

JS-96-003

**AUDIT
REPORT**

SPACE SHUTTLE SAFETY REVIEW

JOHNSON SPACE CENTER

June 28, 1996



National Aeronautics and
Space Administration

OFFICE OF INSPECTOR GENERAL

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



Reply to Attn of:

W

JUN 28 1996

TO: Johnson Space Center
ATTN: AA/Director

FROM: W/Assistant Inspector General for Auditing

SUBJECT: Final Audit Report
Space Shuttle Safety Review
Assignment No. A-JS-94-005
Report No. JS-96-003

The NASA Office of Inspector General (OIG) has completed an audit of Space Shuttle safety. Survey work was performed at the Johnson Space Center, Kennedy Space Center, and NASA Headquarters. The original audit objective was to determine whether Shuttle safety is adequate. Based on survey findings, we determined this audit objective was too broad for a single audit. Consequently, we revised the audit objective and limited the scope to a review of Shuttle crew escape safety issues. We determined that NASA has implemented processes and procedures for ensuring Shuttle safety and metrics to evaluate the extent that the safety goals are being met. However, the Shuttle crew escape system and related crew egress training procedures need increased management attention.

We issued a May 8, 1995, management letter to you that summarized the astronauts' responses to our questionnaire on Shuttle safety. We found that the majority of the astronauts expressed no serious safety issues and believe NASA management listens to their concerns and has made the Shuttle program as safe as possible considering the current configuration, i.e., mature state of the Shuttle hardware and the economic environment. However, there were several astronaut responses that we felt warranted NASA management attention. Our management letter with those astronaut responses is presented as Appendix 1.

Additionally, the audit showed that: (1) astronauts could be physically unable to perform an emergency egress following reentry into Earth's atmosphere because current flight crew training does not simulate the affects of microgravity while wearing 91 pounds of Shuttle crew escape equipment; and (2) the reliability of a Criticality 1 pip pin that fastens the crew escape pole to the Shuttle Orbiter's middeck ceiling during ascent and entry should be improved. Because of earlier meetings held to discuss the findings of this audit, JSC opted to respond directly to our February 16, 1996, discussion draft report and waive an exit conference. Management's written response was received on June 4, 1996. JSC concurred with the five report recommendations.

The Center's written response is presented after each recommendation and is included in its entirety as Appendix 2 in this final report. The NASA OIG concurs that the actions planned and taken by JSC are sufficient for the closure of recommendations 1, 2, and 3. In accordance with NMI 9910.1A, please include our office in the concurrence cycle for closing recommendations 4 and 5.


Debra A. Guentzel

Enclosure

cc:
HQ/M/W. Trafton
JSC-BU/P. Ritterhouse
MA/T. Holloway
W/J. Goodnight (w/o enclosure)

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ACRONYMS

ASAP	Aerospace Safety Advisory Panel
GAO	General Accounting Office
JSC	Johnson Space Center
KSC	Kennedy Space Center
STS	Space Transportation System

SPACE SHUTTLE SAFETY REVIEW

JOHNSON SPACE CENTER (JSC)
HOUSTON, TEXAS

EXECUTIVE SUMMARY

INTRODUCTION

The NASA Office of Space Flight mission is to provide safe, assured, and economic transportation to and from space for people and payloads. During the design of the Space Shuttle, the idea was to avoid single point failures and, with respect to avionics, avoid double point failures. The complexity and sophistication of the Shuttle made it very difficult to design out all potential risk factors. However, the Agency has implemented processes and procedures for ensuring Shuttle safety. Also, private contractors have been commissioned to assess how well Shuttle safety is being accomplished. Nonetheless, problems with crucial Shuttle parts and NASA budget cuts have raised fears of another Challenger disaster.

OBJECTIVES

The original audit objective was to determine whether Shuttle safety is adequate. During the survey phase, we performed limited tests of significant management controls to assess processes and procedures for ensuring Shuttle safety and metrics for evaluating whether safety goals were being met. However, we determined the original audit objective was too broad for a single audit and, following the survey phase, limited our review to the Shuttle crew escape system. The revised audit objectives for the detailed audit phase were to review the emergency crew egress and assess the reliability of the crew escape pole pip pin fastener.

RESULTS OF AUDIT

NASA has implemented processes and procedures for ensuring Shuttle safety and metrics to evaluate the extent that the safety goals are being met. However, the Shuttle crew escape system and related crew egress training procedures need increased management attention. Astronauts could be physically unable to perform an emergency egress following reentry into Earth's atmosphere because current flight crew training does not simulate the affects of microgravity while wearing 91 pounds of Shuttle crew escape equipment. Also, the reliability of a Criticality 1 pip pin that fastens the crew escape pole to the Shuttle Orbiter's mid-deck ceiling during ascent and entry should be improved.

RECOMMENDATIONS

We recommended:

- 1. The Space and Life Sciences Directorate's Medical Sciences Division determine the extent that the weight and mass of the crew escape equipment reduce/obstruct crew mobility following an extended exposure to microgravity.**
- 2. The Mission Operations Directorate's Space Flight Training Division collaborate with the Medical Sciences Division to develop and implement flight crew training procedures that appropriately relate to the physical requirements of an emergency egress after exposure to microgravity.**
- 3. The Engineering Directorate's Extra-Vehicular & Spacesuit Systems Branch identify hardware modifications and, where feasible, the JSC Projects Office provide adequate funding so that the weight of the crew escape equipment is reduced and crew mobility is enhanced.**
- 4. The JSC Engineering Directorate and JSC Projects Office identify reliable space fasteners with redundant safety features that can be used to replace the Criticality 1 pip pin that attaches the crew escape pole to the Shuttle Orbiter's mid-deck ceiling.**
- 5. The JSC Projects Office, if deemed feasible, provide the necessary funds to purchase the space fasteners identified in Recommendation 4.**

INTRODUCTION

NASA has well defined processes and procedures for achieving Space Shuttle safety. Specifically, the Agency performs a Failure Modes and Effects Analysis during the design phase for all Shuttle hardware. This analysis documents the worst case effects of failure at the worst time of occurrence. The resultant effect of not properly providing the function determines the "functional criticality" as: "1" for possible loss of life or vehicle; "2" for possible loss of mission or prime mission objective; and "3" for all others. Open hardware problems are reported and maintained in an automated database where they are tracked and managed until closure is made. Program Change Reviews and Configuration Control Boards look at and evaluate all proposed Shuttle changes to determine the safety impact. Finally, NASA conducts a series of readiness reviews at designated times prior to launch in order that Space Shuttle problems/issues are sufficiently discussed and dispositioned to ensure all safety risks associated with the upcoming mission are nominal.

To evaluate the extent that Shuttle safety goals are being met, NASA has several metrics. On several occasions, the Agency has commissioned private contractors to perform independent safety reviews of NASA activities and operations. Further, the Aerospace Safety Advisory Panel (ASAP), established by Section 6 of the NASA Authorization Act of 1968, provides oversight and counsel to the NASA Administrator and Congress on the safety aspects of NASA's programs. ASAP submits an annual report to the Administrator and Congress. Finally, the Agency has developed the NASA Safety Reporting System so that individuals can make anonymous reports of Shuttle safety concerns and issues.

Still, the risk of catastrophic failure during the Shuttle's ascent into orbit is estimated by NASA at about 1 in 75 missions and by private experts at about 1 in 60. Following the Challenger accident, the Rogers Commission recommended that NASA provide a crew escape system. Accordingly, NASA developed a bailout crew escape system for in-flight emergencies and an emergency slide and sky genie for post-landing events.

For an in-flight bailout, the crew must be able to release from their Shuttle Orbiter seats, move to the side hatch door, connect to the escape pole, and jump out of the vehicle. For post-landing emergencies, the astronauts must be capable of reaching the Shuttle Orbiter's side hatch door and exiting the vehicle via the emergency egress slide or climbing through an overhead window and using the sky genie to escape the Shuttle Orbiter.

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OBJECTIVES, SCOPE, AND METHODOLOGY

OBJECTIVES

The original audit objective was to determine whether Shuttle safety is adequate. During the survey phase, we performed limited tests of significant management controls to assess processes and procedures for ensuring Shuttle safety and metrics for evaluating whether safety goals were being met. However, we determined the original audit objective was too broad for a single audit and, following the survey phase, limited our review to the Shuttle crew escape system. The revised audit objectives for the detailed audit phase were to review the emergency crew egress and assess the reliability of the crew escape pole pip pin fastener.

SCOPE AND METHODOLOGY

We interviewed key NASA and contractor personnel, reviewed pertinent records, and performed limited tests of management controls. Audit field work was conducted from June 1994 through July 1995 at the Johnson Space Center (JSC), Kennedy Space Center (KSC), and NASA Headquarters.

Specifically, we:

- Attended the Pre-Launch Assessment Review at JSC and the Flight Readiness Review at KSC for the Space Transportation System (STS) 65 mission.
- Met with NASA Headquarters managers who are responsible for Shuttle operations and safety. Separate meetings were held with the Deputy Associate Administrator for Space Shuttle, the Director of Space Flight Safety and Mission Assurance Division, and the Director of Safety & Risk Management Division. We discussed NASA's overall goal, mission, and issues/concerns involving Shuttle safety. Also, we met with the Staff Director for the ASAP and discussed ASAP's overall assessment of the adequacy of Shuttle safety.
- Conducted teleconference calls and meetings with the General Accounting Office (GAO) evaluators that are performing audits at NASA that relate to Shuttle safety. We wanted to preclude any audit duplication and establish our audit scope. Specifically, we had discussions with the evaluator who is assessing whether NASA is sufficiently considering safety when identifying ways to reduce Shuttle Program costs. Therefore, our audit does not address how cost and budget

constraints affect Shuttle safety. Also, we met with the GAO evaluators reviewing how NASA identifies, assesses, and manages Shuttle risks.

- Identified and reviewed selected NASA Safety Reporting System files to evaluate whether NASA had taken appropriate corrective actions regarding Shuttle safety concerns that had been reported anonymously.
- Developed and issued an open-ended astronaut questionnaire to obtain the flight crew members' concerns and comments on Shuttle safety. Astronaut responses that we felt warranted management attention were discussed with managers in JSC's Flight Crew Operations Directorate and summarized in a management letter to the JSC Director (see Appendix 1).
- Reviewed NASA policy for granting flight waivers. Also, reviewed some Launch Commit Criteria flight waivers to determine the frequency of waivers and why they were issued.
- Identified and reviewed safety issues related to the Shuttle crew escape system.
- Met with JSC management and discussed our Finding and Attribute Lead Sheets.

***MANAGEMENT
CONTROLS REVIEWED***

We reviewed significant management controls to determine NASA's:

- processes and procedures for achieving Shuttle safety; and
- metrics for evaluating the extent that Shuttle safety goals are met.

AUDIT STANDARDS

The audit was accomplished in accordance with generally accepted government auditing standards and included such examinations and tests of applicable records and documentation as were considered necessary.

OBSERVATIONS AND RECOMMENDATIONS

OVERALL EVALUATION

NASA has implemented processes and procedures for ensuring Space Shuttle safety and metrics for evaluating the extent that the safety goals are being met. However, the Shuttle crew escape system and related crew egress training procedures need increased management attention.

EMERGENCY CREW EGRESS

Current flight crew egress training does not simulate how exposure to microgravity affects an astronaut's ability to perform an emergency egress. The Shuttle crew escape system and related crew egress training procedures should provide the capability for astronauts to safely escape the Shuttle during emergency situations. However, current flight crew training does not simulate the affects of microgravity because JSC management believes it is extremely improbable events will occur that require an emergency egress during reentry/landing. Astronauts wearing 91 pounds of escape equipment who have not been properly trained could be unable to perform an emergency egress.

MICROGRAVITY DECONDITIONS ASTRONAUTS

The microgravity environment of low Earth orbit causes the astronauts to become deconditioned. The technical publication, "Space Physiology and Medicine," Third Edition, expounds on the degrading physiological changes that occur to the human body after exposure to microgravity. The publication states that:

"A...study of five Space Shuttle crewmembers conducted during flight concluded that total body water decreased by 3.4% after 1 to 3 days in flight.... When a crewmember with reduced fluid volume first stands in 1 g [gravity], large portions of the fluid, including plasma, tend to pool in the lower extremities, leaving that crewmember susceptible to ... the possibility of fainting.... These ... adaptations influence ... the capacity of the astronauts to stand and to ambulate upon return to the 1 g environment.... Exposing humans to weightlessness during space flight seems to induce significant structural changes in the muscle and spindle fibers. ...manifested as loss of

muscle size and strength ... including muscle fatigue, abnormal reflex behavior, and diminished neuromuscular efficiency.... When an individual first enters weightlessness, fluids shift toward the head and torso.... In-flight decrements in calf girth of up to 30% provide additional evidence of the headward migration of fluids ... the body responds to the need to eliminate the fluid-volume overload by reducing the central volume [through diuresis].... Plasma volume declines during missions within hours and stabilizes about 12% below normal.... Although these physiological changes begin during flight, they pose the most significant operational concern during landing, when astronauts must be able to pilot the Shuttle and exit quickly in the event of an emergency. [Emphasis added.]"

***CREW ESCAPE
SYSTEM AND EGRESS
TRAINING SHOULD
PROVIDE EMERGENCY
ESCAPE CAPABILITY***

The Shuttle crew escape system and related crew egress training procedures should provide the capability for astronauts to safely escape the Shuttle Orbiter during emergency situations. After exposure to the microgravity environment of low Earth orbit, astronauts must be sufficiently strong, mobile, and adequately trained to perform NASA's prescribed emergency egress procedures.

The bailout crew escape system requires the astronauts be physically able to attach and slide down a crew escape pole extended out of the Shuttle Orbiter's side hatch door and parachute below into a body of water. The astronauts are expected to bailout during a two-minute period. Bailout should be initiated at about 25,000 feet. Since the minimum altitude to enable full parachute opening is 1,200 feet and the Shuttle has a nominal descent rate of approximately 4,000 feet per minute, the total bailout must be completed in approximately 6.5 minutes.

For post-landing emergencies such as a cabin fire, the flight crew must jettison the Shuttle Orbiter side hatch and manually activate the emergency egress slide from the mid-deck through the egress side hatch opening. Then the flight crew must pull a lanyard to inflate the slide and proceed to evacuate the Shuttle Orbiter. If the Shuttle Orbiter side hatch fails to jettison, the flight crew must jettison the overhead emergency escape panel and use the sky genie descent devices to lower themselves to the ground.

***EGRESS TRAINING
FAILS TO SIMULATE
THE EFFECTS OF
MICROGRAVITY***

Current flight crew egress training does not simulate how exposure to microgravity affects an astronaut's ability to perform an emergency egress. In order to train the astronauts for emergency egresses, the Mission Operations Directorate conducts the following courses:

- "Bailout 2102" (1 hour - Workbook) provides information on the crew escape system and procedures used for inflight bailout.
- "Escape System Introduction 2101" (3 hours - Classroom) introduces the student to crew-worn equipment, cabin vent and hatch jettison, escape pole and slide deployment, parachute operation, sky genie usage, survival gear, and search and rescue operations.
- "Escape Procedures 2120" (4 hours - Crew Compartment Trainer) provides experience on procedures for bailout and postlanding slide egress.
- "Bailout 2127" (3 hours - Weightless Environment Training Facility) is performed at the Weightless Environment Training Facility to enable the crew members to experience bailout, water entry, and water survival procedures.
- "Water Survival 2101" (2 hours - classroom) discusses in detail the inflight bailout procedures including parachute operations, survival/rescue gear usage and the Search and Rescue posture.

Rather than incorporate ground-based microgravity simulations into crew egress training, NASA flight doctors interview the returning astronauts following each STS mission. The flight doctors then use that data to inform upcoming flight crews of problems and limitations that might be experienced due to physiological changes induced by time spent in a microgravity environment.

On February 22, 1995, we observed the crew for STS-70 perform bailout training in the mocked-up Full Fuselage Trainer at JSC. The training did not require that the crew complete the bailout in the maximum 6.5 minutes available for an emergency egress. More importantly, we noted that the training did not simulate the loss of strength and mobility that is experienced after exposure to microgravity and how that phenomenon will impact the crew's ability to effectively perform an emergency egress.

We believe it is imperative that flight crews be adequately trained to perform Shuttle emergency egress procedures when they are deconditioned.

***NASA MANAGEMENT
BELIEVES AN
EMERGENCY CREW
EGRESS FOLLOWING
REENTRY IS IMPROBABLE***

However, current flight crew training does not simulate the affects of microgravity because JSC management believes it is extremely improbable events will occur that require an emergency egress during reentry/landing. Nonetheless, a recent NASA-commissioned study estimated there was a 1 in 97.4 chance that a bailout maneuver would be required during reentry/landing for the STS-71 Shuttle/Mir mission and identified 38 events that could have required an emergency crew egress. The study recognized that on STS-71, there were three crew members (two Russian cosmonauts and one U.S. astronaut) so deconditioned that they would have been constrained by their lack of strength and would have needed to crawl over the Shuttle Orbiter seats/floor to reach the exit hatch in case of a bailout.

***ASTRONAUTS COULD
BE UNABLE TO
EGRESS***

Astronauts who are wearing 91 pounds of escape equipment and have not been properly trained could be unable to perform an emergency egress. The 91 pounds of crew escape equipment could make it extremely difficult or impossible to perform an emergency egress when deconditioned following exposure to microgravity. According to a NASA flight doctor, the Agency has not performed any studies to determine how each pound of mass, i.e., crew escape equipment, impacts the mobility of a deconditioned crew member upon re-exposure to Earth's gravitational forces.

Based on biographical data, we determined that 29 (28 percent) of NASA's 104 astronauts weighed 150 pounds or less. For this group of astronauts, the escape equipment represents 60 percent or more of their body weight. The heavier elements of the crew escape equipment are the 16.5 pound advanced crew escape suit overalls, the 20.5 pound torso harness and harness sub-assembly, and the 26.2 pound parachute assembly. NASA engineers advised us that the weight of the parachute assembly could be reduced by 8 to 10 pounds. This parachute modification would cost the Shuttle program an estimated \$500,000 to \$600,000 primarily for certification testing. We believe that reducing the weight of the crew escape equipment would enhance the crew's ability to perform an emergency egress and offset any hardware modification costs by allowing NASA to lift heavier payloads on STS missions.

A NASA flight doctor explained that the extent of deconditioning caused by microgravity will vary based on the size and strength of each crew member and the amount of time spent in the weightless environment of low Earth orbit. Still, NASA has not incorporated any ground-based microgravity simulations into its emergency crew egress training procedures. "Space Physiology and Medicine" states that several ground-based simulations have yielded a great deal of insight into how the various body systems respond to conditions resembling those of brief and extended space flight. Particularly, it mentions that "bed rest," the most widely used simulation of the space flight environment, causes decreased orthostatic tolerance similar to that demonstrated by returning astronauts. Further, it notes that the "dry immersion" technique has resulted in physiological changes that are caused by microgravity. We believe that NASA should carefully consider the feasibility of using proven ground-based microgravity simulations during crew egress training to better prepare the astronauts for an emergency escape when they are deconditioned after spending time in a weightless environment.

RECOMMENDATION 1

The Space and Life Sciences Directorate's Medical Sciences Division should determine the extent that the weight and mass of the crew escape equipment reduce/obstruct crew mobility following an extended exposure to microgravity.

Management's Response

We concur with the recommendation. Neuroscience investigations indicate the crewmembers experience significant postural and locomotor disturbances following space flight. The Launch Escape Suit parachute combination introduces a greater stresser to postural stability particularly in smaller crewmembers. The added weight and physical constraining properties of the Launch Escape Suit may bring crewmembers closer to their instability boundaries during the critical early readaptation phase immediately after flight. Even without the parachute, the physical loads of egress, escape slide or rappelling down an overhead window, and then ambulating "x" meters upwind will be substantial. The hardware will all weigh more or less the same, but astronauts come in a wide range of sizes, so the relative load on a small astronaut will be proportionately greater than the relative load on a large astronaut. Orthostatic worst case is bail-out, due to hanging in a parachute harness which is an ideal way to sequester blood volume in the passive legs. The post-landing egress involves less orthostatic stress, more exercise stress. Recent data from exercise investigations suggest that crewmembers may not be able to walk immediately after landing even with minimal weight on their backs. However, post-land readaptation is rapid and egress from the Orbiter after some sort of landing could conceivably be aided by other

crewmembers or the crash rescue team. We consider the current procedures and the on-going investigations as responsive to the recommendation, and with your acceptance of these actions, this recommendation will be considered closed upon issuance of the final report.

***Evaluation of
Management's
Responses***

JSC's on-going investigations of microgravity's impact upon crewmembers' ability to perform an emergency Shuttle egress are responsive to Recommendation 1. The NASA OIG concurs that the current procedures and the on-going investigations are sufficient for closure of this recommendation.

RECOMMENDATION 2

The Mission Operations Directorate's Space Flight Training Division should collaborate with the Medical Sciences Division to develop and implement flight crew training procedures that appropriately relate to the physical requirements of an emergency egress after exposure to microgravity.

Management's Response

A study on locomotion postflight is being conducted, with STS-75 crew the first participants. For this study, crewmembers will exit into the Crew Transfer Vehicle (CTV) and walk on a treadmill in the back of the CTV wearing the full Launch Escape Suits/Advanced Crew Escape Suits. Results of this study could reveal information that might lead to changes in the egress training. The Mission Operations Directorate Crew Systems personnel continue to work with the medical branch concerning a project designed to evaluate the way NASA currently trains astronauts for stressful situations. In order to gain insight, medical personnel will participate as suited subjects in the Weightless Environment Training Facility bailout sessions and in a modified version of the Escape Procedures. In addition, the Engineering Directorate is working on lighter-weight equipment such as parachutes and harnesses. In training exercises, the returning station crewmembers train jointly with Shuttle crewmembers for all phases of flight and for all emergency egress scenarios including egress by parachute during freeflight and by the hatch/chute while on the ground. An example of this type of training occurred for STS-71 with MIR-18 crew training with the Shuttle crew prior to launch. The mid-deck astronaut worked with the three returning cosmonauts (who would be in space for more than 90 days) to develop techniques for rapid egress, even when the long-duration crewmember was completely immobile. All crews on flights bringing back MIR crewpersons are given extra training in the recumbent seats. We expect this type collaborative training to continue. We consider the

current procedures and the on-going studies as responsive to the recommendation, and with your acceptance of these actions, this recommendation will be closed upon issuance of the final report.

Evaluation of Management's Responses

Current flight crew training and on-going studies to improve emergency Shuttle egress procedures are responsive to Recommendation 2. The NASA OIG concurs that the actions planned and taken are sufficient for closure of this recommendation.

RECOMMENDATION 3

The Engineering Directorate's Extra-Vehicular & Spacesuit Systems Branch should identify hardware modifications and, where feasible, the JSC Projects Office provide adequate funding so that the weight of the crew escape equipment is reduced and crew mobility is enhanced.

Management's Response

We concur with the recommendation. The Engineering Directorate is presently addressing alternatives for reducing escape equipment weight. An effort is under way to reduce the weight and descent rate of the present parachute. The amount of weight reduced will be small as reducing the overall weight of the escape system would require deletion of specific survival equipment. The implementation of the full pressure advanced crew escape suit (ACES) will improve mobility. With the addition of the thermal electric cooling system, the crew comfort during entry and postlanding is greatly enhanced, resulting in improved crew physiologic condition at end of mission. With actions currently under way, and your acceptance of those actions, this recommendation will be closed upon issuance of the final report.

Evaluation of Management's Responses

On-going efforts to reduce the weight and descent rate of the present parachute and to improve crew mobility by the implementation of the ACES are responsive to Recommendation 3. The NASA OIG concurs with management's decision to close this recommendation.

RELIABILITY OF CREW ESCAPE POLE PIP PIN FASTENER

A Criticality 1 pip pin that fastens the 275-pound crew escape pole to the Orbiter's mid-deck ceiling does not have a redundant lock and, in effect, is a single point of failure. The escape pole must remain firmly affixed to the mid-deck ceiling during the mission ascent and entry phases in order to accommodate an in-flight emergency crew bailout.

Some JSC managers are confident that the current pip pin is sufficiently reliable, even though it only has a single-acting lock. However, a single failure of the current pip pin fastener could cause the escape pole to inadvertently release from the Orbiter's mid-deck ceiling.

***POLE MUST REMAIN
AFFIXED TO ORBITER
CEILING BY PIP PIN***

The crew escape pole must remain firmly affixed to the mid-deck ceiling during the mission ascent and entry phases in order to accommodate an in-flight emergency crew bailout. One end of the pole's 126.75 inch arched housing is attached by the pip pin to the mid-deck ceiling above the airlock hatch and the other end in the 2 o'clock position above the side hatch door. In case a bailout is required, the escape pole will be deployed from its housing assembly and extended approximately 9.8 feet out of the Orbiter's side hatch door. Sliding down the pole will allow the crew member to fall below the wing and free of the Orbiter.

***PIP PIN DOES NOT
HAVE REDUNDANT
LOCK***

A Criticality 1 pip pin that fastens the 275-pound crew escape pole to the Orbiter's mid-deck ceiling does not have a redundant lock and, in effect, is a single point failure. Two retention balls at the end of the pip pin provide the sole safety locking mechanism. The two retention balls have been designed to recess only when the release button is depressed. However, human errors (poor quality, inadequate hardware processing/inspection) and/or environmental impediments (hardware corrosion, foreign objects embedded around the pin retention balls or inside the pip pin) could render the pip pin ineffective for securing the pole. Two of the three mission specialists in the Orbiter mid-deck are seated beneath the escape pole.

***NASA MANAGERS
FEEL PIP PIN
RELIABLE***

Some JSC managers are confident that the current pip pin is sufficiently reliable even though it only has a single-acting lock. However, we found that astronauts carry a spare, identical pip pin in the Orbiter crew cabin for use in reinstalling the pole for landing phases in the event the primary pin fails. JSC managers may have not sufficiently discussed the pip pin safety issue and the feasibility of procuring more reliable replacement space pins with redundant safety features. We were advised that JSC Engineering had been busy redesigning the Orbiter seats and had not contacted the managers in JSC Projects Office concerning the pip pin replacement. However, Engineering recognized the safety risks associated with the current pip pin and, therefore, had obtained vendor quotes for replacement space pins. One vendor had given Engineering a written quote of \$3,750 for 15 space pins with redundant locks. At a February 1, 1995 meeting,

some JSC managers insisted that the \$3,750 quote was too low and, subsequently, provided an updated cost estimate of \$13,000 for redundant pip pins with hitch pins. The JSC managers stated that, regardless of the replacement cost, Shuttle program funds are scarce and should be spent on expenditures other than the acquisition of a redundant lock for the escape pole pip pin.

***AN INOPERABLE OR
MALFUNCTIONING
PIP PIN COULD
CAUSE THE ESCAPE
POLE TO FALL FROM
SHUTTLE ORBITER'S
MID-DECK CEILING***

However, a single failure of the current pip pin fastener could cause the escape pole to inadvertently release from the Orbiter's mid-deck ceiling. As a result, the 275-pound crew escape pole could fall onto the astronauts seated in the Orbiter's mid-deck. Also, the weight and force of a falling pole could tear a hole into the Orbiter's exterior wall above the side hatch door. Such a tear in the Orbiter's exterior wall would cause a sudden loss of cabin pressure and potentially a loss of the Shuttle vehicle. Finally, if a pip pin failure caused the pole assembly to fall from the mid-deck ceiling during ascent or entry, the astronauts could not perform an emergency bailout.

RECOMMENDATION 4

The JSC Engineering Directorate and JSC Projects Office should identify reliable space fasteners with redundant safety features that can be used to replace the Criticality 1 pip pin that attaches the crew escape pole to the Shuttle Orbiter's mid-deck ceiling.

Management's Response

We concur with the recommendation. The Engineering Directorate and JSC Projects Office will initiate a search for a reliable fastener, with redundant safety features, that will lead to an assessment on replacing the existing pip pin on the Escape Pole.

***Evaluation of
Management's
Responses***

The actions planned by JSC are responsive to Recommendation 4.

RECOMMENDATION 5

The JSC Projects Office, if deemed feasible, should provide the necessary funds to purchase the space fasteners identified in Recommendation 4.

Management's Response

We concur with the recommendation. As stated in the above response to recommendation 4, efforts are under way to identify a reliable space fastener.

***Evaluation of
Management's
Responses***

The actions planned by JSC are responsive to Recommendation 5.

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GENERAL COMMENT

We appreciate the courtesy, assistance, and cooperation extended by JSC, KSC, Headquarters, and contractor personnel contacted during the audit.

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MAJOR CONTRIBUTORS TO THIS AUDIT

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APPENDIX 1

Reply to Attn of:

W

May 8, 1995

TO: Johnson Space Center
Attn: AA/Director

FROM: W-JS/OIG Center Director

SUBJECT: Management Letter on Space Shuttle Safety
Assignment No. A-JS-94-005

The NASA Office of Inspector General (OIG) is performing an audit of Shuttle safety. The overall purpose of this audit is to determine whether Shuttle safety is adequate. As part of the audit, we developed an Astronaut Questionnaire (see Enclosure 2) to facilitate a record of the crew members' comments, opinions, and suggestions concerning Shuttle safety.

On August 24, 1994, we met with some Johnson Space Center (JSC) Flight Crew Operations Directorate (FCOD) managers and discussed our plans for issuing an astronaut questionnaire. The FCOD managers suggested that interviews with knowledgeable management personnel would provide a more informed source for response to questions regarding Shuttle safety. We explained that the OIG is very interested in obtaining the views of NASA management. Therefore, during July 1994, we conducted separate interviews at NASA Headquarters with the Deputy Associate Administrator for Space Flight (Space Shuttle); the Director, Space Flight Safety and Mission Assurance Division; the Director, Safety and Risk Management Division; and the Staff Director, Aerospace Safety Advisory Panel to obtain NASA's corporate views regarding Shuttle safety. However, we told the FCOD managers that it is imperative the Shuttle is, in fact, safe and perceived as such by the astronaut crews that operate the vehicle. We cited the following rationale why an astronaut questionnaire should logically be an integral part of our review of Shuttle safety.

- Astronauts play a pivotal role in the Shuttle program with enormous safety implications regarding planning, training, and operations. Can the flight crew perform effectively if safety concerns exist?;

- Astronauts occupy a unique position in the Shuttle program that is not duplicated elsewhere--they travel in the space vehicle;
- Astronauts assume a degree of risk unparalleled by other program participants;
- The astronauts' opinion/perspective on safety is a logical component of a safety audit; and
- It is extremely beneficial to determine if the astronauts have any personal safety concerns or can identify potential Shuttle issues that require management attention.

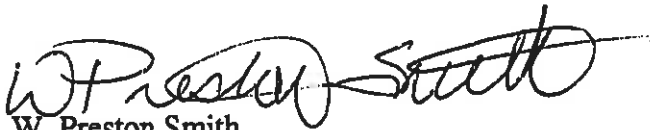
The FCOD managers generally agreed with our rationale for wanting to know how the astronauts feel about Shuttle safety. However, they expressed concerns regarding: (1) the "factual bases" for individual crew responses to the questionnaire; and (2) the potential divisiveness that unsubstantiated crew comments could create between the Astronaut Office and cognizant NASA support organizations, i.e., safety, mission operations, engineering, etc. In response to the concerns raised by the FCOD managers, we modified our questionnaire. The crew members were asked to specify how long they have been astronauts and consider their flight experiences and training when answering the questions. Further, we agreed to meet with the FCOD managers to discuss and ensure the validity of the questionnaire results before including such information in an audit report.

The astronaut questionnaire was initially sent out on August 29, 1994, and resubmitted on September 27, 1994. One hundred and four questionnaires were sent out and 68 responses were received. We found that the majority of the astronauts expressed no serious safety concerns and believe NASA management has made the Shuttle program as safe as possible considering the current configuration, i.e., mature state of the Shuttle hardware, and economic environment. Also, crew members generally feel that the Shuttle Program Office listens to their concerns.

However, there were several crew responses that we believe warrant NASA management attention. Those astronaut responses are listed in Enclosure 1. Questions where the astronauts expressed no serious concerns are omitted. On March 3, 1995, we met with the FCOD managers and discussed the crew responses in Enclosure 1. The FCOD managers expressed minor concerns over some comments regarding training but, overall, indicated that the astronaut responses were generally accurate.

We hope that the astronaut responses contained herein will assist NASA management efforts to ensure Shuttle safety. Since we did not validate or perform a detailed review of the astronaut responses, there will be no formal recommendations on this audit based upon the crew comments. We appreciate the astronauts' openness and diligence in responding to the questionnaire. Also, the overall crew response rate was enhanced by FCOD's management support and cooperation in this matter.

Our Acting Deputy Assistant Inspector General for Auditing will transmit a copy of this management letter to Codes M and Q. If you have any questions or desire additional information, please call Janice Goodnight, Audit Manager, or me at extension 34773.



W. Preston Smith

Enclosures

cc:

JSC-BU/D. Westfall

HQs-W/C. Little

JMC/P. Chait

Space Shuttle Safety Review
A-JS-94-005

Summary of Responses to Astronaut Questionnaire

Each of the following bullets is an individual astronaut response to the question that was asked.

QUESTION #2. Comment on training procedures that should be modified to improve Shuttle safety.

- Budget pressures have pushed people and facilities to a bare minimum. The tremendous station assembly challenge will burn people out.
- Budget cuts have adversely impacted the astronauts' input to operational development and the ongoing research and testing to improve flight techniques and procedures that include training.
- Fly crew more often and train to fly as a crew. Reduce long technical assignments that interfere with training.
- Use of a mission specialist training aircraft to shuttle astronauts back and forth to training in Huntsville would reduce aircrew fatigue.
- Make simulators work correctly, multiple simulators, all with different models and lack of state of the art visuals.
- Add two organized reviews of vehicle Loss of Control (LOC) as a crew. Currently, LOC is a table top review.
- Training improvements would be in the areas of workload preflight and ground controllers.

QUESTION #4. Is NASA management receptive to astronaut concerns regarding Shuttle safety? Explain.

- Yes, unless it costs them money or makes the Shuttle weigh more.

example #1 The crews who fly the Shuttle would like to have a better escape system (i.e., ejection seats).

example #2 NASA management wants to raise crosswind limits for the Return to Launch Site abort contingency. The crew office doesn't really like the idea. However, it will probably help launch probability. Therefore, the program managers will probably raise the limits anyway.

QUESTION #4. Is NASA management receptive to astronaut concerns regarding Shuttle safety? Explain. (cont.)

- Yes, they listen politely but their budgets are limited. The really important improvements to Shuttle safety, assisted egress from the crew compartment during powered flight, have never been considered seriously enough.
- In an environment of reduced resources, it often becomes the task of the person raising a safety concern to prove there is a problem rather than the task of the system to prove their plan of operation is really safe despite the expressed concern.
- Depends on the issue. Why do we continue to push for increased crosswind limits without crosswind Detailed Test Objective? Let's get a landing with 10 knots of crosswind so we can feel confident landing with 15.
- Only if budget will allow and/or the software memory will allow and/or there are no other operational issues which get more attention. In software, it's very difficult to sell an expensive software change for a (10)⁻⁸ probability of occurrence (i.e., 3-engine out) if it's competing with an operational change we'd use every flight. Software should insure crew safety by doing things the crew can't do, especially during degraded ops.
- I'm not sure. There seem to have been several issues (landing at KSC, clearing... Shuttles for launches with known problems) in which there was significant disagreement within the astronaut office over possible safety issues.
- Sometimes they are and sometimes they are not. Two examples: In 1993 the Return To Launch Site crosswind limit was waived in order to launch STS-52. I never heard a rational technical argument that supported waiving this Launch Commit Criteria. In 1989, 1990, or 1991, NASA management decided to start landing at KSC against the recommendations of JSC's Flight Crew Operations and Mission Operations directorates. These groups recommended delaying returning to KSC for end of mission until after the orbiters received the dragchute, new brakes and improved nose steering.

QUESTION #7. What are some suggested improvements/changes that would enhance Shuttle safety? What safety procedures need to be revised or updated to be more effective?

- NASA is making arbitrary budget cuts to the Shuttle to preserve dollars for Station. This will lead us to cut budgets below the safety threshold until it bites us.
- Pay more attention to crew 16-hour work days. This may cause mental fatigue and subsequent error.

QUESTION #7. What are some suggested improvements/changes that would enhance Shuttle safety? What safety procedures need to be revised or updated to be more effective?
(cont.)

- Spacing out the launch schedule so there's more time between landing and the next launch.
- Use available technology to obtain real time wind data at launch and landing sites, using wind balloons yields potentially inaccurate data.
- Hazard review process should be reviewed/streamlined/baselined/or eliminated.
- Emphasize personnel attitudes and critical effect on safety.
- Don't let budget cuts lull us into cutting training or margin of safety.
- Emphasize a fleet leader analysis program to analyze aging equipment.
- De-emphasize reports, paperwork and accounting.
- Improvements to Space Shuttle Main Engines & turbopumps is critical and ongoing.
- A new pressure garment is needed for launch and re-entry.
- Ensure the Shuttle program is funded properly.
- Add ejection system or crew module separation mechanism for powered flight, if you are serious about improving our chances of survival during a Shuttle accident.
- Upgrade cockpit to Multifunctional Electronic Display System and fund follow-on's.
- Incorporate a functional Global Positioning System.
- The intact abort capability should be enhanced, down range aborts to runways.
- Fly sleep stations on single shift flights.
- Target 39 degrees inclinations to avoid sleep shifting when performance and payload allow higher than 28.5 degrees.
- Automate three engine out aborts in software.
- Develop better abort capabilities for 51.6 degrees inclination launch, and the implementation of a Global Positioning System.
- Preservation of talent in Shuttle workforce at KSC/JSC.

QUESTION #11. How might the crew escape system be improved to facilitate crew safety should emergency evacuation become necessary during the Shuttle ascent and landing phases?

- Install ejection seats.
- Have a crew escape capsule on a future vehicle.
- Lighter and less bulky suits.
- ACES suits are coming on line slowly and are better suits.
- Liquid cooling needed for all on a crew.

QUESTION #12. Do you know of any cases where Shuttle payload, or ferry hardware were not adequately certified for flight? If so, elaborate.

- No, but certification for late breaking changes close to flight is shaky, especially in payloads. STS-39 Infrared Background Signature Survey/Shuttle Pallet Satellite sun sensor improper software code resulted in improper altitude -- could have lost all science. STS-51: Super zip fired in improper sequence resulting in shrapnel in payload bay. STS-46 late added bolt to cable reel caused reel to stop unwinding -- could have jammed and caused safety concern.
- I think the tethered Satellite System failure (caused by an improperly added bolt to the tether housing or an inadequately understood addition) and the control system failure of the Wake Shield Facility.
- We inadvertently did some entry flight tests on STS-50 which placed the elevons out of our certification envelope (from a thermal standpoint).
- One of the biggest areas that needed work was toxic/hazard materials associated with payloads in spacelab, spacehab, or mid-deck environment.

QUESTION# 13. Describe any instances where the issuance of flight waivers resulted in unsafe flight operations.

- The only one that comes to mind right off is STS-52 when the Mission Management Team (MMT) re-interpreted/over-ruled the Return to Launch Site (RTLS) crosswind landing rule, against the recommendation of the Flight Director. It was potentially unsafe, not actually unsafe, because they did not do an RTLS!

QUESTION# 13. Describe any instances where the issuance of flight waivers resulted in unsafe flight operations. (cont.)

- I think the only example I can give really didn't take a waiver (as I recall) but a change in "rule interpretation," that was the crosswind exceeded for the launch of STS-52. Houston Flight was not "GO" based on his interpretation of the wind readings at the Shuttle Landing Facility, yet the MMT had a different view of the readings given by the wind towers. We have since changed our rules to make this case less ambiguous. But on that particular day we probably should not have launched. In general, I think waiver processing is treated very seriously and never accomplished without adequate rationale.
- Auxiliary Power Units (APUs) on STS-46 and STS-43. We flew with known, "understood" problems to say we could get one more flight on some hardware and save Orbiter Processing Facility time. As it turns out, not only did we not understand the problem, we had trouble on other APUs. We have dodged several bullets in the name of schedule and expediency.

QUESTION #14. Comment on Shuttle hardware/software issues that may compromise safety of the crew, vehicle, or mission?

- The biggest challenge in the safety area are the mods to increase payload weight to orbit for station lift requirements, and flight rule changes to make the 5 minute station launch windows. We will reduce operating margins and increase risk no matter what anyone says about it.
- The lack of three engine out capability (specifically hardware capability of external tank-orbiter attach support structure is a concern).
- Lack of budget that makes us force a system or software to really be broke; or we won't fix it.
- The range safety boundaries compromise crew safety on 57 degrees inclination launches. The crew must delay a contingency East Coast Abort Landing to avoid crossing the range safety boundaries and subjecting themselves to being destroyed. The range safety package theoretically protects a person on the ground from being killed by the external tank's return to earth. The range safety destruct package (explosives) present an unnecessary risk to astronauts.
- Why don't we have Global Positioning System so we can emergency de-orbit to a multitude of runways around the world? We have them in the T-38 and don't have them in the Shuttle.

QUESTION #14. Comment on Shuttle hardware/software issues that may compromise (cont.) safety of the crew, vehicle, or mission?

- There are hardware and software improvements that are driven by safety concerns. Many of these are in development and not yet implemented in the program. Some of these include: main engine upgrades, additional contingency abort software, Multifunctional Electronic Display System, Advanced Crew Escape System, Global Positioning System, On-board display capability, improved Thermal Protection System. Some improvements are not implemented as rapidly as we would like to see, normally due to budget cuts. Improvements that have been recently incorporated include: carbon brakes, dragchute, auto contingency abort, and liquid cooling.

QUESTION #15. Do you feel that the Shuttle program is safe? Address the strengths and weaknesses.

- In general, yes. I still think the pressure to launch and meet the schedule is too much of a factor for launch decisions. I have concerns that the poor morale (due to layoffs, budget cuts and poor leadership) may influence safety in the future. Budget cuts may directly increase risks and impact safety.

NAME _____

DATE _____

NASA OFFICE OF INSPECTOR GENERAL
Johnson Space Center
Houston, Texas 77058

Space Shuttle Safety Review
A-JS-94-005

Astronaut Questionnaire

1. To what extent has Shuttle safety been incorporated into crew training?
2. Comment on training procedures that should be modified to improve Shuttle safety.
3. Are there adequate avenues available to express safety concerns and issues without fear of reprisal? If not, what changes do you recommend?
4. Is NASA management receptive to astronaut concerns regarding Shuttle safety? Explain.
5. What input or direct involvement do you have for ensuring Shuttle safety?

Is the current level of astronaut involvement appropriate? Explain.

6. How long have you been with NASA? Astronaut tenure? Have you worked on any safety review panels? Which Shuttle missions have you flown?

7. What are some suggested improvements/changes that would enhance Shuttle safety? What safety procedures need to be revised or updated to be more effective?
8. Do you feel adequately informed about the safety risks associated with Space Shuttle flights? Explain.
9. On the morning of August 18, 1994, mission STS-68 was aborted on the launch pad within two seconds of the scheduled lift-off when onboard computers shutdown the Shuttle main engines. Are the procedures for crew evacuation, under these circumstances, adequate? Explain.
10. How do you feel about the Crew Escape System (CES) and the opportunity(ies) that it affords for crew evacuation during the Shuttle's ascent-to-orbit and landing phases? Comment on the flight conditions (altitude range, vehicle speed, etc.) that must prevail, along with the probability that such conditions can be obtained in order that the CES be used during Shuttle ascent and landing.
11. How might the CES be improved to facilitate crew safety should emergency evacuation become necessary during the Shuttle ascent and landing phases?
12. Do you know of any cases where Shuttle, payload, or ferry flight hardware were not adequately certified for flight? If so, elaborate.
13. Describe any instances where the issuance of a flight waiver(s) resulted in unsafe flight operations.
14. Comment on Shuttle hardware/software issues that may compromise the safety of the crew, vehicle, or mission.
15. Do you feel that the Shuttle Program is safe? Address strengths and weaknesses.

National Aeronautics and
Space Administration
Lyndon B. Johnson Space Center
2101 NASA Road 1
Houston, Texas 77058-3696



APPENDIX 2

MAY 31 1996

Reply to Attn of: **BU**

TO: W-JS/OIG Audit Field Office Manager

FROM: AA/Director

SUBJECT: Management Response to Draft Audit Report, Space Shuttle Safety Review, Assignment No. A-JS-94-005

Because of earlier meetings held to discuss the findings of this audit, JSC opted to respond directly to the draft audit report and waive an exit conference. We have addressed the recommendations and findings individually in the enclosure. In addition, we acknowledge the statement found in the management letter dated May 8, 1995, which transmitted a summary of the questionnaire to the astronauts. As shown in this letter, the majority of the astronauts expressed no serious safety concerns and believe NASA management has made the Shuttle program as safe as possible.

With actions taken or procedures in place that we consider responsive to the recommendations, and your acceptance of those actions, recommendations 1, 2 and 3 will be considered closed upon issuance of the final report. If you have any questions, please contact Pat Ritterhouse at 483-4220.


George W. S. Abbey

Enclosure

cc:
CA/D. C. Leestma
EA/L. S. Nicholson
DA/J. D. Shannon
FA/J. H. Greene
SA/D. Short
HQ/JM/P. I. Chait

**Management Response to Draft Audit Report, Space Shuttle Safety Review,
Assignment No. A-JS-94-005**

Auditors Findings

"The Shuttle crew escape system and related crew egress training procedures should provide the capability for astronauts to safely escape the Shuttle Orbiter during emergency situations. After exposure to the microgravity environment of low Earth orbit, astronauts must be sufficiently strong, mobile, and adequately trained to perform NASA's prescribed emergency egress procedures."

Recommendation 1

"The Space and Life Sciences Directorate's Medical Sciences Division should determine the extent that the weight and mass of the crew escape equipment reduce/obstruct crew mobility following an extended exposure to microgravity."

JSC's Comments

We concur with the recommendation. The Space and Life Sciences Directorate has reviewed the audit findings regarding the impact of weight and mass of the crew escape equipment in emergency egress following extended exposure to microgravity. While weight and mass is a factor in emergency egress, all organizations work together to make the Shuttle program as safe as possible.

There are two primary types of crew escape: (1) bail-out before landing, followed by parachute descent into ocean or onto land, and (2) egress from the Orbiter after some sort of landing. Both probably put the same stress on the crewmember from seat egress through side-hatch egress, except bail-out requires carrying the parachute along, whereas post-landing does not. Data show the single greatest orthostatic stress in space flight occurs on first standing up after landing. Post-landing readaptation is rapid. Either of these types of crew escape could be unaided or aided by other crewmembers, and egress from the Orbiter after some sort of landing could conceivably involve aid from the crash rescue team.

Even without the parachute, the physical loads of egress, escape slide or rappelling down from an overhead window, and then ambulating "x" meters upwind will be substantial. The hardware will all weigh more or less the same, but astronauts come in a wide range of sizes, so the relative load on a small astronaut will be proportionately greater than the relative load on a large astronaut. Orthostatic worst case is bail-out, due to hanging in a parachute harness which is an ideal way to sequester blood volume in the passive legs. The post-landing egress involves less orthostatic stress, more exercise stress.

Recent data from exercise investigations suggest that crewmembers may not be able to walk immediately after landing even with minimal weight on their backs. The effect of adding additional weight would be to further hinder their ability to move 400 meters in a minimal period of time (our goal is 5 minutes). The slower they move, the more likely

Enclosure

they will run out of oxygen, resulting in having to open their helmets and breathe air potentially containing toxic fumes. There is probably a direct relationship between weight carried and speed of locomotion. If it takes crewmembers more than about 8 minutes to get 400 meters away (the assumed safe distance), then they will run out of air.

Neuroscience investigations indicate that crewmembers experience significant postural and locomotor disturbances following space flight. The Launch Escape Suit (LES) parachute combination introduces a greater stressor to postural stability particularly in smaller crewmembers. The added weight and physical constraining properties of the LES may bring crewmembers closer to their instability boundaries during the critical early readaptation phase immediately after flight.

Some egress scenarios may require jumping from a particular height. Our experimental data indicate that unsuited subjects experience significant modification in the ability to program the lower limbs to effectively absorb energy on impact following a voluntary jump (30 cm in height) after flight. This change in motor control is a neural adaptation related to alterations in central nervous system reinterpretation of acceleration following the space flight. The operational implication is that crewmembers have a higher probability of falling post flight following even a relatively small jump. However, even if the landing following the jump is successful, more energy is transmitted through the body up to the head which in turn will exacerbate on-going neuro-vestibular disturbances. This change in energy modulation will also contribute to oscillopsia (blurred vision) during any running required following an emergency egress. The additional mass provided by the LES may increase the severity of these problems.

We consider the current procedures and the on-going investigations as responsive to the recommendation, and with your acceptance of these actions, this recommendation will be considered closed upon issuance of the final report.

Recommendation 2

"The Mission Operations Directorate's Space Flight Training Division should collaborate with the Medical Sciences Division to develop and implement flight crew training procedures that appropriately relate to the physical requirements of an emergency egress after exposure to microgravity."

JSC Comments

We concur with the recommendation. We believe that all reasonable methods are currently being used to acquaint and prepare the crews for the environments that might be associated with the various emergency egress modes. We continue to look for improvements in the tools and techniques for providing effective training as well as working to reduce the probabilities of having to invoke an emergency. A study on locomotion postflight is being conducted, with STS-75 crew the first participants. For this study, crewmembers will exit into the Crew Transfer Vehicle (CTV) and walk on a treadmill in the back of the CTV wearing the full Launch Escape Suits/Advanced Crew Escape Suits (LES/ACES). Results of this study could reveal information that might lead to changes in the egress training.

The Mission Operations Systems Division performs crew emergency egress training which covers the crew escape suit, pad emergency egress training, postlanding emergency egress (slide), and bailout. There is no reasonable way to simulate a deconditioned state during egress training that does not significantly increase the risk of injury to crewmembers, or that is too impractical. To subject the crew to bed rest or add-on weights would impose far greater risk of injury to the crew in training than the risk of having to use one of the emergency escape modes. The MOD Crew Systems personnel continue to work with the medical branch concerning a project designed to evaluate the way NASA currently trains astronauts for stressful situations. In order to gain more insight, medical personnel will participate as suited subjects in the Weightless Environment Training Facility (WETF) bailout sessions and in a modified version of the Escape Procedures. In addition, the Engineering Directorate is working on lighter-weight equipment such as parachutes and harnesses.

For normal Shuttle flights, the major effects seen at landing are orthostasis and neurovestibular effects. The incidence of orthostasis is about 10 percent and is usually mild. For the most part, if crews exercise, maintain hydration inflight, fluid load properly, use the G-suit and liquid cooling, they have minimal symptoms if any. Orthostasis does not seem to worsen with increasing mission length. While studies indicate that a week of bed rest can give similar effects, this is not practical.

Neurovestibular symptoms affect postflight, to a mild degree, about 93 percent of the flown people. About 9 percent have severe symptoms with severe balance instability, moderate to severe motion illusions (vertigo), and severe nausea and vomiting. There are no known preventatives nor ways to simulate this effect while on the ground, but prophylactic medications are available for crewmembers with histories of severe symptoms, and crew are briefed extensively by the crew surgeon before flight. New crewmembers are also briefed about the expected environments by experienced crews and by the crew escape instructors based on multiple interviews with experienced crews.

For missions of Space Station length, muscle deconditioning is expected in addition to the above problems. The amount of muscle deconditioning varies by individuals but can be decreased by inflight exercise. Bed rest of at least a week would be required to simulate this environment. Additional weight during training would significantly increase the risk of injury to crewmembers. Crews are informed of the likely environment and are trained to invoke the "buddy" system for station crew-return flights. Medical personnel brief the crew twice during their training flow on the effects of microgravity on the human body and potential problems which might result. When a long-duration crew is returned from a station, they are placed in reclining (recumbent) seats on the mid-deck. A member of the Space Shuttle crew is flown in the mid-deck with them to assist during any type of egress, including emergency egress. In training exercises, the returning station crewmembers train jointly with the Shuttle crewmembers for all phases of flight and for all emergency egress scenarios including egress by parachute during freeflight and by the hatch/chute while on the ground. An example of this type of training occurred for STS-71 with the MIR-18 crew training with the Shuttle crew prior to launch. The mid-deck astronaut worked with the three returning cosmonauts (who would be in space for more than 90 days) to develop techniques for rapid egress, even when the long-duration crewmember was completely immobile. All crews on flights

bringing back MIR crewpersons are given extra training in the recumbent seats. We expect this type collaborative training to continue.

We consider the current procedures and the on-going studies as responsive to the recommendation, and with your acceptance of these actions, this recommendation will be closed upon issuance of the final report.

Auditors Findings

"Based on biographical data, we determined that 29 (28 percent) of NASA's 104 astronauts weighed 150 pounds or less... For this group of astronauts, the escape equipment represents 60 percent or more of their body weight. The heavier elements of the crew escape equipment are the 16.5 pound advanced crew escape suit overalls, the 20.5 pound torso harness and harness sub-assembly, and the 26.2 pound parachute assembly. NASA engineers advised us that the weight of the parachute assembly could be reduced by 8 to 10 pounds. This parachute modification would cost the Shuttle program an estimated \$500,000 to \$600,000 primarily for certification testing. We believe that reducing the weight of the crew escape equipment would enhance the crew's ability to perform an emergency egress and offset any hardware modification costs by allowing NASA to lift heavier payloads on STS missions."

Recommendation 3

"The Engineering Directorate's Extra-Vehicular & Spacesuit Systems Branch should identify hardware modifications and, where feasible, the JSC Projects Office provide adequate funding so that the weight of the crew escape equipment is reduced and crew mobility is enhanced."

JSC Comments

We concur with the recommendation. The Engineering Directorate is presently addressing alternatives for reducing escape equipment weight. An effort is under way to reduce the weight and descent rate of the present parachute. The amount of weight reduced will be small as reducing the overall weight of the escape system would require deletion of specific survival equipment. The implementation of the full pressure escape suit (the advanced crew escape suit-ACES) will improve mobility. With the addition of the thermal electric cooling system (TELCS), the crew comfort during entry and postlanding is greatly enhanced, resulting in improved crew physiologic condition at end of mission.

With the actions currently under way, and your acceptance of those actions, this recommendation will be closed upon issuance of the final report.

Auditors Findings

"A Criticality 1 pip pin that fastens the 275 pound crew escape pole to the Orbiter's middeck ceiling does not have a redundant lock and, in effect, is a single point failure. Two retention balls at the end of the pip pin provide the sole safety locking mechanism."

Recommendation 4

"The JSC Engineering Directorate and JSC Projects Office should identify reliable space fasteners with redundant safety features that can be used to replace the Criticality 1 pip pins that attach the crew escape pole to the Shuttle Orbiter's middeck ceiling."

JSC Comments

We concur with the recommendation. The Engineering Directorate and JSC Projects Office will initiate a search for a reliable fastener, with redundant safety features, that will lead to an assessment on replacing the existing pip pin on the Escape Pole.

Recommendation 5

"The JSC Projects Office, if deemed feasible, should provide the necessary funds to purchase the space fasteners identified in Recommendation 4."

JSC Comments

We concur with the recommendation. As stated in the above response to recommendation 4, efforts are under way to identify a reliable space fastener.



