. The results and findings of these studies are being reviewed and changes to the processes or specification will be made if it is concluded that they will be beneficial to the program.

A very detailed study of many process and material parameters that influence slag formation has been conducted to determine if a statistical correlation exists between these parameters and the pressure perturbations. Examples of these parameters include humidity, time in process, ammonium perchlorate (AP) moisture content, mix times, cast times, viscosity, mechanical properties, and many others. No special causes or process deviations related to pressure perturbations have been identified. Analyses have shown that, under the worst case conditions, the safety of the Shuttle system is not compromised by the pressure phenomenon. The results of this extensive study are currently being documented by Thiokol.

Chamber pressures are being analyzed or monitored by Statistical Process Control charts. Eighteen acceptance tests are conducted for each lot of AP. The flight and static test pressure perturbation history is reviewed before every launch. Additionally, several other studies are being conducted to improve the predictability of pressure excursions. Quench bomb tests recorded with high-speed film have been used to identify burn-rate differences in the various propellant mixes. Five-inch diameter spin motor tests are being conducted to evaluate the amount of slag that is generated in a motor. This testing employs a design of experiments to evaluate the effects of ground AP, unground AP, differences in AP vendors, aluminum-particle sizes and vendor differences, particle-size distributions, iron oxide surface area, and several other parameters.

EXTERNAL TANK

Finding #23: A Super Light Weight External Tank (SLWT) has been proposed as a means of increasing the payload performance of the Space Shuttle. The tank would employ structural changes and be made from an Aluminum-Lithium (Al-Li) alloy. The SLWT appears to involve no safety decrement and low technical risk.

Recommendation #23: The impact of the SLWT on the total system should be care- fully examined.

NASA Response: The External Tank Project and Shuttle program are thoroughly committed to an integrated system approach to the design and development of the SLWT. A systems integration plan to ensure the timely assessment of SLWT effects on the Shuttle system, and to ensure programwide-managed implementation is currently in development.

LOGISTICS AND SUPPORT

Finding #24: The Integrated Logistics Panel (ILP), which meets at 6-month intervals to report and coordinate the activities of the NASA Centers and their contractors, is performing a vital service in helping to control the entire Space Shuttle logistics program.

Recommendation #24: The ILP should continue to be supported as an effective means of maintaining control and coordination of the entire logistics program.

NASA Response: NASA Centers and contractors continue to support the ILP and related integration activities. All project elements benefit from the exchange of technical data presented at ILP meetings. NSTS 07700, Volume XII, "Integrated Logistics Requirements", the program's requirements for integrated logistics was recently updated, and the ILP provided a focus for this effort. The ILP will continue to serve as the forum for problem solving, technical information exchange, and the appropriate level of control, coordination, and integration of Shuttle logistics support.

Finding #25: The *Vision 2000* cost-reduction program promulgated in May 1993 includes some major changes in the logistics and support areas.

Recommendation #25: All changes that might impair logistics and support functions in the name of cost-cutting should be most carefully reviewed before implementation.

NASA Response: As the program continues to plan for the future, the *Vision 2000* approach to the program will remain relevant. The *Vision 2000* approach is based on the following two principles: operate within SSP experience and locate decisionmaking near operations. Notwithstanding the advantages these principles offer to the current Shuttle logistics community, the SSP office will remain vigilant and exercise caution when making cost-cutting decisions and changes necessitated by funding reductions.

Finding #26: Introduction of the Just-In-Time (JIT) manufacturing and shelf-stocking concept by NASA logistics at KSC is a potentially effective method of cost control.

Recommendation #26: JIT should be used with caution and with a thorough understanding of how it may impact the availability of Space Shuttle spares and hardware supplies.

NASA Response: All projects have cautiously considered the JIT method of spares provisioning and are in different stages of planning and implementation. Launch and Landing Project (L&L) has applied the JIT method to manufacturing activity. In addition, L&L is further studying alternative methods of prioritizing repair work which may be applied to JIT repairs at a later date. Operational availability will be uppermost in any JIT implementation decision strategy affecting spares and hardware supplies.

Finding #27: A review of the main logistics system performance parameters indicates that the program is generally performing effectively. There are minor problems with zero balances, and repair turnaround times appear to be worsening. Cannibalization, with the exception of the IAPU, is at a minimum. Because of manufacturing and assembly quality problems, the number of spare engines is at a minimum and could become a logistics problem.

Recommendation #27: Additional emphasis should be focused on repair turnaround time improvement and the reduction of cannibalization of SSME and IAPU components. NASA should continue the efforts to improve SSME manufacturing control and quality processes to preclude future engine availability problems.

__NASA Response:__ Supportability indicators for improved performance are continually monitored. Increased coordination with vendors, transition of selected tasks from vendors, and resolution of technical issues related to higher-than-normal hardware failure rates have assisted in expediting hardware delivery. The average repair turnaround time for L&L is 25 percent lower than FY 1988, but supportability is the key measurement of logistics success. Items that are not needed to ensure support (on either a vehicle or the shelf) are no longer being repaired on a priority basis to save dollars. Minor problems associated with zero balances should improve through the identification of single-source vendors and continued efforts to identify alternate sources.

IAPU's continue to be worked on a priority basis. Most of the technical problems associated with cannibalization in 1993 have been solved. There was no cannibalization during the period January through April 1994, as there are spare units at KSC. In addition, ongoing discussions with vendors are attempting to improve production issues, and a redesign is underway as a long-term solution. Monitoring of this critical asset will continue.

The SSME Project Office encountered a short-term issue with contamination of temperature transducer probes. Plans for resolution of this issue include process changes and testing (green run) prior to delivery to L&L. Pump and nozzle shortages are the result of natural disaster (Northridge earthquake), other technical issues, and the SSME project standdown period. Full implementation of changes in methods of support to manufacturing control and quality processes should improve availability of SSME hardware. We will intensively manage the correction of these issues to ensure availability of complex SSME hardware.

C. AERONAUTICS

__Finding #28:__ The Dryden Flight Research Facility (DFRF) does not presently have a range safety policy and system for Unmanned Aerial Vehicles (UAVs) such as the Perseus, which is about to enter extensive testing. A working group under the DFRF Chief Engineer is examining the issue.

__Recommendation #28:__ DFRF should develop a range safety policy and system that are adequate to cover its contemplated UAV projects.

NASA Response: The Director of the Dryden Flight Research Center (DFRC), *nee* Dryden Flight Research Facility (DFRF), has recently established a policy document on UAV flight operations and activities. This policy has been coordinated closely with Edwards Air Force Flight Test Center (AFFTC) officials, since air space and facilities are managed by the local Air Force establishment.

The Perseus UAV, having just completed its initial contracted flight test activity, during which it achieved an altitude of 16,500 feet, is being operated in accordance with this policy. It is our intent to continue using the Perseus vehicle as a pathfinder for validation of UAV operational procedures during step-by-step expansion of the flight envelopes for expanding the flight altitude up to 85,000 feet. DFRC will continue to assure safe flight operations and control of UAV flight activities through technical risk analysis, management reviews, and the imposition of appropriate range safety precautions prior to each flight.

__Finding #29:__ The DFRF flight safety and mission assurance organization now reports directly to the Director of the facility.

__Recommendation #29:__ None.

NASA Response: This change in reporting authority will continue to ensure that flight safety and mission assurance issues are addressed in a timely manner and to the appropriate level of Center management.

__Finding #30:__ The X-31 aircraft exhibited some undesirable stability characteristics at higher subsonic speeds and an unexpected departure during a high angle of attack test. It also carries an insufficient quantity of hydrazine to run its emergency power unit long enough to return to the Edwards runway from the typically used flight test site.

__Recommendation #30:__ Future test objectives for the X-31 should be based on an assessment of the specific program objectives that can only be uniquely and safely performed by this aircraft.

NASA Response: The X-31 has no undesirable stability characteristics at higher subsonic speeds within its current cleared flight envelope. There is, however, a pitch-up tendency between 0.91 and 0.95 Mach number when the aircraft is between 10 degrees and

12 degrees angle of attack (AoA). This represents flight at elevated gravitational (g) loading (2.5g to 4.5g, depending on altitude) outside of the 0.9 Mach number envelope limit. The condition is caused by a positive (nose up) break in the airframe pitching moment. It was predicted by wind tunnel tests and was a known condition prior to being encountered in flight when the aircraft inadvertently exceeded the Mach limit during a wind-up turn.

To mitigate the risks associated with this characteristic, the X-31 now operates with the flight envelope restricted to 0.85 Mach number, except for planned test maneuvers. As an added precaution, the Master Caution/Warning (MCW) tone activates when the Mach number exceeds 0.88 and a caution light is illuminated in the cockpit. When specific tests, such as the supersonic quasi-tailless demonstration, require exceeding this Mach number, the air crew and engineering staff are briefed, an AoA limitation is enforced, and responsibilities for real-time monitoring are reviewed. The reduced Mach limit and other procedures have not affected achievement of the X-31's flight test goals. No subsequent pitch-up incidents have occurred since these procedures were emplaced.

The X-31 experienced a yawing departure very early in its poststall envelope expansion flight test program. The test, a split-s and pull to 60 degree AoA from 125 knots calibrated airspeed (KCAS) at 35,000 feet (about 1.3g's maximum), was only the third elevated g post-stall entry test and represented a modest step toward the goal of 0.7 Mach number post-stall entries. Both the pilot and the control room quickly recognized the departure and called for recovery according to the prebriefed monitoring procedures. The pilot was able to immediately pitch down to conventional AoA and recover the aircraft to controlled flight.

The departure was due to an unexpected aerodynamic asymmetry, but such occurrences were not unanticipated. The pitch recovery margin designed into the aircraft, the planned and gradual buildup of flight maneuvers and conditions, and the monitoring procedures ensure the maximum chance for safe recovery from this kind of unexpected problem.

Further, after the "departure," poststall flight-envelope expansion was suspended until the cause of the departure was identified, understood, and fixed. Wind tunnel tests indicated that the large aerodynamic yaw asymmetries that caused the departure were due to the very sharp nose of the X-31 aircraft. The asymmetries experienced during flight were more than five times as large as wind tunnel predictions, but it was discovered that the aircraft was built with a nose that was sharper than the wind tunnel models. The wind tunnel tests further suggested that a slight blunting of the aircraft nose to match the wind tunnel model would probably eliminate the problem and that small nose strakes would further improve the asymmetries and the directional stability of the aircraft at 60 degree AoA.

The aircraft was modified to blunt the nose and add the nose strakes. Maneuver and flight condition buildup was changed to increase in smaller steps. Monitoring procedures were reviewed (and subsequently adjusted), and the flight test expansion of the elevated-g, poststall entry and maneuver envelope resumed. Since then, no departures or near-departures have occurred, and the aircraft has been cleared to poststall entries up to 265 KCAS or 0.7 Mach number (almost 6g's maximum) with unrestricted maneuvering up to 70 degrees AoA. These flight test operating modifications will enable the project to accomplish its tactical utility program objectives.

During the design, fabrication, and assembly of the X-31, Rockwell, MBB, and the Naval Air Systems Command were confronted with a number of difficult tradeoffs in attempting to achieve the desired thrust-to-weight ratio in the aircraft. One of the most deliberated issues was the purpose and function of the electrical power unit (EPU). As a result of these deliberations, the EPU was sized for the purpose of providing uninterrupted electrical and hydraulic power for enough time to restart the engine in the event of a engine flameout. The EPU was never intended nor, more importantly, designed to provide the capability to return to base.

The philosophy for the utilization of the EPU is consistent with other single engine aircraft (i.e., the X-29A and the F-16). The X-31 EPU run time is nominally 4.5 minutes, while the X-29A had 8.0 minutes and the F-16 has a minimum of 10.0 minutes. DFRC's current operating procedures do not recommend a dead-stick landing (neither did the X-29A's); however, it is a pilot option if the aircraft is close to a landing flight condition.

The ability to land "engine-out" is determined by both the EPU time and the flame-out landing distance of the aircraft. The flame-out landing distance is an imaginary inverted cone of distance versus altitude determined by the glide ratio of the aircraft. This cone may be further restricted in altitude and distance by EPU duration. Outside of this cone, no amount of EPU time will permit an "engine-out" landing. Much of the flight test site areas typically used at Edwards are beyond the flame-out landing range of any fighter aircraft. Flights at 10,000 feet, for example, would have to be performed within approximately 10 miles of Edwards to remain within this glide cone.

When the aircraft were moved to Dryden and NASA became an active member of the International Test Organization and assumed flight clearance authority, a complete independent review of the aircraft systems and issued flight clearance using the Dryden Basic Operations Manual was conducted. During the course of this review, DFRC focused on two major concerns--the potential for the engine to stall during high AoA testing and the quantity of hydrazine available for the EPU.

The potential for the engine to stall during high AoA was studied at the outset of flight test operations, as an undesired event, and was subsequently assigned the probability for occurrence as being unlikely (but possible), and the risk for potential loss of aircraft (with safe ejection of the pilot) was accepted. As the result of a more recent review of the accepted risks, the probability of occurrence was downgraded to ***extremely improbable*** based on the completion of high AoA envelope expansion and more than 170 hours of aggressive maneuvering performed during the tactical utility phase of the program with ***no*** engine anomalies or stalls experienced. Engine operation will continue to be monitored "real time" from start through shutdown, and any additional knowledge obtained will modify our risk knowledge data base or, more importantly, it may form the basis for changes to mitigate risk.

To assess the potential impact due to the low quantity of hydrazine available for the EPU, Dryden performed a complete-risk analysis of the aircraft, including engine and subsystem reliability, proximity of flight operations to landing areas, and other pertinent factors. Based on this review, a hydrazine quantity gage was installed to give the pilot essential information on whether or not to remain with the aircraft in the event of a system failure. The gage quantity is checked as part of the aircraft preflight inspection and the hydrazine quantity is monitored "real time".

Based on our experience with the X-29A, we concluded that the philosophy embodied in the original design was reasonable, and the risk was acceptable if we instituted and maintained a closely managed quality control and maintenance inspection program. Therefore, Dryden management placed hydrazine quantity on the accepted risk list. We are managing risks that are entirely acceptable for this experimental aircraft program, sponsored by the Advanced Research Projects Agency (ARPA). This has been borne out by the successful completion of all program objectives to date.

Safety of the operation of the aircraft test vehicle and safety of the test points to be performed are continually reviewed and improved. The "unexpected departure during a high angle of attack test" is an excellent example of how an unexpected problem was dealt with and eliminated.

As a result of the extremely successful completion of the X-31 flight test program objectives, an 8-month follow-on program is being planned to explore in-flight virtual targeting development, assessment of high AoA/off boresight missiles, pseudo tailless aircraft flight tests, using thrust vectoring; and evaluation of high AoA handling qualities and design criteria, as evolutionary steps to the completed program. These programs will use the existing flight envelope and the same airspace used in the completed program. The only planned use of the supersonic corridor, which results in the greatest excursion from the Edwards Air Force Base airspace, is during a portion of the Agile Warrior virtual-adversary demonstration.

This high-priority Navy/ARPA-sponsored follow-on program takes advantage of the unique capabilities of the X-31 aircraft to begin pursuing these objectives immediately. These capabilities include providing support for existing research and laying the groundwork for follow-on efforts, such as the Joint Advanced Strike-Fighter Technology Program.

At the completion of the 8-month follow-on program, an assessment and review will evaluate the feasibility and risks associated with the reduction of vertical tail size as a further extension of the study of thrust vectored flight capability. Results from this assessment will be briefed to the Dryden Airworthiness Board as part of the new program proposal and appropriate action will be taken. The ASAP Chair will be invited to the Air Force Safety Review Board review of this subject.

The reduced tail size tests will use the X-31's mature simulation data base, its fully integrated thrust vectoring/flight control system, and the experience gained in the quasi-tailless tests to investigate tailless flight. This will provide valuable experience and data to support design drag, weight, and manufacturing savings to commercial and to military aircraft. Military aircraft would also benefit from the reduced-radar signature of these new designs.

The "Agile Warrior" program will integrate key enabling technologies, such as advanced pilot situational aids, helmet displays, cockpit displays, and a wide-area distributed simulation network, to create a realistic war fighting/training environment linking airborne aircraft with multiple ground-based simulators. This promises cost savings in both training and in rapid assessment of advanced technologies in a large-scale, realistic simulation environment.

Other tests investigate sensor design, maneuverability, agility, performance, and handling qualities during poststall maneuvering and in conventional flight using thrust vectoring. The valuable data from these envelope-expanding flight tests will enhance integration of these technologies into operational aircraft designs.

In conclusion, safety of flight for the X-31 International Test Organization has always been and will continue to remain our foremost guiding principal. The achievement of planned flight test objectives will continue to be guided by a methodical process of flight data evaluation and gradual, deliberate expansion of flight envelopes. Risks will be understood and prudently accepted with the safety of the pilot and aircraft as the principal considerations.

D. OTHER

Finding #31: NASA's past approach to software development has been to incorporate it within the individual programs, allowing them to determine their own requirements and development, verification, and validation procedures. In the future, as the complexity of NASA's computer systems and the need for interoperability grow, this mode of operation will be increasingly less satisfactory. While NASA has some good software practices, it does not have the overall management policies, procedures, or organizational structure to deal with these complex software issues.

Recommendation #31: NASA should proceed to develop and implement an Agencywide policy and process for software development, verification, validation, and safety as quickly as possible.

NASA Response: A software process action team, sanctioned by the Acting Deputy Administrator and the Information Resource Management Council, is working on Agency software issues including roles, responsibilities, standards, and procedures. The Office of Safety and Mission Assurance is leading the Agency in strategic planning for the Agencywide software program with a NASA working group consisting of members from Centers, industry, and academia.

A Software Safety Standard has been completed. Our present plan is to establish this as an interim standard for 1 year at which time it will become a mandatory requirement for newly developed software. The Software Independent Verification and Validation Facility will focus on the Agency software processes for development, verification, and validation in accordance with the Software Strategic plan currently being developed.

Finding #32: NASA has consolidated life and microgravity sciences and applications, including human factors in the Office of Life and Microgravity Sciences and Applications (Code U). A *Space Human Factors & Engineering Program Plan* is being prepared to guide future ***research*** activities. There remains, however, a clear need for more ***operational*** human factors input in both the Space Shuttle and Space Station programs.

Recommendation #32: The Program Plan should be expanded to include support of the operating space flight programs to ensure that sufficient human factors expertise is included.

NASA Response: The Life and Biomedical Sciences and Applications Division is committed to developing a new, dynamic Space Human Factors Engineering Program that will integrate human factors knowledge and methodologies into the Shuttle and Space Station programs. Leadership of this program resides within the Environmental Systems and Technology Branch of Code U, which is responsible for directing an integrated Space Human Factors Engineering research and development program. New processes and procedures will be developed to enhance crew training, augment the design of complex automated systems, and use extreme and isolated environments to conduct analog studies. Research programs will continue; however, the primary focus of the program will shift from ***knowledge acquisition to knowledge application***. This shift will extend human factors support to operational areas and emphasize the improvement of processes and products.

The Space Human Factors Engineering Program Plan, developed in 1993, is being revised to reflect this shift of emphasis, and an implementation plan will be developed to establish and maintain this new focus. Emphasis will be placed on identifying specific, adequate funding for meaningful results, and promoting the added value of human factors through concurrent engineering throughout the Agency. A Space Human Factors Engineering Customer Team, currently being established at Headquarters with representatives from Codes U, M, R, and Q, is being received in a spirit of cooperation and collaboration. These changes should create a safer and more productive operational environment for all flight and ground activities planned for current and future programs.

Finding #33: There are excellent examples of Total Quality Management (TQM) principles and practices in various contractor and NASA activities.

Recommendation #33: NASA and contractor management should use the existing ***effective*** TQM implementations as models for their continuing TQM efforts.

NASA Response: The Office of Continual Improvement is aggressively pursuing implementation of TQM across NASA. Particular emphasis has been focused on the Agency Quality Steering Team (QST) and Continual Improvement Council (CIC) activities. The Agency Continual Improvement Plan is in the final stages of development and is expected to be signed in late summer 1994 by the Chair of the QST (the Acting Deputy Administrator). In addition, the Office of Continual Improvement has worked with the Office of Human Resources and Education in developing and establishing training courses for enhancing individual expertise in applying TQM concepts. As an example, a 2-day Joiner Team Training session focusing on a common team framework for continual improvement teams was presented in May 1994 to the Headquarters CIC and others.

Although the Panel's report cites specific positive applications of TQM in providing an assessment of the NASA results, we recognize that continual improvement across the Agency and its contractors is necessary. We will continue to encourage and practice continual improvement in all areas to affect the necessary changes.

APPENDIX C

NASA AEROSPACE SAFETY ADVISORY PANEL ACTIVITIES JANUARY 1994 - JANUARY 1995

JANUARY

19	Total Quality Management Letter Report to Administrator

FEBRUARY

3	Congressional Staff Visit re Panel's Annual Report, Washington, DC
15	Panel Review of NASA's Strategic Plan
23-25	Review of Multi-Function Electronic Display System/Pilot Assisted Landing Program; Aircraft Guidance and Navigation Activity; General Aviation/Commuter Technology; and Human Factors, Ames Research Center

MARCH

16	Aerospace Safety Advisory Panel Presentation to the Senior Management Council, NASA Headquarters
22	Review of Space Station/Russian Programs, NASA Headquarters
23	Review of Total Quality Management, NASA Headquarters
23	Aerospace Safety Advisory Panel Annual Meeting, NASA Headquarters
24	Review of NASA Safety Programs with Office of Management and Budget, Washington, DC

APRIL

5-7	STS-59 Mission Activities, Kennedy Space Center
15	Review of Improved Auxiliary Power Unit, Sundstrand, Rockford, IL

MAY

10	Solid Rocket Motor Review, Thiokol, UT
11	Filament Wound Case Review, Hercules, Salt Lake City, UT
17-19	Reviews of Multi-Function Electronic Display System and Space Station, Johnson Space Center
31	Intercenter Aircraft Operations Panel Meeting, El Paso, TX

JUNE

28	Review of Space Shuttle Main Engine Testing, Stennis Space Center
29	Review of External Tank Programs, Michoud Assembly Facility

JULY

1	Review of Office of Safety and Mission Assurance role in safety certification; Review of Space Shuttle/Mir Safety; Space Shuttle reliability discussions with Japanese News Agency, NASA Headquarters
15	Perseus A Flight Readiness Review, Dryden Flight Research Center
21	Software Process Action Team Meeting, NASA Headquarters

AUGUST

2	Perseus B Flight Readiness Review, Dryden Flight Research Center
8	Discussions with Administrator re Russian safety program; Assured Crew Return Vehicle policy; ASAP position on Improved Auxiliary Power Unit; aging aircraft; Solid Rocket Motor nozzle manufacturing; Human Factors Research, NASA Headquarters
9-10	Review of wind shear/wake vortex program; flight deck research/ simulators; aging aircraft; tire wear and crash safety; High-Speed Research Program; Zero Visibility Landing, Langley Research Center
15-18	Review of structured surveillance progress; receipt and handling of Russian hardware; quality control for European supplied hardware; Space Station Processing Facility, Kennedy Space Center
17	Software Process Action Team Meeting, NASA Headquarters
31	Review of Improved Auxiliary Power Unit, Sundstrand, Rockford, IL

SEPTEMBER

12-13	Review of Fire Safety Research; Aircraft Operations; US/Russian Solar Dynamic Power System; Launch Vehicles; Aeronautics; and Chemical Rockets, Lewis Research Center
19	Letter Report to the Administrator, New Gas Generator Valve Module and Auxiliary Power Unit
27	Letter Report to the Administrator, Measures of Safety

OCTOBER

4-5	Integrated Logistics Panel Meeting, New Orleans, LA
18	Safety Program Review, Dryden Flight Research Center
19	Space Shuttle Main Engine and Manufacturing Processes and Supplier Management Reviews, Rocketdyne, Canoga Park, CA
20	Review of Orbiter return to launch site; tiles; Global Positioning System; Multi-Function Electronic Display System; and Space Shuttle/Russian Program, Rockwell, Downey, CA

NOVEMBER

8-9	Integrated Logistics Panel Meeting, Kennedy Space Center
9-10	Review of the Space Station Program; Russian Safety Process; Assured Crew Return Vehicle; and Shuttle/Mir, Johnson Space Center
16-17	Review of TU-144 Program and Shuttle/Mir, NASA Headquarters
23	Review of Microwave Scanning Beam Landing System, Rockwell, Downey, CA
30	Review of the Shuttle/Mir Docking Mechanism, NASA Headquarters

DECEMBER

5	Review of NASA Independent Verification and Validation Lab, Fairmont, WV
14-17	Panel Plenary Session, NASA Headquarters

JANUARY

9	Review of safety functions, Kennedy Space Center
18	STS-63 Flight Readiness Review, Kennedy Space Center

National Aeronautics and
Space Administration

For Further Information Please Contact:

Aerospace Safety Advisory Panel
NASA Headquarters