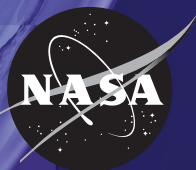


January 30, 2004
Volume 1, Revision 1.2

NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond

*A periodically updated document
demonstrating our progress
toward safe return to flight
and implementation of the
Columbia Accident Investigation
Board recommendations*





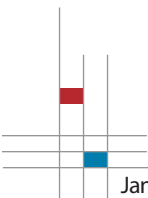
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An electronic version of this implementation plan is available at www.nasa.gov





January 30, 2004

NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond

Revision 1.2 Summary

January 30, 2004



This revision to *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* reflects our progress to date in responding to the recommendations and observations of the *Columbia* Accident Investigation Board (CAIB). This revision does not change the entire document, but only selected pages in the sections listed below. The changed pages can be inserted in place of the current pages of the Plan.

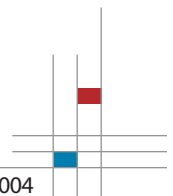
As we issue this revision, NASA is embarking on a new and exciting chapter in space exploration. The President's new vision for U.S. space exploration, "A Renewed Spirit of Discovery," calls for a sustained, achievable, and affordable human and robotic program to explore the solar system and beyond. The first necessary and critical step in achieving these ambitious goals is returning the Space Shuttle safely to flight.

As a result, our near-term mission for the Space Shuttle remains unchanged—to return the Shuttle to flight as soon as safely possible in order to complete assembly of the International Space Station (ISS). The Space Shuttle will be phased out with completion of ISS assembly, planned for the end of this decade. With the change in the planned service life of the Space Shuttle and a shift in Agency priorities, we will reassess our investment strategy to ensure safety and sustainability for the remainder of the Shuttle service life.

Future revisions of *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* will reflect the role of the Space Shuttle defined in this new vision.

The following is a list of the sections affected by this Revision:

- Response Summaries
- CAIB Recommendations Implementation Schedule
- Return to Flight Cost Summary
- Part 1 – NASA's Response to the *Columbia* Accident Investigation Board's Recommendations
 - 3.3-2 Orbiter Hardening [RTF]
 - 3.3-1 Reinforced Carbon-Carbon Nondestructive Inspection [RTF]
 - 3.3-4 Reinforced Carbon-Carbon Database
 - 3.3-5 Minimizing Zinc Primer Leaching
 - 3.8-1 Reinforced Carbon-Carbon Spares
 - 4.2-3 Closeout Inspection [RTF]
 - 4.2-5 Foreign Object Debris Processes [RTF]
- Part 2 – Raising the Bar – Other Corrective Actions
 - 2.1 – Space Shuttle Program Actions
 - SSP-1 Quality Planning and Requirements Document/Government Mandated Inspection Points
 - 2.2 – CAIB Observations
 - O10.1-1 Public Risk Policy
 - O10.4-1 KSC Quality Planning Requirements Document
 - O10.10-1 External Tank Attach Ring



The following pages have been changed or added in this Revision 1.2:

Add Page

Revision 1.2 Summary page

Remove Pages

Title page (Nov. 20, 2003)

xix (Oct. 15, 2003) – xxxii (Sep. 8, 2003)

xxxiii (Oct. 15, 2003) – xxxvi (Oct. 15, 2003)

xxxvi-a (Nov. 20, 2003) - xxxvi-b (Nov. 20, 2003)

1-11 (Sep. 8, 2003) – 1-16 (Oct. 15, 2003)

1-27 (Oct. 15, 2003) – 1-32 (Sep. 8, 2003)

1-57 (Oct. 15, 2003)– 1-58 (Sep. 8, 2003)

1-61 (Oct. 15, 2003) – 1-62 (Sep. 8, 2003)

2-1 (Nov. 20, 2003) – 2-2 (Sep. 8, 2003)

2-35 – 2-36 (Sep. 8, 2003)

2-41 (Oct. 15, 2003) – 2-42 (Oct. 15, 2003)

2-69 (Oct. 15, 2003) – 2-70 (Oct. 15, 2003)

B-9 (Oct. 15, 2003) – B-12 (Sep. 8, 2003)

Replace With Pages

Title page (Jan. 30, 2004)

xix (Jan. 30, 2004) – xxxii (Jan. 30, 2004)

xxxiii (Jan. 30, 2004) – xxxvi (Oct. 15, 2003)

xxxvi-a (Jan. 30, 2004) - xxxvi-b (Jan. 30, 2004)

1-11 (Jan. 30, 2004) – 1-16 (Jan. 30, 2004)

1-27 (Jan. 30, 2004) – 1-32 (Sep. 8, 2003)

1-57 (Jan. 30, 2004) – 1-58 (Sep. 8, 2003)

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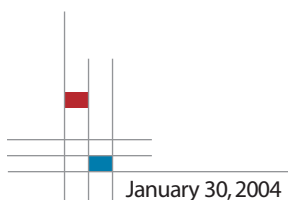
2-41 (Jan. 30, 2004) – 2-42 (Jan. 30, 2004)

2-69 (Jan. 30, 2004) – 2-70 (Jan. 30, 2004)

B-9 (Jan. 30, 2004) – B-12 (Sep. 8, 2003)

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Changes made in Revision 1.1, issued November 20, 2003, are described in the following summary.



Revision 1.1 Summary

November 20, 2003



This revision to *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* includes (1) our initial responses to additional data released by the *Columbia* Accident Investigation Board (CAIB), (2) preliminary cost estimates for return to flight activities, (3) a description of NASA's Space Shuttle return to flight suggestion process, and (4) updates to selected CAIB and Space Shuttle Program (SSP) actions. This revision does not change the entire document, but only selected pages which are listed below. These changed pages can be inserted into the existing document to reflect the Revision 1.1 update. A more detailed explanation of Revision 1.1 changes follows:

Initial Responses to Additional CAIB Data. In October 2003, the CAIB released additional data to supplement their August 2003, Volume I, CAIB Report. This Revision 1.1 provides NASA's initial responses to Volume II, Appendix D.a, also known as the "Deal Appendix." In this appendix, Brigadier General Duane Deal outlined concerns and made fourteen recommendations aimed at preventing another Shuttle accident. NASA's initial responses can be found in a new section 2.3 to this Implementation Plan.

Preliminary Cost Estimates for RTF. NASA's process for RTF includes developing cost estimates for RTF activities as they are defined. Since our RTF activities are at varying states of maturity, the cost estimates provided in this Revision 1.1 are not all-inclusive. The estimates represent those RTF activities that have been approved for implementation and funding by the Space Shuttle Program and verified by the RTF Planning Team. Estimates of total cost are presented, excluding reserves. This data can be found at the end of the Summary section.

NASA's Process for RTF Suggestions. As part of NASA's response to the CAIB recommendations, NASA put in place a means for NASA employees and the public to provide their ideas to help NASA safely return to flight. NASA created an electronic mailbox to receive RTF suggestions and a process for responding to each message individually, including information about where the message will be forwarded for further review and consideration. A description of the process and a table summarizing results to date are provided immediately following the Response Summaries.

Updates to Selected CAIB and SSP Actions. Status and schedule updates are provided to action SSP-1, Quality Planning and Requirements Document/Government Mandated Inspection points; CAIB Observation O10.4-3, KSC Quality Assurance Personnel Training Programs; and CAIB Observation O10.4-4, ISO 9000/9001, and Observation O10.5-3, NASA Oversight Process. These changes can be found in Part 2, Raising the Bar – Other Corrective Actions.

The following pages have been changes or added in this Revision 1.1:

Add Pages

i-a – i-b (Rev. 1.1 Summary)

xxxii-a – xxxii-d

xxxvi-a – xxxvi-b

2-75 – 2-90

Remove Pages

Title Page (Oct. 10, 2003)

ix (Oct. 15, 2003) – xii (Oct. 15, 2003)

2-1 (Oct. 15, 2003) – 2-2 (Sept. 8, 2003)

2-45 (Oct. 15, 2003) – 2-46 (Oct. 15, 2003)

2-47 (Oct. 15, 2003) – 2-48 (Oct. 15, 2003)

2-53 (Oct. 15, 2003) – 2-54 (Oct. 15, 2003)

A-3 (Oct. 15, 2003) – A-4 (Sept. 8, 2003)

Replace With Pages

Title Page (Nov. 20, 2003)

ix (Nov. 20, 2003) – xii (Nov. 20, 2003)

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2-45 (Nov. 20, 2003) – 2-46 (Oct. 15, 2003)

2-47 (Nov. 20, 2003) – 2-48 (Oct. 15, 2003)

2-53 (Nov. 20, 2003) – 2-54 (Oct. 15, 2003)

A-3 (Nov. 20, 2003) – A-4 (Sept. 8, 2003)

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Changes made in Revision 1, issued October 15, 2003, are described in the following summary.

Revision 1 Summary

October 15, 2003



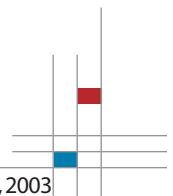
This first revision to *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* reflects our progress to date in responding to the recommendations and observations of the *Columbia Accident Investigation Board (CAIB)*, as well as additional actions initiated by the Space Shuttle Program. This revision supercedes the first iteration of our return to flight Implementation Plan released on September 8, 2003, and includes formatting that indicates where changes and updates have been made to show progress since the first Plan was released. We have renamed the document to ensure that its focus on Shuttle return to flight activities is clear and to recognize the fact that NASA still has critical programs that are continuing to fly while the Shuttle is grounded, including the International Space Station. In the future we anticipate that other areas of NASA may develop their own implementation plans in response to the CAIB report and other lessons-learned from the *Columbia* accident.

Since the initial release of the Implementation Plan, NASA has made progress in a number of critical areas of planning and implementation. In this revision, NASA has added responses to the observations contained in Chapter 10 of the CAIB Report. These responses are included in Section 2, "Raising the Bar – Other Corrective Actions." Beyond the CAIB observations, NASA continues to receive and evaluate inputs from a variety of sources, including the soon to be released Volume II, Appendix D of the CAIB Report, ideas submitted by our own employees, submittals to our virtual suggestion box at rftfsuggestions@nasa.gov, and suggestions from individual members of the CAIB. We are systematically assessing the proposed corrective actions and will incorporate these actions into future revisions of this Implementation Plan. In addition to our own monitoring of progress, which is reflected in this document, the Return to Flight Task Group will assess NASA's success in implementing return to flight requirements before we commit to flight.

NASA has progressed from planning to implementation in many critical return to flight areas. Several examples of our significant progress are in the areas of External Tank (ET), Thermal Protection System (TPS) repair and inspection, and cultural and organizational issues.

ET Foam Loss Mitigation. NASA completed high-fidelity tests duplicating the foam imperfections that contributed to the ET foam loss on STS-107. The results of these tests will help identify the root cause of foam loss, a fundamental prerequisite for return to safe flight. At the same time, based on our ongoing analysis of mitigation strategies, we deferred further development of containment boots in favor of more effective options. To further reduce the risk of foam loss, NASA completed design and testing of a new hydrogen tank/intertank flange configuration that will reduce the possibility of voids. To improve our ability to detect potential problems, NASA built backscatter x-ray and terahertz imaging prototypes, two alternative methods of advanced nondestructive inspection (NDI) of the ET foam. These two methods provide complementary data and may be used to screen for voids.

Impact Testing. NASA also conducted additional foam impact tests on Reinforced Carbon-Carbon (RCC) panels used on the Shuttle's wings. These foam tests showed no



visible damage, but we will be performing NDI to verify the results. Additional impact tests of varying size and velocity will be performed over the next several months to define the actual structural capability of RCC and tile to withstand impacts from a wide range of debris, including foam, ice, and other material. These tests will help to define which debris is critical and validate improved impact prediction software models.

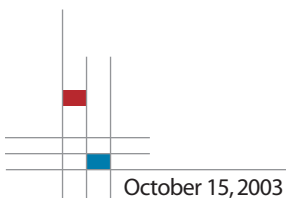
Thermal Protection System Inspection and Repair. We have also made significant progress in our ability to perform on-orbit tile repair. NASA completed the first series of tests on repaired tile, using arc jets to simulate the heating they will experience on entry. The preliminary results of these tests are promising and will be confirmed using both NDI and destructive evaluations. Proposed EVA processes and tools for on-orbit tile repair have now been tested on KC-135 zero gravity flights. Finally, NASA has begun work necessary to establish on-orbit Shuttle RCC repair procedures; to define Orbiter damage tolerances; and to develop and integrate the Shuttle robotic arm's extension boom and the attached laser/camera sensor package for TPS inspection.

Organization and Culture. The NASA Administrator continues to assess the organization and culture of NASA. A NASA team led by the Associate Administrator chartered a team led by the Associate Administrator for Safety and Mission Assurance to develop options for responding to CAIB recommendations 7.5-1 on the establishment of an Independent Technical Authority and 7.5-2 on safety organization improvements. As a part of this effort, the Space Shuttle Program is working with industry and the Department of Defense to benchmark their independent oversight processes. The Goddard Space Flight Center Director is leading a complementary team to make recommendations on how the CAIB findings and recommendations can be applied beyond the Shuttle Program and across the Agency. Additionally, the core team for the NASA Engineering and Safety Center (NESC) is now in place at the NASA Langley Research Center. They are in the process of hiring the full NESC staff and expect to formally open the Center in November 2003. NASA is taking a number of positive steps to identify cultural obstacles to effective risk management, including seeking suggestions from external experts. We will then make specific and fundamental changes to remove those obstacles with training programs and other management initiatives.

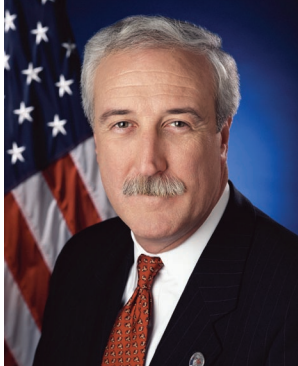
The progress NASA has made has also enabled us to develop a better estimate of when we will be able to return safely to flight. We are now working toward a return to flight date between September 12, 2004, and October 10, 2004. This date will be adjusted further if necessary to allow us to implement our return to flight actions and verify our readiness with the Return to Flight Task Group.

To ensure we have the logistics necessary to support the ISS crew and continued assembly, NASA has added an additional flight to the Shuttle manifest. The new flight, STS-121, will accomplish some of the International Space Station utilization objectives that were removed from STS-114. These tasks were deferred to accommodate critical RTF activities such as demonstrating TPS inspection and repair.

We have accomplished much in the last several months, and there is much more work to be done. The combined efforts of every NASA Center, our contractors, and our other industry and government partners have put us on a path that will allow us to return safely to flight as soon as possible. The ingenuity and dedication of the NASA workforce and the commitment of the nation to the NASA mission will continue to propel us toward our shared goal of safely returning the Shuttle to flight, and safely returning it home.



A Message From Sean O'Keefe



Shortly after the tragic loss of Mike Anderson, David Brown, Kalpana Chawla, Laurel Clark, Rick Husband, Willie McCool, Ilan Ramon, and the Space Shuttle *Columbia*, I committed on behalf of the NASA family that we would find the cause of the terrible disaster, fix it, and safely fly again. To do less would be a disservice to the memory of the STS-107 crew.

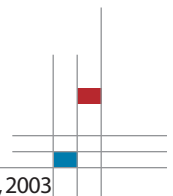
In order to achieve the first objective, I assigned a group of distinguished, uniquely qualified individuals led by Admiral Harold W. Gehman, Jr. (USN-Ret.) to form the *Columbia* Accident Investigation Board (CAIB) and determine the cause of this tragic event. The CAIB thoroughly and intensely examined the cause of the accident and recently issued its exhaustive report and recommendations, completing our first objective. We deeply appreciate the personal sacrifice that the CAIB members and staff have made over the last seven months in conducting this extraordinary investigation. NASA and the entire nation are in their debt.

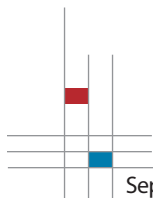
Now we embark on the second objective—to fix the problems identified by the CAIB. In this, our Return to Flight Implementation Plan, we embrace the CAIB report and its recommendations as our roadmap to do so. But we will not stop there. We have also undertaken to raise the bar above the CAIB recommendations. In this plan, we have included critical actions to respond to our own internal review as well as observations from external sources that will make flying the Space Shuttle safer. This plan is intended to be a living document and will be modified as progress is accomplished or as other safety concerns require.

When the fixes are completed and the Space Shuttle is fit to fly safely, then, and only then, will we be able to meet our third objective—return to flight. In the meantime, I offer this plan as a tribute to the memory of the STS-107 crew who were dedicated to the NASA vision and devoted their lives to further it. It is our job to see their vision through.

A handwritten signature in black ink that reads "Sean O'Keefe".

Sean O'Keefe





Return to Flight Message from the Space Flight Leadership Council

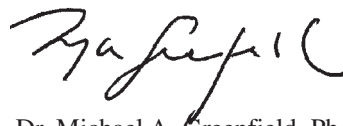
The *Columbia* Accident Investigation Board (CAIB) Report has provided NASA with a roadmap “to resume our journey into space.” The recommendations “reflect the Board’s strong support for return to flight at the earliest date consistent with the overriding objective of safety.” NASA fully accepts the Board’s findings and will comply with its recommendations.

To do this, the NASA Implementation Plan for Return to Flight and Beyond outlines the path that NASA will take to respond to the CAIB Report. It is a “living document” that will be continually updated to record NASA’s progress toward safe return to flight as well as activities to institutionalize the technical, managerial, cultural, communications, and safety changes necessary to sustain safe flight operations for as long as the Space Shuttle’s unique capabilities are needed.

This implementation plan addresses each CAIB recommendation with a specific plan of action. Recommendations identified as return to flight by the CAIB or NASA must be completed before resuming Space Shuttle flight operations. All other recommendations and their implementation timing and strategies are included as well.

We are beginning a new chapter in NASA’s history, recommitted to excellence in all aspects of our work, strengthening our culture, and enhancing our technical capabilities. In doing so, we will ensure that the legacy of *Columbia* continues as we strive to improve the safety of human space flight.

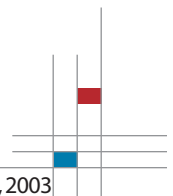
Smarter, stronger, safer!

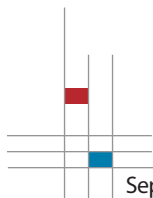


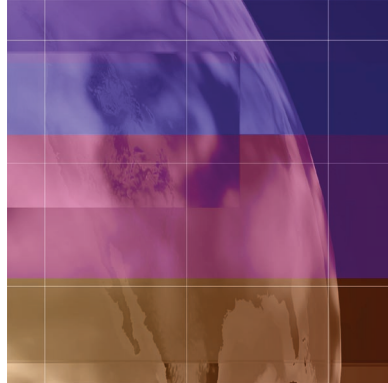
Dr. Michael A. Greenfield, Ph.D.
Associate Deputy Administrator
for Technical Programs



William F. Readdy
Associate Administrator
for Space Flight

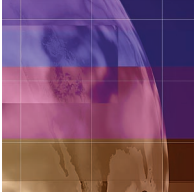






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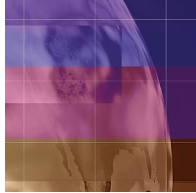
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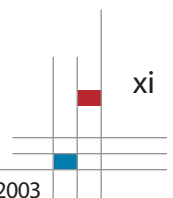
2.1 – Space Shuttle Program Actions

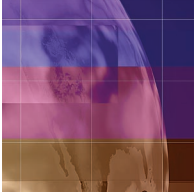
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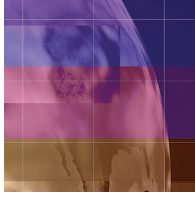


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Appendix A – NASA’s Return to Flight Process

Appendix B – Return to Flight Task Group



Summary

Overview

The *Columbia* Accident Investigation Board (CAIB) report has provided NASA with the roadmap for moving forward with our return to flight efforts. The CAIB, through its diligent work, has determined the causes of the accident and provided a set of comprehensive recommendations to improve the safety of the Space Shuttle Program. NASA accepts the findings of the CAIB, we will comply with the Board's recommendations, and we embrace the report and all that is included in it. This implementation plan outlines the path that NASA will take to respond to the CAIB recommendations and safely return to flight.

At the same time that the CAIB was conducting its assessment, NASA began pursuing an intensive, Agency-wide effort to further improve our human space flight programs. We are taking a fresh look at all aspects of the Space Shuttle Program, from technical requirements to management processes, and have developed a set of internally generated actions that complement the CAIB recommendations.

NASA will also have the benefit of the wisdom and guidance of an independent, advisory Return to Flight Task Group, led by two veteran astronauts, Apollo commander Thomas Stafford and Space Shuttle commander Richard Covey. Members of this Task Group were chosen from among leading industry, academia, and government experts. Their expertise includes knowledge of fields relevant to safety and space flight, as well as experience as leaders and managers of complex systems. The diverse membership of the Task Group will carefully evaluate and publicly report on the progress of our response to implement the CAIB's recommendations.

The space program belongs to the nation as a whole; we are committed to sharing openly our work to reform our culture and processes. As a result, this first installment of the implementation plan is a snapshot of our early efforts and will continue to evolve as our understanding of the action needed to address each issue matures. This implementation plan integrates both the CAIB recommendations and our self-initiated actions. This document will be periodically

updated to reflect changes to the plan and progress toward implementation of the CAIB recommendations, and our return to flight plan.

In addition to providing recommendations, the CAIB has also issued observations. Follow-on appendices may provide additional comments and observations from the Board. In our effort to raise the bar, NASA will thoroughly evaluate and conclusively determine appropriate actions in response to all these observations and any other suggestions we receive from a wide variety of sources, including from within the Agency, Congress, and other external stakeholders.

Through this implementation plan, we are not only fixing the causes of the *Columbia* accident, we are beginning a new chapter in NASA's history. We are recommitting to excellence in all aspects of our work, strengthening our culture and improving our technical capabilities. In doing so, we will ensure that the legacy of *Columbia* guides us as we strive to make human space flight as safe as we can.

Key CAIB Findings

The CAIB focused its findings on three key areas:

- Systemic cultural and organizational issues, including decision making, risk management, and communication;
- Requirements for returning safely to flight; and
- Technical excellence.

This summary addresses NASA's key actions in response to these three areas.

Changing the NASA Culture

The CAIB found that NASA's history and culture contributed as much to the *Columbia* accident as any technical failure. NASA will pursue an in-depth assessment to identify and define areas where we can improve our culture and take aggressive corrective action. In order to do this, we will

- Create a culture that values effective communication and empowers and encourages employee ownership over work processes.
- Assess the existing safety organization and culture to correct practices detrimental to safety.
- Increase our focus on the human element of change management and organizational development.
- Remove barriers to effective communication and the expression of dissenting views.
- Identify and reinforce elements of the NASA culture that support safety and mission success.
- Ensure that existing procedures are complete, accurate, fully understood, and followed.
- Create a robust system that institutionalizes checks and balances to ensure the maintenance of our technical and safety standards.
- Work within the Agency to ensure that all facets of cultural and organizational change are continually communicated within the NASA team.

To strengthen engineering and safety support, NASA

- Is reassessing its entire safety and mission assurance leadership and structure, with particular focus on checks and balances, line authority, required resources, and funding sources for human space flight safety organizations.
- Is restructuring its engineering organization, with particular focus on independent oversight of technical work, enhanced technical standards, and independent technical authority for approval of flight anomalies.
- Has established a new NASA Engineering and Safety Center to provide augmented, independent technical expertise for engineering, safety, and mission assurance. The function of this new Center and its relationship with NASA's programs will evolve over time as we progress with our implementation of the CAIB recommendations.
- Is returning to a model that provides NASA subsystem engineers with the ability to strengthen government oversight of Space Shuttle contractors.
- Will ensure that Space Shuttle flight schedules are consistent with available resources and acceptable safety risk.

To improve communication and decision making, NASA will

- Ensure that we focus first on safety and then on all other mission objectives.
- Actively encourage people to express dissenting views, even if they do not have the supporting data on hand, and create alternative organizational avenues for the expression of those views.
- Revise the Mission Management Team structure and processes to enhance its ability to assess risk and to improve communication across all levels and organizations.

To strengthen the Space Shuttle Program management organization, NASA has

- Increased the responsibility and authority of the Space Shuttle Systems Integration Office in order ensure effective coordination among the diverse Space Shuttle elements. Staffing for the Office will also be expanded.
- Established a Deputy Space Shuttle Program Manager to provide technical and operational support to the Manager.
- Created a Flight Operations and Integration Office to integrate all customer, payload, and cargo flight requirements.

To continue to manage the Space Shuttle as a developmental vehicle, NASA will

- Be cognizant of the risks of using it in an operational mission, and manage accordingly, by strengthening our focus on anticipating, understanding, and mitigating risk.
- Perform more testing on Space Shuttle hardware rather than relying only on computer-based analysis and extrapolated experience to reduce risk. For example, NASA is conducting extensive foam impact tests on the Space Shuttle wing.
- Address aging issues through the Space Shuttle Service Life Extension, including midlife recertification.

To enhance our benchmarking with other high-risk organizations, NASA is

- Completing a NASA/Navy benchmarking exchange focusing on safety and mission assurance policies, processes, accountability, and control measures to

identify practices that can be applied to NASA programs.

- Collaborating with additional high-risk industries such as nuclear power plants, chemical production facilities, military flight test organizations, and oil-drilling operations to identify and incorporate best practices.

To expand technical and cultural training for Mission Managers, NASA will

- Exercise the Mission Management Team with realistic in-flight crisis simulations. These simulations will bring together the flight crew, flight control team, engineering staff, the Mission Management Team, and other appropriate personnel to improve communication and to teach better problem recognition and reaction skills.
- Engage independent internal and external consultants to assess and make recommendations that will address the management, culture, and communications issues raised in the CAIB report.
- Provide additional operational and decision-making training for mid- and senior-level program managers. Examples of such training include, Crew Resource Management training, a US Navy course on the *Challenger* launch decision, a NASA decision-making class, and seminars by outside safety, management, communications, and culture consultants.

Returning Safely to Flight

The physical cause of the *Columbia* accident was insulation foam debris from the External Tank left bipod ramp striking the underside of the leading edge of the left wing, creating a breach that allowed superheated air to enter and destroy the wing structure during entry. To address this problem, NASA will identify and eliminate critical ascent debris and will implement other significant risk mitigation efforts to enhance safety.

Critical Ascent Debris

To eliminate critical ascent debris, NASA

- Is redesigning the External Tank bipod assembly to eliminate the large foam ramp and replace it with electric heaters to prevent ice formation.
- Will assess other potential sources of critical ascent debris and eliminate them. NASA is already pursuing a comprehensive testing program to

understand the root causes of foam shedding and develop alternative design solutions to reduce the debris loss potential.

- Will conduct tests and analyses to ensure that the Shuttle can withstand potential strikes from noncritical ascent debris.

Additional Risk Mitigation

Beyond the fundamental task of eliminating critical debris, NASA is looking deeper into the Shuttle system to more fully understand and anticipate other sources of risk to safe flight. Specifically, we are evaluating known potential deficiencies in the aging Shuttle, and are improving our ability to perform on-orbit assessments of the Shuttle's condition and respond to Shuttle damage.

Assessing Space Shuttle Condition

NASA uses imagery and other data to identify unexpected debris during launch and to provide general engineering information during missions. A basic premise of test flight is a comprehensive visual record of vehicle performance to detect anomalies. Because of a renewed understanding that the Space Shuttle will always be a developmental vehicle, we will enhance our ability to gather operational data about the Space Shuttle.

To improve our ability to assess vehicle condition and operation, NASA will

- Implement a suite of imagery and inspection capabilities to ensure that any damage to the Shuttle is identified as soon as practicable.
- Use this enhanced imagery to improve our ability to observe, understand, and fix deficiencies in all parts of the Space Shuttle. Imagery may include
 - ground-, aircraft-, and ship-based ascent imagery
 - new cameras on the External Tank and Solid Rocket Boosters
 - improved Orbiter and crew handheld cameras for viewing the separating External Tank
 - cameras and sensors on the International Space Station and Space Shuttle robotic arms
 - International Space Station crew inspection during Orbiter approach and docking
- Establish procedures to obtain data from other appropriate national assets.

- For the time being we will launch the Space Shuttle missions in daylight conditions to maximize imagery capability until we fully understand and can mitigate the risk that ascent debris poses to the Shuttle.

Responding to Orbiter Damage

If the extent of the *Columbia* damage had been detected during launch or on orbit, NASA would have done everything possible to rescue the crew. In the future, we will fly with plans, procedures, and equipment in place that will offer a greater range of options for responding to on-orbit problems.

To provide the capability for Thermal Protection System on-orbit repairs, NASA is

- Developing materials and procedures for repairing Thermal Protection System tile and reinforced carbon-carbon panels in flight. Thermal Protection System repair is feasible but technically challenging. The effort to develop these materials and procedures is receiving the full support of the Agency's resources, augmented by experts from industry, academia, and other U.S. Government agencies.

To enhance the safety of our crew, NASA

- Is evaluating a contingency concept for an emergency procedure that will allow stranded Shuttle crew to remain on the International Space Station for extended periods until they can safely return to Earth.
- Will apply the lessons learned from *Columbia* on crew survivability to future human-rated flight vehicles. We will continue to assess the implications of these lessons for possible enhancements to the Space Shuttle.

Enhancing technical excellence

The CAIB and NASA have looked beyond the immediate causes of the *Columbia* tragedy to proactively identify both related and unrelated technical deficiencies.

To improve the ability of the Shuttle to withstand minor damage, NASA will

- Develop a detailed database of the Shuttle's thermal protection system, including reinforced carbon-carbon and tiles, using advanced non-destructive inspection and additional destructive testing and evaluations.

- Enhance our understanding of the reinforced carbon-carbon operational life and aging process.
- Assess potential thermal protection system improvements for Orbiter hardening.

To improve our vehicle processing, NASA

- And our contractors are returning to appropriate standards for defining, identifying, and eliminating foreign object debris during vehicle maintenance activities to ensure a thorough and stringent debris prevention program.
- Has begun a review of existing Government Mandatory Inspection Points. The review will include an assessment of potential improvements, including development of a system for adding or deleting Government Mandatory Inspection Points as required in the future.
- Will institute additional quality assurance methods and process controls, such as requiring at least two employees at all final closeouts and at External Tank manual foam applications.
- Will improve our ability to swiftly retrieve closeout photos to verify configurations of all critical subsystems in time critical mission scenarios.
- Will establish a schedule to incorporate engineering changes that have accumulated since the Space Shuttle's original design into the current engineering drawings. This may be best accomplished by transitioning to a computer-aided drafting system, beginning with critical subsystems.

To safely extend the Space Shuttle's useful life, NASA

- Will develop a plan to recertify the Space Shuttle, as a part of the Shuttle Service Life Extension
- Is revalidating the operational environments (e.g., loads, vibration, acoustic, and thermal environments) used in the original certification.
- Will continue pursuing an aggressive and proactive wiring inspection, modification, and refurbishment program that takes full advantage of state-of-the-art technologies.
- Is establishing a prioritized process for identifying, approving, funding, and implementing technical and infrastructure improvements.

To address the public overflight risk, NASA will

- Evaluate the risk posed by Space Shuttle overflight during entry and landing. Controls such as entry ground track and landing site changes will be considered to balance and manage the risk to persons, property, flight crew, and vehicle.

To improve our risk analysis, NASA

- Is fully complying with the CAIB recommendation to improve our ability to predict damage from debris impacts. We are validating the Crater debris impact analysis model use for a broader range of scenarios. In addition, we are developing improved physics-based models to predict damage. Further, NASA is reviewing and validating all Space Shuttle Program engineering, flight design, and operational models for accuracy and adequate scope.
- Is reviewing its Space Shuttle hazard and failure mode effects analyses to identify unacknowledged risk and overly optimistic risk control assumptions. The result of this review will be a more accurate assessment of the probability and severity of potential failures and a clearer outline of controls required to limit risk to an acceptable level.
- Will improve the tools we use to identify and describe risk trends. As a part of this effort, NASA will improve data mining to identify problems and predict risk across Space Shuttle program elements.

To improve our Certification of Flight Readiness, NASA is

- Conducting a thorough review of the Certification of Flight Readiness process at all levels to ensure rigorous compliance with all requirements prior to launch.
- Reviewing all standing waivers to Space Shuttle program requirements to ensure that they are necessary and acceptable. Waivers will be retained only if the controls and engineering analysis associated with the risks are revalidated. This review will be completed prior to return to flight.

Next Steps

The CAIB directed that some of its recommendations be implemented before we return to flight. Other actions are ongoing, longer-term efforts to improve our overall human space flight programs. We will continue to refine our plans and, in parallel, we will identify the budget required to implement them. NASA will not be able to

determine the full spectrum of recommended return to flight hardware and process changes, and their associated cost, until we have fully assessed the selected options and completed some of the ongoing test activities.

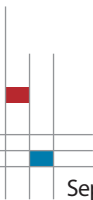
Conclusion

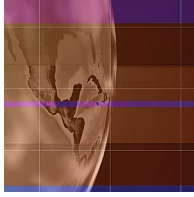
The American people have stood with NASA during this time of loss. From all across the country, volunteers from all walks of life joined our efforts to recover *Columbia*. These individuals gave their time and energy to search an area the size of Rhode Island on foot and from the air. The people of Texas and Louisiana gave us their hospitality and support. We are deeply saddened that some of our searchers also gave their lives. The legacy of the brave Forest Service helicopter crew, Jules F. Mier, Jr., and Charles Krennek, who lost their lives during the search for *Columbia* debris will join that of the *Columbia*'s crew as we try to do justice to their memory and carry on the work for the nation and the world to which they devoted their lives.

All great journeys begin with a single step. With this initial implementation plan, we are beginning a new phase in our return to flight effort. Embracing the CAIB report and all that it includes, we are already beginning the cultural change necessary to not only comply with the CAIB recommendations, but to go beyond them to anticipate and meet future challenges.

With this and subsequent iterations of the implementation plan, we take our next steps toward return to safe flight. To do this, we are strengthening our commitment to foster an organization and environment that encourages innovation and informed dissent. Above all, we will ensure that when we send humans into space, we understand the risks and provide a flight system that minimizes the risk as much as we can. Our ongoing challenge will be to sustain these cultural changes over time. Only with this sustained commitment, by NASA and by the nation, can we continue to expand human presence in space—not as an end in itself, but as a means to further the goals of exploration, research, and discovery.

The *Columbia* accident was caused by collective failures; by the same token, our return to flight must be a collective endeavor. Every person at NASA shares in the responsibility for creating, maintaining, and implementing the actions detailed in this report. Our ability to rise to the challenge of embracing, implementing, and perpetuating the changes described in our plan will ensure that we can fulfill the NASA mission—to understand and protect our home planet, to explore the Universe and search for life, and to inspire the next generation of explorers.





Response Summaries

Part 1 – NASA’s Responses to the Columbia Accident Investigation Board’s Recommendations

The following section provides brief summaries of the NASA response to each CAIB recommendation in the order that they appear in the CAIB report. We must comply with those actions marked “RTF” before we return to flight. Additional detail on each response can be found in the following sections of this implementation plan. This is a preliminary plan that will be periodically updated. As we begin to implement these recommendations and continue our evaluation of the CAIB report, we will be able to respond more completely. Program milestones built on the CAIB recommendations will determine when we can return to safe flight.

3.2-1 Initiate an aggressive program to eliminate all External Tank Thermal Protection System debris-shedding at the source with particular emphasis on the region where the bipod struts attach to the External Tank. [RTF]

The immediate cause of the *Columbia* accident was debris shed by the External Tank during launch. As a result, we are focused on minimizing External Tank-generated debris, which may include ice, foam, and other materials. The Space Shuttle Program is assessing the entire External Tank Thermal Protection System design, examining potential ascent debris sources. Our work will focus primarily on the following areas:

- *Forward Bipod Ramp* – NASA has redesigned the ramp to eliminate the foam ramp and incorporate redundant heaters.
- *LO₂ Feedline Bellows (Ice)* – The baseline solution being pursued is a “drip lip” and drain concept. As a backup solution, development will continue on the purge system concept.
- *Protuberance Airload (PAL) Ramps* – Potential solutions are to verify the current design; replace the ramps with a more controlled foam application technique; or eliminate the ramps altogether.
- *LH₂/Intertank Flange Closeout* – Potential solutions are performing a localized gas purge; sealing the flow path from the intertank joint to the foam;

improving Thermal Protection System closeout to prevent voids; and improving procedures to minimize post-manufacturing foam damage.

- *Foam Verification Reassessment* – NASA is reassessing the Thermal Protection System verification rationale and data for all processes for applying foam to the External Tank. NASA will ensure that at least two employees attend all final closeouts and critical hand-spraying procedures to ensure proper processing.
- *Nondestructive Inspection (NDI) of Foam* – NASA has initiated a long-term program to develop NDI techniques for foam for improved process verification.
- *Long-Term Activities* – As part of the Shuttle Service Life Extension activities, NASA is evaluating potential long-term changes in the External Tank design to continue our aggressive program to eliminate debris shedding at the source.

3.3-2 Initiate a program designed to increase the Orbiter’s ability to sustain minor debris damage by measures such as improved impact-resistant Reinforced Carbon-Carbon and acreage tiles. This program should determine the actual impact resistance of current materials and the effect of likely debris strikes. [RTF]

NASA is defining potential redesigns that will harden the Space Shuttle against damage caused by debris impacts.

In April 2003, NASA developed 17 redesign candidates. Eight near-term options were selected for further study. NASA is developing detailed feasibility assessments for each of these options.

NASA is also conducting foam impact tests on RCC and tile to determine their ability to withstand impacts and to build computer models that will accurately predict impact damage. Three full-scale impact tests of RCC were recently conducted at the Southwest Research Institute using exponential increases in the kinetic energy of the impacts. The first test used a foam projectile of 0.1 lb. mass at 700 ft/sec (fps), and the second test doubled the

kinetic energy of the initial test by using a 0.2 lb. projectile at 700 fps. Neither test resulted in damage to the RCC panel. The third test doubled the kinetic energy of the second test by using a 0.16 lb. projectile at 1167 fps. This test resulted in multiple through cracks and permanent deflections in the RCC panel.

3.3-1 Develop and implement a comprehensive inspection plan to determine the structural integrity of all Reinforced Carbon-Carbon system components. This inspection plan should take advantage of advanced nondestructive inspection technology. [RTF]

NASA is committed to clearing all RCC components and hardware by certified inspection techniques before return to flight. We have removed the OV-104 RCC nose cap, chin panel, and all wing leading edge components and returned them to the vendor for comprehensive nondestructive inspection (NDI). To date, the results compare favorably to data collected when the components were manufactured, indicating mass loss and coating degradation are within acceptable limits.

For the long term, the Space Shuttle Program is reviewing inspection criteria and advanced on- and off-vehicle NDI techniques for the Orbiter RCC system components. For instance, we have already introduced advanced off-vehicle flash thermography to inspect RCC components. Efforts to develop advanced on-vehicle NDI continue. We have identified and are pursuing five candidates with good potential for near-term deployment.

6.4-1 For missions to the International Space Station, develop a practicable capability to inspect and effect emergency repairs to the widest possible range of damage to the Thermal Protection System, including both tile and Reinforced Carbon-Carbon, taking advantage of the additional capabilities available when near to or docked at the International Space Station.

For non-Station missions, develop a comprehensive autonomous (independent of Station) inspection and repair capability to cover the widest possible range of damage scenarios.

Accomplish an on-orbit Thermal Protection System inspection, using appropriate assets and capabilities, early in all missions.

The ultimate objective should be a fully

autonomous capability for all missions to address the possibility that an International Space Station mission fails to achieve the correct orbit, fails to dock successfully, or is damaged during or after docking. [RTF]

NASA's near-term Thermal Protection System risk mitigation plan includes eliminating critical debris-shedding from the External Tank; fielding improved ground-based and vehicle-based cameras for debris damage discovery; surveying the vehicle on orbit using the Space Shuttle and International Space Station remote manipulator system cameras; and using International Space Station crew observations during Shuttle approach and docking. Near-term corrective actions under development include extravehicular activities for tile and RCC repair. A combination of new capabilities in this area should help to ensure that we can detect any damage and react successfully should damage occur. NASA's long-term objective is to provide a fully autonomous Thermal Protection System repair capability for all Space Shuttle missions.

3.3-3 To the extent possible, increase the Orbiter's ability to successfully re-enter Earth's atmosphere with minor leading edge structural sub-system damage.

The Space Shuttle Program is evaluating the Orbiter's capability to enter the Earth's atmosphere with minor damage, taking into account design limitations. NASA will define minor and critical damage using RCC foam impact tests, arc jet tests, and wind tunnel tests; modify existing flight design while remaining within certification; and explore ways to expand the flight certification envelope. Additionally, we will evaluate trajectory design changes to provide additional thermal relief on the leading edge support system.

3.3-4 In order to understand the true material characteristics of Reinforced Carbon-Carbon components, develop a comprehensive database of flown Reinforced Carbon-Carbon material characteristics by destructive testing and evaluation.

The Space Shuttle Program is currently developing and implementing an RCC test plan to develop a comprehensive database of flown and nonflown RCC material characteristics. A multicenter team will continually update the test plan to assist with directing design upgrades, mission/life adjustments, and other critical concerns for the service life of the leading edge support system and RCC.

NASA will use the foam impact tests on RCC and tile to build computer models that will accurately predict impact damage.

3.3-5 Improve the maintenance of launch pad structures to minimize the leaching of zinc primer onto Reinforced Carbon-Carbon components.

Zinc-rich coatings are used to protect the launch pad structure against environmental corrosion. Before return to flight, the NASA Kennedy Space Center will enhance the launch pad structural maintenance program to reduce RCC zinc oxide exposure and prevent zinc-induced pinhole formation in the RCC. We are also pursuing enhanced inspection, structural maintenance, wash-down, enhanced physical protection, and sampling options.

3.8-1 Obtain sufficient spare Reinforced Carbon-Carbon panel assemblies and associated support components to ensure that decisions related to Reinforced Carbon-Carbon maintenance are made on the basis of component specifications, free of external pressures relating to schedules, costs, or other considerations.

The Space Shuttle Program will maintain one complete set of RCC panel assembly spares for flight use. We will also develop a prioritized list of additional spare panels that will be ordered after the initial four panels are delivered.

3.8-2 Develop, validate, and maintain physics-based computer models to evaluate Thermal Protection System damage from debris impacts. These tools should provide realistic and timely estimates of any impact damage from possible debris from any source that may ultimately impact the Orbiter. Establish impact damage thresholds that trigger responsive corrective action, such as on-orbit inspection and repair, when indicated.

Foam impact testing showed that existing computer models need to be improved. NASA will evaluate the adequacy of all preflight and in-flight analysis tools that provide assessments critical to mission safety and success and make all necessary improvements.

3.4-1 Upgrade the imaging system to be capable of providing a minimum of three useful views of the Space Shuttle from liftoff to at least Solid Rocket Booster separation, along any expected ascent azimuth. The operational status of these

assets should be included in the Launch Commit Criteria for future launches. Consider using ships or aircraft to provide additional views of the Shuttle during ascent. [RTF]

NASA and the United States Air Force are working to improve the use of ground assets for viewing launch activities. To help ensure safe Space Shuttle missions, we are jointly evaluating various still and motion imagery capabilities, the best camera locations for both types of imagery, day and night coverage, live transmission and recorded imagery, and minimum weather requirements.

NASA is still deciding which combination of assets will be required for launch, but the selection criteria will ensure improved damage detection and engineering assessment capability. NASA has determined that STS-114 will be launched in daylight with a lighted External Tank separation. This will maximize our ability to obtain three useful camera views during ascent to allow us to pinpoint areas of engineering interest.

3.4-2 Provide a capability to obtain and downlink high-resolution images of the External Tank after it separates. [RTF]

To provide the capability to downlink images of the ET after separation to the MCC in Houston, NASA is assessing options for modifying the cameras in the Orbiter umbilical well. These images may be downlinked in real time or shortly after safe orbit is achieved, depending on which option is selected. Beginning with STS-114, and until these modifications are complete, the flight crew will use handheld digital still imagery to document the ET separation and downlink the images to the MCC.

3.4-3 Provide a capability to obtain and downlink high-resolution images of the underside of the Orbiter wing leading edge and forward section of both wings' Thermal Protection System. [RTF]

NASA will add a suite of ascent cameras in various locations on the Space Shuttle's External Tank (ET) and Solid Rocket Boosters (SRBs) to view selected areas of interest. For near-term return-to-flight, these cameras will supplement the on-orbit inspections that will provide the primary source of complete, high-resolution coverage needed to clear the Orbiter's Thermal Protection System of unacceptable damage. The ascent cameras will provide additional valuable engineering data on vehicle condition,

including confirmation of the performance of the ET modifications to reduce debris. For STS-114, a camera with downlink capability is being added to the ET to view portions of the Orbiter wing leading edge and underside tile acreage, and the modified ET bipod attachment fitting. A camera will also be added to each SRB to provide views of the ET intertank region. For subsequent missions, additional cameras will be mounted on the ET and the SRBs to provide multiple views of the ET and almost the entire Orbiter wing leading edge and underside, including critical landing gear door and umbilical door areas. For the long-term, NASA will evaluate upgrades to the on-vehicle ascent imaging and sensor suite that might make redundant some of the on-orbit inspections.

6.3-2 Modify the Memorandum of Agreement with the National Imagery and Mapping Agency (NIMA) to make the imaging of each Shuttle flight while on orbit a standard requirement. [RTF]

NASA did not use the full capabilities of the United States to assess the condition of the *Columbia* during STS-107. NASA has now concluded a Memorandum of Agreement with the National Imagery and Mapping Agency and has engaged other national agencies and assets to help us assess the condition of the Orbiter during launch, on orbit, and during entry. NASA has determined which personnel and positions require access to the national capabilities, and we are writing implementation procedures.

3.6-1 The Modular Auxiliary Data System instrumentation and sensor suite on each Orbiter should be maintained and updated to include current sensor and data acquisition technologies.

NASA agrees that the Modular Auxiliary Data System needs to be maintained until a new replacement concept is developed and implemented. The Space Shuttle Program is currently reviewing sensor requirements for various Orbiter subsystems, evaluating and updating sustainability requirements, investigating alternative manufacturers of the magnetic tape, and improving the procedures and process to lengthen the life of the Modular Auxiliary Data System recorder.

3.6-2 The Modular Auxiliary Data System should be redesigned to include engineering performance and vehicle health information and have the ability to be reconfigured during flight in order to allow certain data to be recorded, telemetered, or both, as needs change.

NASA is evaluating a replacement for the Modular Auxiliary Data System that will address system obsolescence and also provide additional capability. The Vehicle Health Monitoring System (VHMS) is a project within the Service Life Extension activities to replace the existing Modular Auxiliary Data System with an all-digital, industry-standard instrumentation system. VHMS will provide increased capability to enable easier sensor addition that will lead to significant improvements in monitoring vehicle health.

4.2-2 As part of the Shuttle Service Life Extension Program and potential 40-year service life, develop a state-of-the-art means to inspect all Orbiter wiring, including that which is inaccessible.

NASA is creating a roadmap for developing a state-of-the-art Shuttle wiring inspection capability. As a first step, we are collaborating with industry and other government agencies to find the most effective means to address these concerns.

4.2-1 Test and qualify the flight hardware bolt catchers. [RTF]

The External Tank is attached to the Solid Rocket Boosters (SRBs) at the forward skirt thrust fitting by the forward separation bolt. Approximately two minutes after launch, a pyrotechnic device is fired that breaks each forward separation bolt into two pieces, allowing the SRB to separate from the External Tank. The bolt catcher attached to the External Tank fitting retains half of the separation bolt while the other half of the bolt is retained within a cavity in the SRB forward skirt. The STS-107 investigation showed that the Bolt Catcher Assembly's factor of safety was approximately 1 instead of the required factor of safety of 1.4. We are redesigning the Bolt Catcher Assembly. Testing and qualification of the redesigned Bolt Catcher Assemblies and External Tank attachment bolts and inserts is in progress.

4.2-3 Require that at least two employees attend all final closeouts and intertank area hand-spraying procedures. [RTF]

| The Space Shuttle Program has approved a general approach for External Tank Thermal Protection System certification; the Space Flight Leadership Council has in turn approved the approach for review by the Return to Flight Task Group. Material Processing Plans will be revised to require that, at a minimum, all ET critical hard-

ware processes be performed in the presence of two certified Production Operations employees. TPS verification activities are under way and specific applicable ET processing procedures are under review.

4.2-4 Require the Space Shuttle to be operated with the same degree of safety for micrometeoroid and orbital debris as the degree of safety calculated for the International Space Station. Change the micrometeoroid and orbital debris safety criteria from guidelines to requirements.

To improve Shuttle safety regarding micrometeoroid and orbital debris (MMOD), NASA is evaluating potential vehicle modifications, such as new impact debris sensors, next-generation tiles and toughened strain isolation pad materials, improved Reinforced Carbon-Carbon, and improved crew module aft bulkhead protection. Additionally, a study is under way to assess the advantages afforded by alternative docking locations on ISS as well as other ISS modifications that reduce the Orbiter's exposure to MMOD while docked to the ISS. Hypervelocity impact tests will continue; and BUMPER code, a computer simulation and modeling tool for MMOD, will be updated to support the risk reduction effort.

4.2-5 Kennedy Space Center Quality Assurance and United Space Alliance must return to the straightforward, industry-standard definition of "Foreign Object Debris," and eliminate any alternate or statistically deceptive definitions like "processing debris." [RTF]

NASA will implement a consistent definition of foreign object debris across all processing activities; current metrics to measure such debris will be improved; NASA will provide foreign object debris prevention surveillance throughout the entire processing timeline; and foreign object debris training will be updated and improved. A team of NASA and United Space Alliance employees was formed and has completed benchmarking industry and Department of Defense processing facilities.

6.2-1 Adopt and maintain a Shuttle flight schedule that is consistent with available resources. Although schedule deadlines are an important management tool, those deadlines must be regularly evaluated to ensure that any additional risk incurred to meet the schedule is recognized, understood, and acceptable. [RTF]

Our priorities will always be flying safely and accomplishing our missions successfully. We will fly only when the necessary milestones are achieved, and not be driven by planning schedules.

NASA will adopt and maintain a Shuttle flight schedule that is consistent with available resources. Schedule risk will be regularly assessed and unacceptable risk will be mitigated. NASA will develop a process for Shuttle launch schedules that incorporates all of the manifest constraints and allows adequate margin to accommodate a normalized amount of changes. This process will entail launch margin, cargo/logistics margin, and crew timeline margin. The Space Shuttle Program (SSP) will enhance and strengthen the existing risk management system that assesses technical, schedule, and programmatic risks. Additionally, the SSP will examine the risk management process that is currently used by the International Space Station. The data will be placed in the One NASA Management Information System so that the senior managers in the Space Flight Enterprise can virtually review schedule performance indicators and risk assessments on a real-time basis.

6.3-1 Implement an expanded training program in which the Mission Management Team faces potential crew and vehicle safety contingencies beyond launch and ascent. These contingencies should involve potential loss of Shuttle or crew, contain numerous uncertainties and unknowns, and require the Mission Management Team to assemble and interact with support organizations across NASA/Contractor lines and in various locations. [RTF]

The Flight Mission Management Team will be reorganized to improve communication, chain of command, and the team's ability to accurately assess the relative risks of options under consideration. A clear reporting path and formal processes will be established for the review of findings from ascent and on-orbit imagery analyses. In complying with this recommendation, this new Mission Management Team structure will be exercised during real-time simulations before return to flight. These simulations will bring together the flight crew, the flight control team, engineering staff, and the Mission Management Team in complex scenarios that teach better problem recognition and reaction skills. Additionally, postlaunch hardware inspections and ascent reconstruction will be implemented. A process will also be established to review and

address mission anomalies and to identify them to the Mission Management Team.

7.5-1 Establish an independent Technical Engineering Authority that is responsible for technical requirements and all waivers to them, and will build a disciplined, systematic approach to identifying, analyzing, and controlling hazards throughout the life cycle of the Shuttle System. The independent technical authority does the following as a minimum:

- Develop and maintain technical standards for all Space Shuttle Program projects and elements
- Be the sole waiver-granting authority for all technical standards
- Conduct trend and risk analysis at the subsystem, system, and enterprise levels
- Own the failure mode, effects analysis and hazard reporting systems.
- Conduct integrated hazard analysis
- Decide what is and is not an anomalous event
- Independently verify launch readiness
- Approve the provisions of the recertification program called for in Recommendation R9.1-1

The Technical Engineering Authority should be funded directly from NASA Headquarters and should have no connection to or responsibility for schedule or program cost.

7.5-2 NASA Headquarters Office of Safety and Mission Assurance should have direct line authority over the entire Space Shuttle Program safety organization and should be independently resourced.

9.1-1 Prepare a detailed plan for defining, establishing, transitioning, and implementing an independent Technical Engineering Authority, independent safety program, and a reorganized Space Shuttle Integration Office as described in R7.5-1, R7.5-2, and R7.5-3. In addition, NASA should submit annual reports to Congress, as part of the budget review process, on its implementation activities. [RTF]

This response applies to recommendations 7.5-1, 7.5-2, and 9.1-1. NASA is committed to putting in place the organizational structure and culture to operate the Shuttle Program safely and with technical excellence for years to come. NASA will take the appropriate time to adequately assess our options, understand the risks, and implement the needed change. Before return to flight, an interdisciplinary team will be formed to develop a detailed plan for defining, establishing, transitioning, and implementing the recommendations. The Office of Safety and Mission Assurance has been assigned as the focal point for this recommendation.

As a first step, NASA recently established the NASA Engineering and Safety Center (NESC) at Langley Research Center. The NESC will provide augmented engineering and safety assessments, and will be operational by October 1, 2003. The Headquarters Office of Safety and Mission Assurance will provide the NESC's budget and policy to assure independence.

7.5-3 Reorganize the Space Shuttle Integration Office to make it capable of integrating all elements of the Space Shuttle Program, including the Orbiter.

NASA has strengthened the role of the Shuttle Integration Office to make it capable of integrating all of the projects and elements of the Program, including the Orbiter Project. The new office, the Shuttle Engineering and Integration Office, reports directly to the Program Manager. The Integration Control Board has also been strengthened and membership has been expanded.

9.2-1 Prior to operating the Shuttle beyond 2010, develop and conduct a vehicle recertification at the material, component, subsystem, and system levels. Recertification requirements should be included in the Service Life Extension Program.

The mid-life certification of the Shuttle is a key element of NASA's Shuttle Service Life Extension work. Efforts to recertify the Shuttle began before the *Columbia* accident. In December 2002, the Space Shuttle Program Council tasked all Space Shuttle Program projects and elements to review their hardware qualification and verification requirements, and confirm that processing and operating conditions are consistent with the original hardware certification. This will be an ongoing process incorporated in the Shuttle Service Life Extension, as appropriate.

10.3-1 Develop an interim program of closeout photographs for all critical sub-systems that differ from engineering drawings. Digitize the closeout photograph system so that images are immediately available for on-orbit troubleshooting. [RTF]

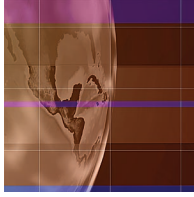
NASA needs the capability to quickly retrieve accurate photos and images of critical Space Shuttle subsystems to support on-orbit troubleshooting and ground operations.

NASA will identify and acquire images of critical areas and details for capture in the digital image database. The images will be stored in a database from which they can be retrieved by cross-referencing to top-level drawings or vehicle zone locators. To improve the quality of broad-area closeout imaging, hardware changes may include advanced technology, such as 360° field-of-view cameras and high-definition photography.

10.3-2 Provide adequate resources for a long-term program to upgrade the Shuttle engineering drawing system including

- **Reviewing drawings for accuracy**
- **Converting all drawings to a computer-aided drafting system**
- **Incorporating engineering changes**

NASA will develop detailed plans and costs for upgrading the Shuttle engineering drawing system. Currently in the formulation phase, the work that remains to be completed includes assessing current design documentation and developing drawing conversion standards, concept of operations, system architecture, and procurement strategies. At the conclusion of this phase, the Digital Shuttle Project will present detailed plans and costs for upgrading the Shuttle engineering drawing system and seek authorization from the Space Shuttle Program to proceed with implementation.



Response Summaries

Part 2 – Raising the Bar – Other Corrective Actions

NASA has embraced the *Columbia* Accident Investigation Board (CAIB) report and will comply with its recommendations. We recognize that we must undertake a fundamental reevaluation of our Agency's culture and processes. To do this, we have begun an intensive, Agencywide effort to identify additional actions above and beyond the CAIB recommendations that will further improve our space flight program as we move toward a return to safe flight. The result of this ongoing effort is a set of internally generated actions that complements and builds upon the CAIB recommendations. These actions also begin to address several of the key observations included in the CAIB report. As we progress in our return to flight work, we will evaluate, address, and report on our response to the other observations. A list of the CAIB observations from Volume I of the CAIB report is included below.

In addition to the actions listed below, as a first step to improve our programs, NASA established the NASA Engineering and Safety Center (NESC) at Langley Research Center to provide an augmented, independent assessment capability. NESC will provide a centralized location for the management of independent, in-depth technical assessments supported by expert personnel and state-of-the-art tools. It will conduct tests to certify problem resolution, validate computer models, and provide independent trend analyses. The NESC is discussed in our response to CAIB Recommendation 7.5-1.

SSP-1 NASA should commission an assessment, independent of the Space Shuttle Program, of the Quality Planning and Requirements Document (QPRD) to determine the effectiveness of government mandatory inspection point (GMIP) criteria in assuring verification of critical functions before each Shuttle mission. The assessment should sample the existing GMIPs against the QPRD criteria and determine the adequacy of the GMIPs in meeting the criteria. Over the long term, NASA should periodically review the effectiveness of the QPRD inspection criteria against ground processing and flight experience to

determine if GMIPs are effective in assuring safe flight operations.

NASA chartered an Independent Assessment Team (IAT) to evaluate the effectiveness of the SSP's government mandatory inspection point verification process for the Shuttle Processing Directorate at Kennedy Space Center and the External Tank Project at the Michoud Assembly Facility. In January 2004, the IAT released a report with findings, recommendations, and observations related to GMIP policy, processes, and workforce. The IAT's preliminary findings, recommendations, and observations were briefed to the Office of Safety and Mission Assurance and the Office of Space Flight, and the final IAT report has been provided to the Space Shuttle Program for implementation.

SSP-2 The Space Shuttle Program will evaluate relative public risk between landing opportunities that encompass all cross-ranges, each operational inclination, and each of the three primary landing sites.

NASA will evaluate the risk posed by Space Shuttle overflight during entry and landing. Controls such as ground track and landing site changes will be considered to manage the risk to persons and property, the flight crew, and the vehicle.

SSP-3 NASA will evaluate the feasibility of providing contingency life support on board the International Space Station (ISS) to stranded Shuttle crewmembers until repair or rescue can be affected.

NASA has developed an International Space Station (ISS) Contingency Shuttle Crew Support concept that could be used in an emergency to sustain a Space Shuttle crew on board the ISS until either the damaged Space Shuttle is repaired or the crew can be returned safely to Earth. NASA's preliminary feasibility study suggests that for the next Space Shuttle mission, should it be necessary, the Space Shuttle crew could be sustained on the ISS for a period of at least 86 days, which is sufficient time to rescue the crew with a second Space Shuttle.

SSP-4 NASA will validate that the controls are appropriate and implemented properly for “accepted risk” hazards and any other hazards, regardless of classification, that warrant review due to working group observations or fault-tree analysis.

Hazard analysis is the determination of potential sources of danger and recommended resolutions for the problems identified. Approval of acceptable risk hazards are those known risks that remain even after all available mitigation efforts are implemented. Approval of acceptable risk hazards is based on a judgment that the possible consequences and likelihood of occurrence are tolerable.

All SSP projects are performing an assessment of each accepted risk hazard report and any additional hazard reports indicated by the STS-107 accident investigation findings.

SSP-5 NASA will determine critical debris sources, transport mechanisms, and resulting impact areas. Based on the results of this assessment, we will recommend changes or redesigns which would reduce the debris risk. And NASA will review all program baseline debris requirements to ensure appropriateness and consistency.

NASA has embarked on a comprehensive effort to analyze, characterize, and reduce potential critical ascent debris sources. Eliminating all ascent debris large enough to inflict serious damage to the Shuttle is a priority for NASA.

SSP-6 All waivers, deviations, and exceptions to Space Shuttle Program requirements documentation will be reviewed for validity and acceptability before return to flight.

Since all waivers, deviations, and exceptions to Program requirements carry the potential for risk, the SSP is reviewing all of them for appropriateness. In addition, each project and element will identify and review in detail those critical items list waivers that have ascent debris as a consequence.

SSP-7 The Space Shuttle Program should consider NASA Accident Investigation Team (NAIT) working group findings, observations, and recommendations.

All NASA Accident Investigation Team technical working groups have an action to present their findings, observations,

and recommendations to the Program Requirements Control Board (PRCB). Each project and element will disposition recommendations within their project to determine which should be return to flight actions. They will forward actions that require SSP or Agency implementation to the SSP PRCB for disposition.

SSP-8 NASA will identify Certification of Flight Readiness (CoFR) process changes, including Program milestone reviews, Flight Readiness Review (FRR), and prelaunch Mission Management Team processes to improve the system.

The certification of flight readiness (CoFR) is the process by which NASA ensures compliance with Program requirements and judges launch readiness. The CoFR process includes multiple reviews at progressively higher management levels, culminating with the Flight Readiness Review. Each organization that signs the CoFR, or that presents or prepares elements of the CoFR, has been assigned a PRCB action to conduct a thorough review of the CoFR process.

SSP-9 NASA will verify the validity and acceptability of failure mode and effects analyses (FMEAs) and critical items lists (CILs) that warrant review based on fault tree analysis or working group observations.

In preparation for return to flight, NASA is developing a plan to evaluate the effectiveness of the Shuttle failure mode and effects analyses (FMEAs) and critical items lists (CILs) processes. This review will validate the documented controls associated with the SSP critical items lists. The SSP will identify FMEAs and CILs that need to be revalidated based on their criticality and overall contribution to Space Shuttle risk. NASA will also assess STS-107 investigation findings and observations that affect FMEAs and CIL documentation and controls.

SSP-10 NASA will review Program, project, and element contingency action plans and update them based on the *Columbia* mishap lessons learned.

NASA will review the lessons learned from the *Columbia* mishap and update the Program-level Contingency Action Plan to reflect those lessons. In addition, NASA will review and update the Headquarters Agency Contingency Action Plan for Space Flight Operations.

SSP-11 Remove and inspect Orbiter rudder speed brake (RSB) actuators for internal corrosion and recommend, if required, corrective actions.

NASA began an inspection program to determine the exact status of all Orbiter rudder speed brake actuators based on corrosion found in the OV-103 body flap actuators. After each actuator is inspected, they will either be refurbished or returned for installation.

SSP-12 NASA will review flight radar coverage capabilities and requirements for critical flight phases

In coordination with the Air Force Eastern Range, NASA is exploring improvements in radar assets used during Shuttle launches to identify and characterize potential debris liberated during ascent. Specific radar cross section signatures will be developed to facilitate identification of debris observed by radar.

SSP-13 NASA will verify that hardware processing and operations are within the hardware qualification and certification limits.

As a result of NASA's investigation into several Orbiter hardware failures that occurred before the Columbia accident, an action to all SSP projects and elements was issued in December 2002 to review their hardware qualification and verification requirements and verify that processing and operating conditions are consistent with the original hardware certification. This action was reissued by the PRCB as a return to flight action. Each project/element is to present completed plans and schedules for validating that hardware operating and processing conditions, along with environments or combined environments, are consistent with the original certification.

SSP-14 Determine critical orbiter impact locations and TPS damage size criteria that will require on-orbit inspection and repair. Determine minimum criteria for which repairs are necessary and maximum criteria for which repair is possible.

NASA has embarked on a substantial effort to determine the critical damage size criteria for on-orbit inspection and repair. NASA is developing models to accurately predict the damage resulting from a debris impact and to develop a comprehensive damage-tolerance testing plan. NASA is also developing more mature models to determine which damage is survivable and which damage must be repaired before safe entry.

SSP-15 NASA will identify and implement improvements in problem tracking, in-flight anomaly (IFA) disposition, and anomaly resolution process changes.

NASA has begun to identify and implement improvements to the problem tracking, in-flight anomaly disposition, and anomaly resolution processes. A team reviewed SSP and internal documentation and processes and audited performance for the past three Shuttle missions. They concluded that, while clarification of the requirements for the Problem Reporting and Corrective Action System is needed, the implementation of those requirements also needs improvement. Issues identified by the team include misinterpretations of definitions, resulting in misidentification of problems and noncompliance with tracking and reporting requirements.

CAIB Observations

The observations contained in Chapter 10 of the CAIB report expand upon the CAIB recommendations, touching on the critical areas of public safety, crew escape, Orbiter aging and maintenance, quality assurance, test equipment, and the need for a robust training program for NASA managers. NASA is committed to examining these observations and has already made significant progress in determining appropriate corrective measures. Future versions of the Implementation Plan will expand to include additional suggestions from various sources. This will ensure that beyond returning safely to flight, we are institutionalizing sustainable improvements to our culture and programs that will ensure we can meet the challenges of continuing to expand the bounds of human exploration.

Public Safety

O10.1-1 NASA should develop and implement a public risk acceptability policy for launch and re-entry of space vehicles and unmanned aircraft.

| NASA is nearing completion of a draft document on public risk, including a risk acceptance policy. The NASA Safety and Mission Assurance Directors reviewed the final draft in October 2003 and their comments have been addressed. The document will enter NASA's formal approval process using the NASA Online Directives Information System by the end of January 2004.

O10.1-2 NASA should develop and implement a plan to mitigate the risk that Shuttle flights pose to the general public.

O10.1-3 NASA should study the debris recovered from *Columbia* to facilitate realistic estimates of the risk to the public during Orbiter re-entry.

Observations O10.1-1, O10.1-2 and O10.1-3 are addressed, in SSP Action 2; the SSP will evaluate relative risk to all persons and property underlying the entry flight path. This study will encompass all landing opportunities from each inclination to each of the three primary landing sites.

Crew Escape and Survival

O10.2-1 Future crewed-vehicle requirements should incorporate the knowledge gained from the *Challenger* and *Columbia* accidents in assessing the feasibility of vehicles that could ensure crew survival even if the vehicle is destroyed.

A multidisciplinary team at the NASA Johnson Space Center, called the Crew Survival Working Group (CSWG), is developing a report incorporating lessons learned from both the *Challenger* and the *Columbia* accidents. The CSWG has participation from the Flight Crew Operations, Engineering, and Space and Life Sciences Directorates. The CSWG report will provide recommendations for enhancing crew survivability for future crewed vehicles. NASA has also established a policy document that codifies human rating requirements for space flight vehicles.

Industrial Safety and Quality Assurance

O10.4-1 Perform an independently led, bottom-up review of the Kennedy Space Center Quality Planning Requirements Document to address the entire quality assurance program and its administration. This review should include development of a responsive system to add or delete government mandatory inspections.

| Observation O10.4-1 is addressed in SSP Action 1;
| NASA chartered an Independent Assessment Team (IAT) to
| evaluate the effectiveness of the SSP's government manda-
| tory inspection point verification process for the Shuttle
| Processing Directorate at Kennedy Space Center and the
| External Tank Project at the Michoud Assembly Facility. In
| January 2004, the IAT released a report with findings,
| recommendations, and observations related to GMIP policy,
| processes, and workforce. The IAT's preliminary findings,
| recommendations, and observations were briefed to Office
| of Space and Mission Assurance and Office of Space Flight,
| and the final IAT report has been provided to the Space
| Shuttle Program for implementation.

O10.4-2 Kennedy Space Center's quality assurance programs should be consolidated under one Mission Assurance office, which reports to the Center Director.

NASA will improve the observed deficiencies in basic quality assurance philosophy by developing a training program comparable to the Defense Contract Management Agency, using existing training programs where possible.

O10.4-3 Kennedy Space Center quality assurance management must work with NASA and perhaps the Department of Defense to develop training programs for its personnel.

NASA will improve the observed deficiencies in basic quality assurance philosophy by developing a training program comparable to the Defense Contract Management Agency, using existing training programs where possible.

O10.4-4 Kennedy Space Center should examine which areas of International Organization for Standardization 9000/9001 truly apply to a 20-year old research and development system like the Space Shuttle.

NASA, along with a team of industry experts, will evaluate the applicability of ISO 9000/9001 to United Space Alliance KSC operations. This evaluation will lead to a recommendation for future use of the standards or changes to surveillance or evaluations of the contractors.

Maintenance Documentation

O10.5-1 Quality and Engineering review of work documents for STS-114 should be accomplished using statistical sampling to ensure that a representative sample is evaluated and adequate feedback is communicated to resolve documentation problems.

NASA has performed a review and systemic analysis of STS-114 work documents for the time period of Orbiter Processing Facility roll-in through system integration test of the flight elements in the Vehicle Assembly Building. The STS-114 Systemic analysis led to six Corrective Action recommendations consistent with the technical observations noted in the STS-107/109 review. Teams were formed to determine the root cause and long-term corrective actions. These recommendations were assigned Corrective Action Requests that will be used to track the implementation and effectiveness of the corrective actions.

O10.5-2 NASA should implement United Space Alliance's suggestions for process improvement, which recommend including a statistical sampling of all



future paperwork to identify recurring problems and implement corrective actions.

Engineering and SMA organizations are evaluating and revising their surveillance plans. Required changes to the Ground Operations Operating Procedures are being identified, and the development of the QPRD change process for government inspection requirements and the supporting database is nearing completion. Additionally, NASA will improve communication between Engineering and SMA through the activation of a Web-based log and the use of the QPRD change process for government inspection requirements.

O10.5-3 NASA needs an oversight process to statistically sample the work performed and documented by United Space Alliance technicians to ensure process control, compliance, and consistency.

The CAIB observed the need for improvements in how NASA performs statistical sampling of documentation and of performed work. NASA formed a Processing Review Team to examine the processes addressed in the observations and expects to have recommendations by December.

Orbiter Maintenance Down Period/Orbiter Major Modification

O10.6-1 The Space Shuttle Program Office must make every effort to achieve greater stability, consistency, and predictability in Orbiter major modification planning, scheduling, and work standards (particularly in the number of modifications). Endless changes create unnecessary turmoil and can adversely impact quality and safety.

The practice of seeking approval for the implementation of all known modifications at the inception of the Orbiter Modification Down Period (OMDP) planning has been restored with the second OV-105 OMDP, currently approved to begin in December 2003. At the Modification Site Requirements Review in June 2003, the PRCB approved the inclusion of all modifications requested for implementation in this OMDP.

O10.6-2 NASA and United Space Alliance managers must understand workforce and infrastructure requirements, match them against capabilities, and take actions to avoid exceeding thresholds.

Additional personnel hiring, focusing on needed critical skill sets, is being coordinated with the NASA Shuttle Processing

Directorate and the NASA Orbiter Project Office.

O10.6-3 NASA should continue to work with the U.S. Air Force, particularly in areas of program management that deal with aging systems, service life extension, planning and scheduling, workforce management, training, and quality assurance.

NASA has initiated a number of aging vehicle assessment activities as part of integrated Space Shuttle Service Life Extension activities. Each of the Space Shuttle element organizations is pursuing appropriate vehicle assessments to ensure that SSP operations remain safe and viable through 2020 and beyond. NASA is also continuing to solicit participation from government and industry aging system experts from across the aerospace and defense sectors. Specifically, NASA will continue to work with the U.S. Air Force in its development of aging vehicle assessment plans.

O10.6-4 The Space Shuttle Program Office must determine how it will effectively meet the challenges of inspecting and maintaining an aging Orbiter fleet before lengthening Orbiter major maintenance intervals.

NASA has initiated a number of assessments to ensure that Space Shuttle operations remain safe and viable throughout the Shuttle's service life. NASA has decided to keep the Orbiter Maintenance Requirements and Specifications Document intervals at 3 years or 8 flights to provide a higher level of confidence.

Orbiter Corrosion

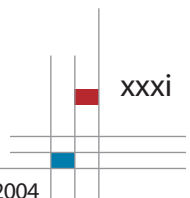
O10.7-1 Additional and recurring evaluation of corrosion damage should include non-destructive analysis of the potential impacts on structural integrity.

O10.7-2 Long-term corrosion detection should be a funding priority.

O10.7-3 Develop non-destructive evaluation inspections to find hidden corrosion.

O10.7-4 Inspection requirements for corrosion due to environmental exposure should first establish corrosion rates for Orbiter-specific environments, materials, and structural configurations. Consider applying Air Force corrosion prevention programs to the Orbiter.

Orbiter Project Office has developed several recommendations to inspect and evaluate corrosion problems. In the next update to this Implementation Plan, we will provide



specific details on activities that have received SSP approval to proceed.

Brittle Fracture of A-286 Bolts

O10.8-1 Teflon (material) and Molybdenum Disulfide (lubricant) should not be used in the carrier panel bolt assembly.

O10.8-2 Galvanic coupling between aluminum and steel alloys must be mitigated.

O10.8-3 The use of Room Temperature Vulcanizing 560 and Koropon should be reviewed.

O10.8-4 Assuring the continued presence of compressive stresses in A-286 bolts should be part of their acceptance and qualification procedures.

The Orbiter Project Office has developed several recommendations to reassess the problems incurred with the components and materials addressed in O10.8-1 through O10.8-4. In the next update to this Implementation Plan, we will provide specific details on activities that have received SSP approval to proceed.

Hold-Down Post Cable Anomaly

O10.9-1 NASA should consider a redesign of the system, such as adding a cross-strapping cable, or conduct advanced testing for intermittent failure.

NASA evaluated five options for redesign of this system and has tentatively selected a configuration that will provide redundancy directly at the T-0 umbilical, which was determined to be the primary contributing cause of an anomaly in the Hold-Down Post Cable system on STS-112. Further assessment of this redesign option is ongoing. A cross-strapping cable was not recommended due to concerns that it would introduce a failure that could inhibit both hold-down post pyrotechnic systems. A NASA Headquarters sponsored Independent Assessment Team was formed to review the STS-112 anomaly and generically review the T-0 umbilical electrical/data interfaces.

Solid Rocket Booster External Tank Attachment Ring

O10.10-1 NASA should reinstate a safety factor of 1.4 for the Attachment Rings – which invalidates the use of ring serial numbers 16 and 15 in their present state – and replace all deficient material in the Attachment Rings.

The Solid Rocket Booster Project Office has completed a more accurate nonlinear analysis and inspection of the first flight set Attachment Rings and determined that all of the Attachment Rings meet NASA's factor of safety and safe-life requirements. Processing of the second flight set is under way. Testing, inspection, and, if necessary, replacement of all remaining flight hardware will ensure the remaining hardware inventory meets factor of safety requirements.

Test Equipment Upgrades

O10.11-1 Assess NASA and contractor equipment to determine if an upgrade will provide the reliability and accuracy needed to maintain the Shuttle through 2020. Plan an aggressive certification program for replaced items so that new equipment can be put into operation as soon as possible.

NASA has initiated an assessment of all critical Program equipment. NASA will continue to assess such equipment through the use of a health assessment process and annual supportability reviews; these assessments will be used to determine where upgrades are needed to support the upkeep and maintenance of the Shuttle fleet through 2020. Identified upgrades will be submitted through the Shuttle Service Life Extension process to ensure funding of specific projects.

Leadership/Managerial Training

O10.12-1 NASA should implement an Agency-wide strategy for leadership and management training that provides a more consistent and integrated approach to career development. This strategy should identify the management and leadership skills, abilities, and experiences required for each level of advancement. NASA should continue to expand its leadership development partnerships with the Department of Defense and other external organizations.

The NASA Office Of Human Resources will establish an Agency team to address the development and implementation of an Agencywide strategy for leadership and management development training. The team will be composed of NASA leaders, Agency and center training and development staff, line managers, and a member from the academic community. NASA will benchmark the leadership and management development programs of other governmental agencies, major corporations, and universities. The Office will also conduct fact finding through such organizations as the American Society of Training and Development and the American Productivity and Quality Center.

CAIB Supplemental Recommendations: Response to Volume II, Appendix D.a, Supplement to the Report

Volume II, Appendix D.a augments the CAIB Report recommendations. The Appendix outlines concerns raised by Brigadier General Duane Deal and others that, if addressed, might prevent a future accident. Some recommendations contained in the Appendix have already been addressed by this Plan and are referenced to the appropriate section. Although the recommendations are not numbered in Appendix D.a, we have assigned a number to the recommendations for tracking purposes.

Quality Assurance

D.a-1 Perform an independently led, bottom-up review of the Kennedy Space Center Quality Planning Requirements Document to address the entire quality assurance program and its administration. This review should include development of a responsive system to add or delete government mandatory inspections. Suggested Government Mandatory Inspection Point (GMIP) additions should be treated by higher review levels as justifying why they should not be added, versus making the lower levels justify why they should be added. Any GMIPs suggested for removal need concurrence of those in the chain of approval, including responsible engineers.

This recommendation is addressed in responses to SSP 1 and Observation 10.4-1 in sections 2.1 and 2.2. An independent assessment team, including representatives from NASA, industry, the Department of Defense, and the Federal Aviation Administration, has recently completed a bottoms-up review of the Quality Planning Requirements Document (QPRD) and activities associated with Government Mandatory Inspections (GMIPs) at the Kennedy Space Center and the Michoud Assembly Facility. Recommendations, findings, and observations from this assessment will be presented to the Space Shuttle Program in the near future.

D.a-2 Kennedy Space Center must develop and institutionalize a responsive bottom-up system to add to or subtract from Government Inspections in the future, starting with an annual Quality Planning Requirements Document review to ensure the program

reflects the evolving nature of the Shuttle system and mission flow changes. At a minimum, this process should document and consider equally inputs from engineering, technicians, inspectors, analysts, contractors, and Problem Reporting and Corrective Action to adapt the following year's program.

This recommendation is partially addressed in responses to SSP 1 and Observation 10.4-1 in sections 2.1 and 2.2. Shuttle Processing has assembled a team to address the QPRD change and a QPRD change process has been implemented. An initial survey of GMIPs has been accomplished and a temporary GMIP change process has been established. Status updates will be included in the next release of this Plan.

D.a-3 NASA Safety and Mission Assurance should establish a process inspection program to provide a valid evaluation of contractor daily operations, while in process, using statistically-driven sampling. Inspections should include all aspects of production, including training records, worker certification, etc., as well as Foreign Object Damage prevention. NASA should also add all process inspection findings to its tracking programs.

This recommendation is addressed in responses to Recommendation 4.2-5 and Observation 10.4-1. Status updates will be prepared as deemed necessary. NASA will implement a consistent definition of foreign object damage debris across all processing activities; current metrics will be improved; NASA will provide foreign object damage prevention surveillance throughout the entire processing timeline; and foreign object debris training will be updated and improved.

D.a-4 The Kennedy quality program must emphasize forecasting and filling personnel vacancies with qualified candidates to help reduce overtime and allow inspectors to accomplish their position description requirements (i.e., more than the inspectors performing government inspections only, to include expanding into completing surveillance inspections).

NASA uses two techniques for selecting and developing qualified Quality Assurance Specialists (QAS). Temporary and term employees can be hired to provide flexibility for short-term staffing issues. Permanent employee hires for QASs is preferred and in work. Formal training is required that includes classroom and on-the-job training.

D.a-5 Job qualifications for new quality program hires must spell out criteria for applicants, and must be closely screened to ensure the selected applicants have backgrounds that ensure that NASA can conduct the most professional and thorough inspections possible.

NASA has benchmarked the Department of Defense's and the Defense Contract Management Agency's training requirements to determine where we can directly use their training opportunities. A team of engineers and QASs from the Space Shuttle and International Space Station Programs has formed to develop and document a more robust training program.

D.a-6 Marshall Space Flight Center should perform an independently-led bottom-up review of the Michoud Quality Planning Requirements Document to address the quality program and its administration. This review should include development of a responsive system to add or delete government mandatory inspections. Suggested Government Mandatory Inspection Point (GMIP) additions should be treated by higher review levels as justifying why they should not be added, versus making the lower levels justify why they should be added. Any GMIPs suggested for removal should need concurrence of those in the chain of approval, including responsible engineers.

NASA commissioned an assessment team independent of the Space Shuttle Program to review the effectiveness of the mandatory inspection document employed at the Michoud Assembly Facility to define GMIPs. The assessment report is in final preparation and will be presented to the Space Shuttle Program for consideration in December 2003.

D.a-7 Michoud should develop and institutionalize a responsive bottom-up system to add to or subtract from Government Inspections in the future, starting with an annual Quality Planning Requirements Document review to ensure the program reflects the evolving nature of the Shuttle system and mission flow changes. Defense Contract Management Agency manpower at Michoud should be refined as an outcome of the QPRD review.

The Shuttle Propulsion Element located at the Marshall Space Flight Center is responsible for overseeing the Mandatory Inspection Document process and implementation of associated GMIPs for Michoud activities. This too was a focus of the independent assessment team activity.

Findings, observations, and recommendations will be forthcoming in the assessment report that will be delivered in December 2003.

D.a-8 Kennedy Space Center should examine which areas of ISO 9000/9001 truly apply to a 20-year-old research and development system like the Space Shuttle. Note: This item is currently Observation O10.4-4 in the Board report; however to avoid further diluting the quality program focus, it is urged this become a Recommendation.

In response to Observation 10.4-4, NASA commissioned an assessment team to review how ISO 9000/9001 is used. The team has established a review methodology and has partially completed the first step, determining the applicability of the ISO standard to United Space Alliance operations at KSC.

Orbiter Corrosion

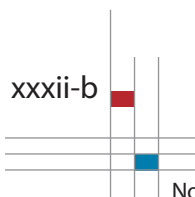
D.a-9 Develop non-destructive evaluation inspections to detect and, as necessary, correct hidden corrosion.

The response to this recommendation will be included in our response to Observations 10.7-1, -2, -3, and -4 in section 2.2 of this Plan. Our response to date from the Vehicle Engineering Project is pending and has not been specified.

Hold-Down Post Cable Anomaly

D.a-10 NASA should evaluate a redesign of the Hold-Down Post Cable, such as adding a cross-strapping cable or utilizing a laser initiator, and consider advanced testing to prevent intermittent failure.

Shuttle Processing is reviewing the design of the hold-down post system and the anomaly that occurred during the STS-112 launch for potential improvements in system reliability. Many prelaunch process modifications have been identified for implementation, including installation of new cables and connectors and not allowing reuse, mandatory visual inspection using bore scopes for blind installations, and evaluation of a cross-strapped ordnance manifold at the hold-down post so that either a system A command or a system B command will cause an individual NASA Standard Initiator to fire. Other activities and enhancements are under evaluation.



Solid Rocket Booster Tank Attach Ring

D.a-11 NASA must reinstate a safety factor of 1.4 for the Attach Rings—which invalidates the use of ring serial numbers 15 and 16 in their present state—and replace all deficient material in the Attach Rings.

This recommendation is addressed in section 2.2, CAIB Observation 10.10-1 in the Implementation Plan. Solid Rocket Booster External Tank Attach Ring sets will be physically tested to verify compliance with the 1.4 factor of safety requirement before each flight until materials can be verified to be compliant.

Crew Survivability

D.a-12 To enhance the likelihood of crew survivability, NASA must evaluate the feasibility of improvements to protect the crew cabin of existing Orbiters.

NASA has a long-term, crew escape system evaluation effort that is included in the Service Life Extension Program portfolio. The Crew Survivability Working Group will consider options and make recommendations for protecting the crew cabin as it evaluates options to enhance crew survivability.

Reusable Solid Rocket Motor (RSRM) Segments Shipping Security

D.a-13 NASA and ATK Thiokol perform a thorough security assessment of the RSRM segment security, from manufacturing to delivery to Kennedy Space Center, identifying vulnerabilities and identifying remedies for such vulnerabilities.

NASA, in conjunction with the ATK Thiokol security program officials, will conduct a full security program vulnerability assessment of the ATK Thiokol RSRM production facility with the goal of identifying and mitigating security vulnerabilities. This assessment will coincide with the next shipment of RSRM segments to KSC.

Michoud Assembly Facility (MAF) Security

D.a-14 NASA and Lockheed Martin complete an assessment of the Michoud Assembly Facility security, focusing on items to eliminate vulnerabilities in its current stance.

NASA, in coordination with the Lockheed-Martin MAF security officials, will conduct a full security program vulnerability assessment of the MAF and External Tank (ET) production activity and the delivery of ETs to KSC.

NASA Space Shuttle Return to Flight (RTF) Suggestions

As part of NASA's response to the CAIB recommendations, the Administrator asked that a process be put in place for NASA employees and the public to provide their ideas to help NASA safely return to flight. With the first public release of NASA's RTF Implementation Plan on September 8, 2003, NASA created an electronic mailbox to receive RTF suggestions. The e-mail address is "RTFsuggestions@nasa.gov." A link to the e-mail address for RTF suggestions was posted on the NASA Web page "www.nasa.gov," near the link to the RTF Implementation Plan and the CAIB Report.

The first e-mail suggestion was received on September 8, 2003. Since then, NASA has received an average of 32 messages per week. NASA responds to each message individually, including answering any questions contained in the suggestion, and providing information about where the message will be forwarded for further review and consideration.

Many of the messages received are provided for review to a Project or Element Office within the Space Shuttle Program, the Safety and Mission Assurance organization, the Training and Leadership Development organization, the newly established NASA Engineering and Safety Center, or to the NASA Team formed to address Agencywide implications for organization and culture.

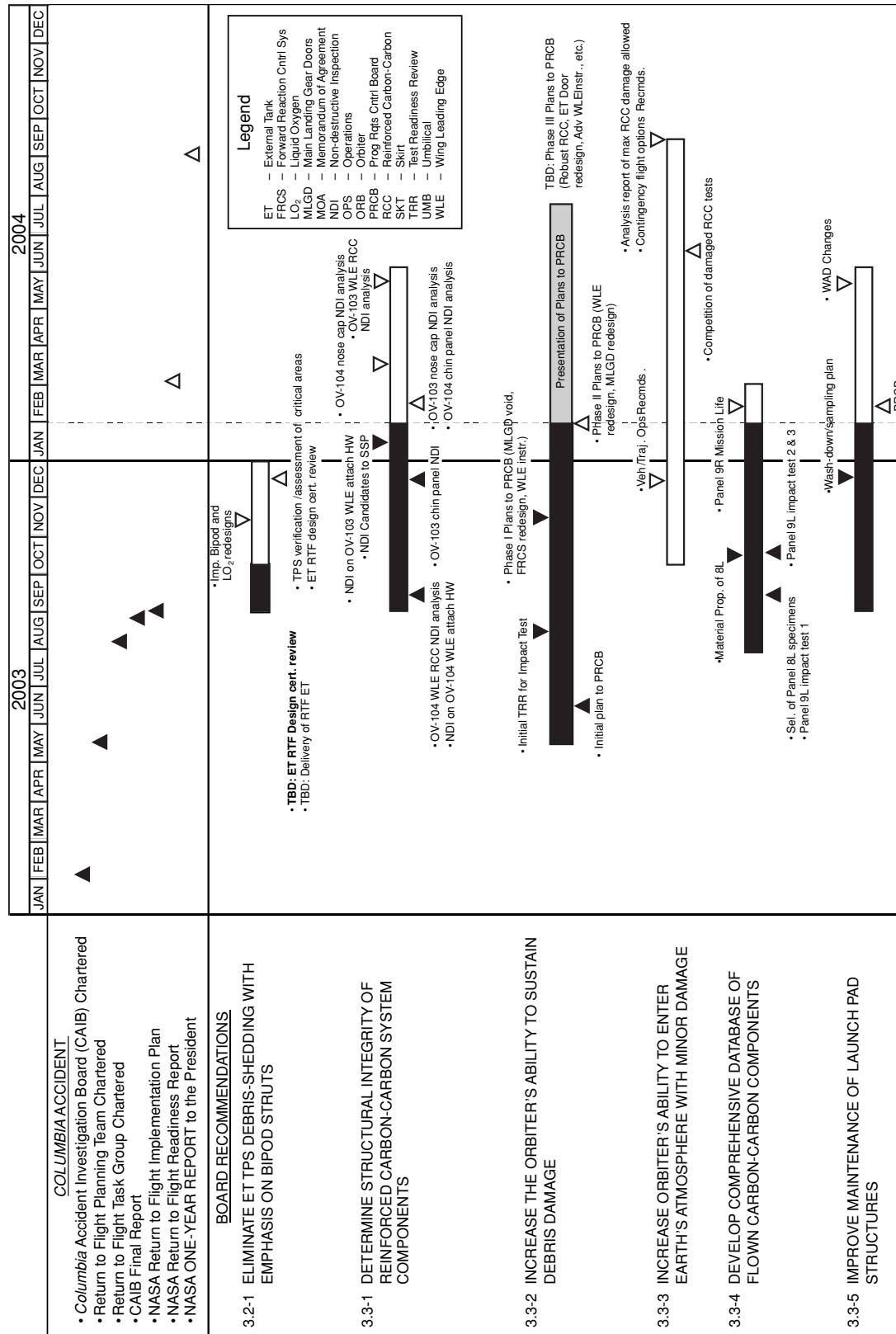
NASA organizations receiving suggestions are asked to review the message and use the suggestion as appropriate in their RTF activities. When a suggestion is forwarded, the recipient is encouraged to contact the individual who submitted the suggestion for additional information to assure that the suggestion's intent is clearly understood.

Table 1 provides a summary of our results to date and includes (1) the categories of suggestions; (2) the number of suggestions received per category; (3) examples of RTF suggestion content from each category; (4) "Action Pending" those suggestions that warranted further review by a project, program, or senior NASA manager(s); (5) "Closed" for those suggestions that required no further review once a reply was sent to the initiator; and (6) "Unprocessed" for suggestions that still require an initial review and reply.

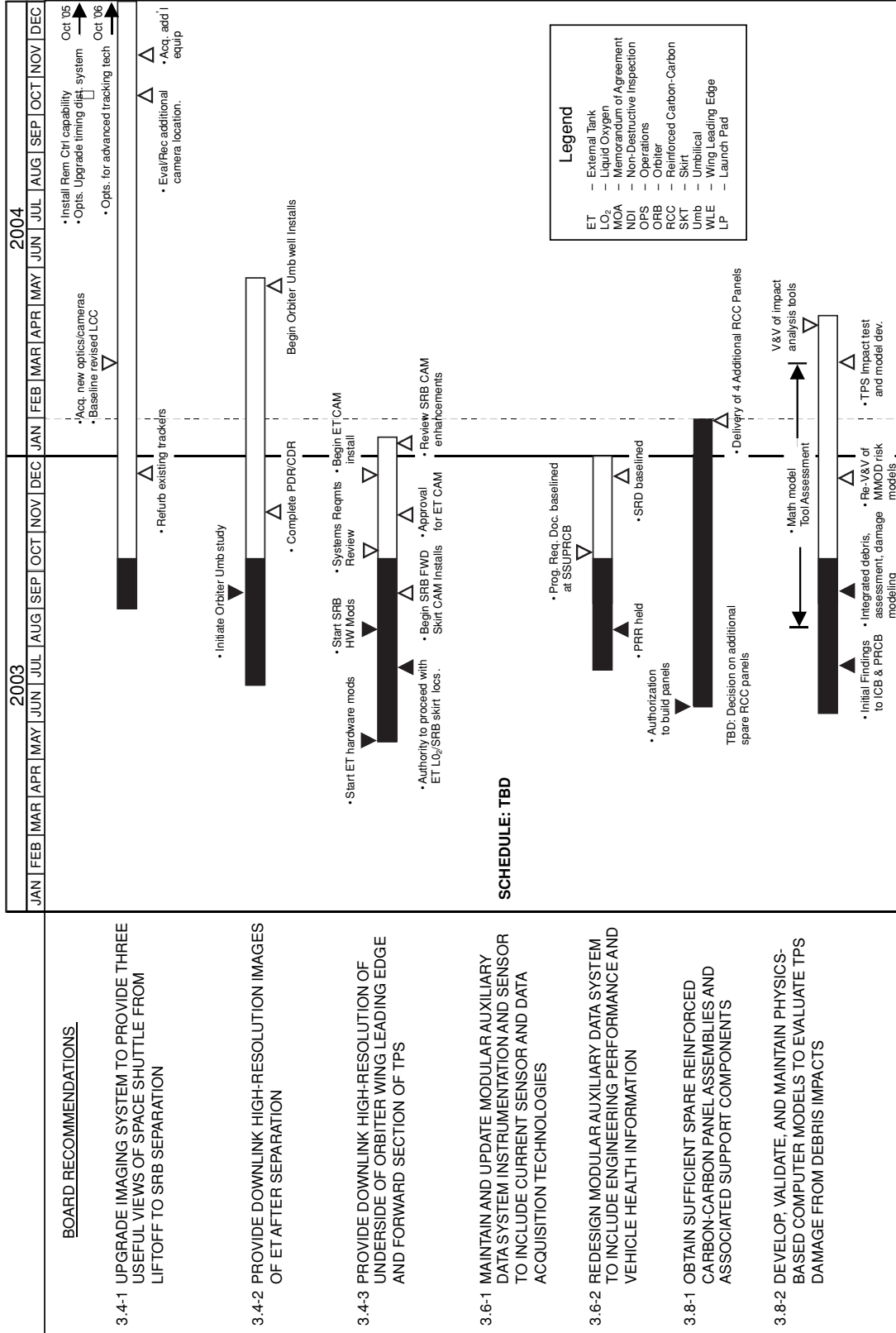
Synopsis of Return to Flight Suggestions

Category	No. of Suggestions	Example Suggestion Content
Action Pending		
Aerospace Technology	2	To quickly develop a short term alternative to the Space Shuttle based on existing technology and past Apollo-type capsule designs
SSP (General)	18	(1) Simulate Return to Launch Site scenarios. (2) Orbit a fuel tank to allow the Orbiter to refuel before entry and perform a slower entry. (3) Establish the ability to return the Shuttle without a crew onboard.
External Tank	33	(1) Insulate the inside of the ET to eliminate the possibility of foam debris hitting the Orbiter. (2) Shrink wrap the ET to prevent foam from breaking loose.
Solid Rocket Boosters	1	Please ensure that the SRB hold-down bolts are properly re-evaluated
Orbiter	54	(1) Develop a redundant layer of RCC panels on the Orbiter Wing Leading edge. (2) Cover the Wing Leading Edge with a titanium skin to protect it from debris during ascent
SSP Systems Integration	5	Try to use the same infrared imagery technology as the US military to enable monitoring and tracking the Space Shuttle during night launches
SSP Safety	5	(1) Develop new SRB's that can be thrust-controlled to provide a safer, more controllable launch. (2) Use rewards and incentives to promote the benefits of reliability and demonstrate the costs of failure.
NASA Safety and Mission Assurance	8	(1) Learn from the Naval Nuclear Reactors Program. (2) The Mandatory Inspection Point review should not be limited to just the MAF and KSC elements of the program.
NASA Engineering and Safety Center	1	(1) Use a group brainstorming approach to aid in identifying how systems might fail. (2) NESC needs to get involved during a project's start as well as during its mission operations.
NASA Culture	23	(1) Host a monthly employee forum for discussing ideas and concerns that would otherwise not be heard. (2) Senior leaders need to spend more time in the field to keep up with what is actually going on.
NASA Leadership/Management Training	3	Employees need to be trained while still in their current job to prepare them for increasing positions of responsibility.
NASA Public Affairs	8	NASA needs to dramatically increase media coverage to excite the public once again, to better convey the goals and challenges of human space flight, and to create more enthusiasm for a given mission.
Closed	54	(1) Use a current version of the Shuttle robotic arm to develop the extension boom for on-orbit inspection. (2) If Atlantis is not ready to fly, try using another Orbiter first.
Unprocessed	71	
Total (As of November 12, 2003)	286	

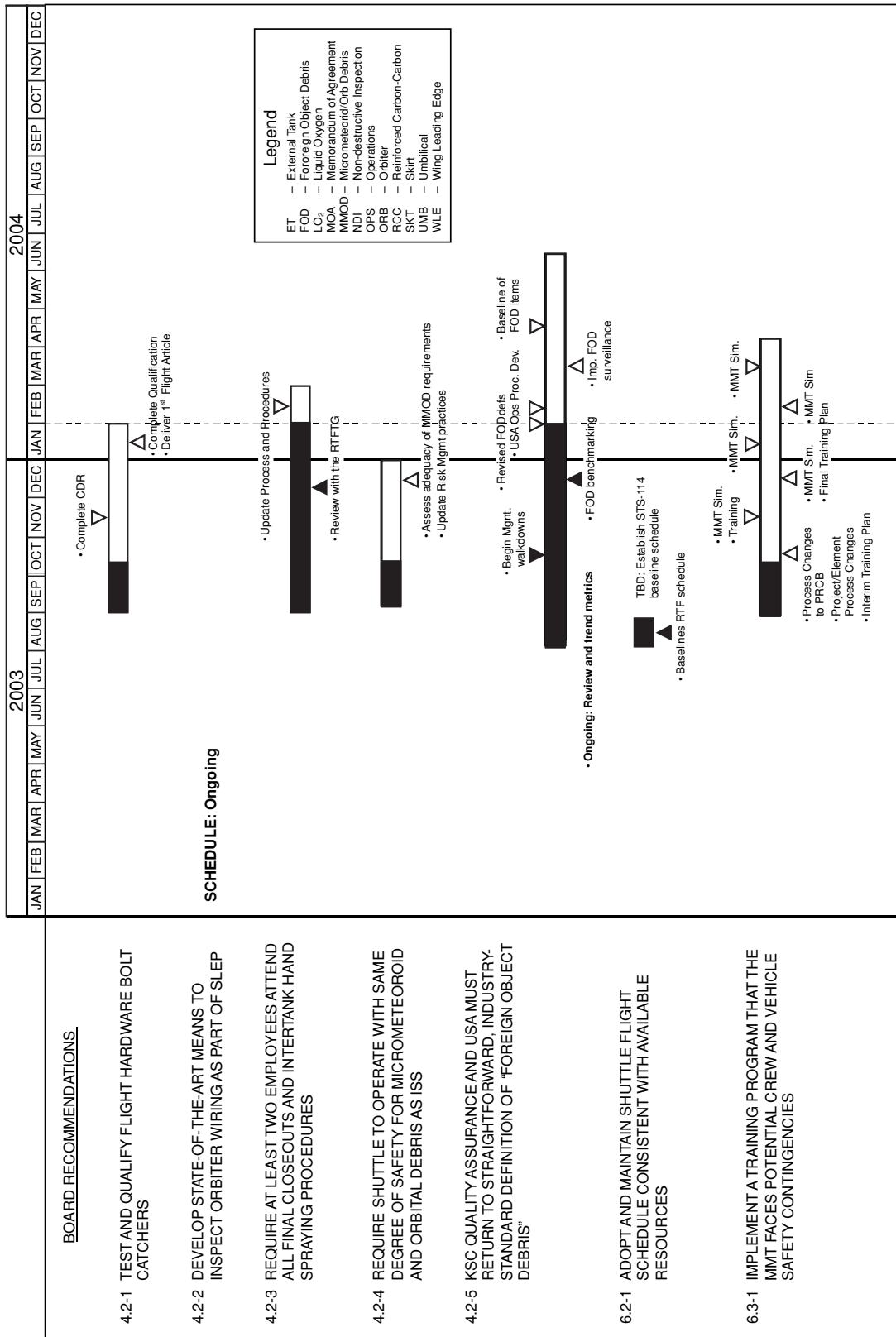
CAIB Recommendations Implementation Schedule



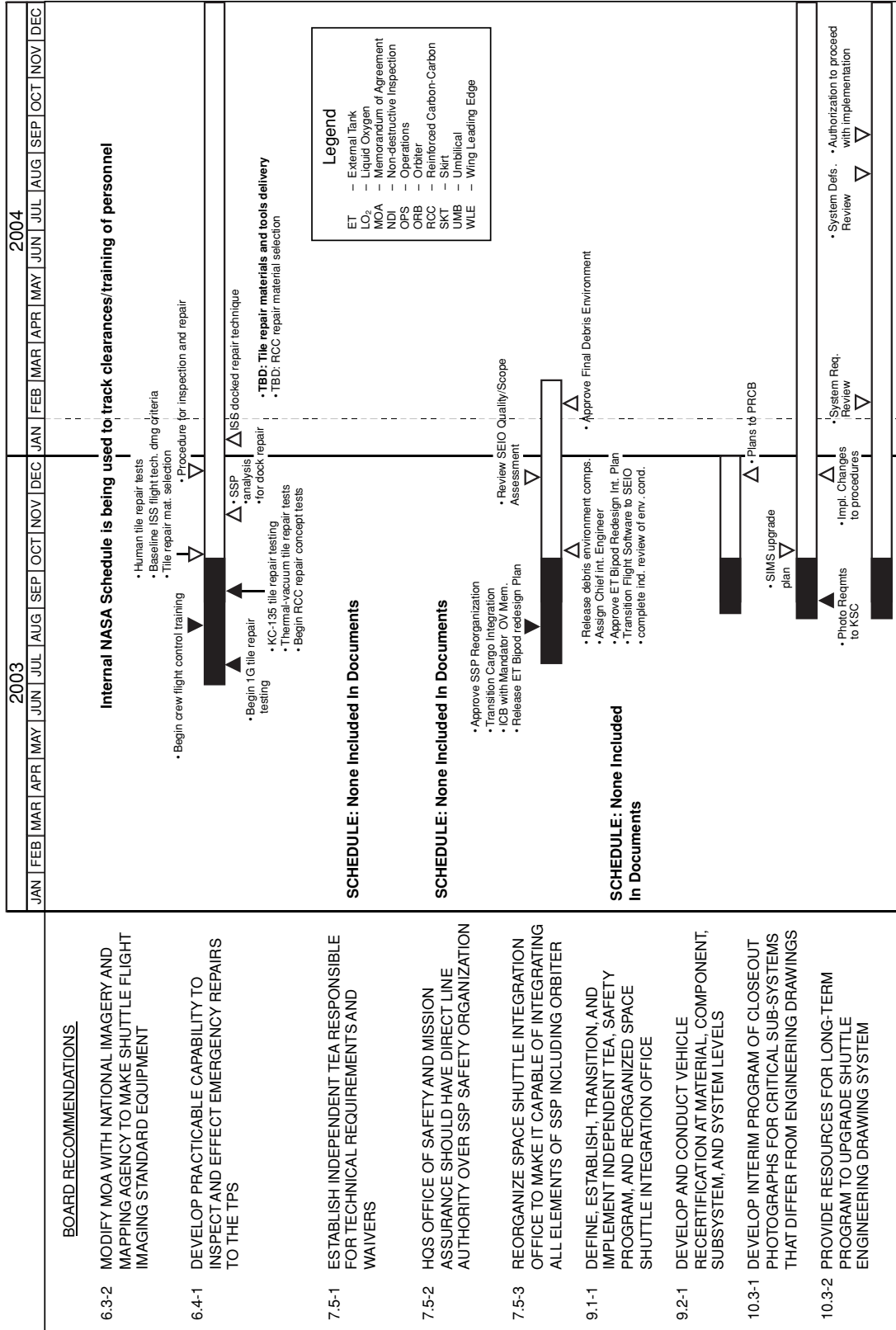
CAIB Recommendations Implementation Schedule

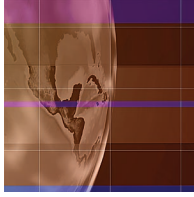


CAIB Recommendations Implementation Schedule



CAIB Recommendations Implementation Schedule





Return to Flight Cost Summary

NASA began to incur costs in FY 2003, originally estimated at approximately \$40.5M, to initiate return to flight (RTF) actions based on preliminary CAIB recommendations and internal Shuttle Program actions. In November 2003, NASA identified a total of \$60M of FY 2003 RTF activities that had sufficient maturity to allow reasonable cost estimates, and had been approved for funding by the Space Shuttle Program Requirements Control Board (PRCB) and verified by the RTF Planning Team (RTFPT). Since November, additional corrective actions have been initiated based on the final CAIB report recommendations and internal Shuttle Program actions. The total cost of FY 2003 RTF activities is now known to be \$93.5M.

For FY 2004, \$265M of potential RTF activities has been identified to date, of which \$124M have been approved through the PRCB and verified by the RTF Planning Team. The remaining \$141M of identified potential FY 2004 RTF activities is still under evaluation to confirm the estimated cost and associated out-year phasing. Cost estimates for RTF activities are dynamic. Additional funding may be required from other Agency sources. As soon as these additional RTF activities are definitized, they will be shared with Congress in the *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond*.

Not included in cost estimates provided are additional RTF elements being evaluated for a start in FY 2004 and other RTF funding requirements resulting from a complete evaluation of the CAIB report, such as replacement of hardware (e.g., cargo integration, Orbiter pressure tanks); other agencies' on-orbit assessment; and program reserves. Several solutions to improve NASA's culture and some of the Space Shuttle Program's (SSP) actions detailed in "Raising the Bar – Other Corrective Actions" (referred to as SSP corrective actions for the remainder of this summary) will be integrated into existing processes and may not always require additional funding.

The proposed SSP solutions for all RTF actions will be reviewed before receiving final NASA implementation approval and included in future updates. This process

applies to solutions to the CAIB recommendations as well as to the SSP corrective actions.

The PRCB has responsibility to direct studies of identified problems, formulate alternative solutions, select the best solution, and develop overall cost estimates. The membership of the PRCB includes the SSP Manager, Deputy Manager, all Project and Element Managers, Safety and Mission Assurance personnel, and the Team Leader of the RTFPT.

PRCB deliberations are further evaluated by the RTFPT to ensure that comprehensive, integrated, and cohesive approaches are selected to address the recommendations and solutions as outlined in this plan. The membership of the RTFPT group includes approximately 30 experienced senior personnel from the Office of Space Flight and its field centers (at JSC, KSC, MSFC, and SSC).

In the process of down-selecting to two or three "best options," the projects and elements approve funding to conduct tests, perform analysis, develop prototype hardware and flight techniques, and/or obtain contractor technical expertise that is outside the scope of existing contracts.

The Space Flight Leadership Council (SFLC) is regularly briefed on the overall activities and progress associated with RTF and becomes directly involved when the SSP and RTFPT are ready to recommend a comprehensive solution to a CAIB recommendation or SSP corrective action. The SFLC receives a technical discussion of the solution as well as an assessment of cost and schedule. With the concurrence of the SFLC, the SSP then receives the authority to proceed. The membership of the SFLC includes the Associate Administrator for the Office of Space Flight, Associate Deputy Administrator for Technical Programs, Deputy Associate Administrator for ISS and SSP, Associate Administrator for Safety and Mission Assurance, RTFPT Team Lead, Space Shuttle Program Manager, and the Office of Space Flight Center Directors (at JSC, KSC, MSFC, and SSC).

All recommended solutions are further reviewed, for both technical merit and to determine if the solution responds to the action, by the Return to Flight Task Group (also known as the Stafford-Covey Task Group).

As decisions are made through the process described above, NASA will provide updated cost estimates in

subsequent revisions of NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond. Current estimates for NASA's initial RTF requirements are based on cost estimating relationships derived from previous cost history, and typically include costs such as studies, engineering, development, integration, certification, verification, implementation, and retrofit, if appropriate.

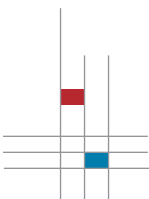
Return to Flight Budget Estimates/Implementation Plan Map for New Estimates Including Threats As of 1/29/04

	(\$ Millions)		Recommendation Numbers Map to Implementation Plan										SSP Recommendation			
	FY 03	FY 04	CAIB #3.2-1	CAIB #3.3-1	CAIB #3.3-2	CAIB #3.3-3	CAIB #3.3-4	CAIB #3.4-1	CAIB #3.4-2	CAIB #3.4-3	CAIB #4.2-1	CAIB #4.2-3		CAIB #6.4-1	CAIB #7.5-1	CAIB #7.5-2
Initiated RTF Activities	92	264														
Orbiter RCC Inspections	4	21	X										X			
On-orbit TPS Inspection & EVA Tile Repair	46	53											X			
Orbiter TPS Hardening	4	17		X												
Orbiter Certification / Verification	2	3	X	X	X											
External Tank Items (Camera, Bipod Ramp, etc.)	26	60	X					X	X	X		X				
SRB Items (Bolt Catcher, ETA Ring Invest., Camera)	0	14							X	X	X					
Ground Camera Ascent Imagery Upgrade	8	36						X	X	X						
Other (System Intgr. JBOSC Sys, SSME Tech Assess)	2	60	X	X	X											
Stafford - Covey Team	2	1														X
Total SSP RTF Related	94	265														
Other RTF Related																
NASA Engineering and Safety Center (NESC)		45											X	X	X	



NASA's Response to the Columbia Accident Investigation Board's Recommendations

The following section details NASA's response to each CAIB recommendation in the order that it appears in the CAIB report. We must comply with those actions marked "RTF" before we return to flight. This is a preliminary plan that will be periodically updated. As we begin to implement these recommendations and continue our evaluation of the CAIB report, we will be able to respond more completely. Program milestones built on the CAIB recommendations will determine when we can return to safe flight.





Columbia Accident Investigation Board

Recommendation 3.2-1

Initiate an aggressive program to eliminate all External Tank Thermal Protection System debris-shedding at the source with particular emphasis on the region where the bipod struts attach to the External Tank. [RTF]

BACKGROUND

Figure 3.2-1-1 illustrates the primary areas on the External Tank (ET) being evaluated as potential debris sources for return to flight (RTF).

ET Forward Bipod Background

Before STS-107, several cases of foam loss from the left (-Y) bipod ramp were documented through photographic evidence. The most significant foam loss events in the early 1990s were attributed to debonds or voids in the “two-tone” foam bond layer configuration on the intertank forward of

the bipod ramp. The intertank foam was thought to have peeled off portions of the bipod ramp when liberated. Corrective action taken after STS-50 included implementation of a two-gun spray technique in the ET bipod ramp area (figure 3.2-1-2) to eliminate the two-tone foam configuration. After the STS-112 foam loss event, the ET Project began developing redesign concepts for the bipod ramp—an activity that was still under way at the time of the STS-107 accident. Dissection of bipod ramps conducted for the STS-107 investigation has indicated that defects resulting from a manual foam spray operation over an extremely complex geometry could produce foam loss.

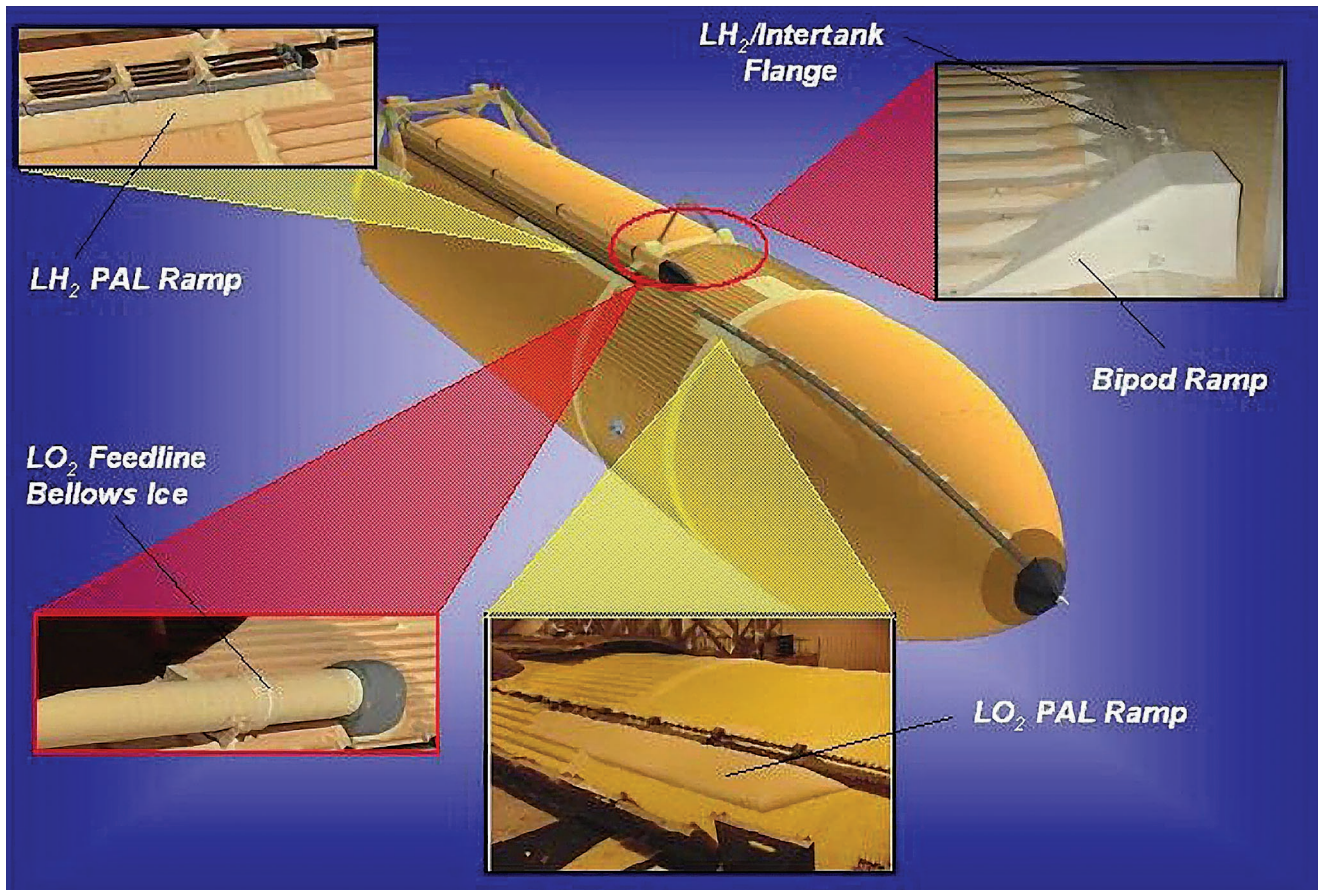


Figure 3.2-1-1. Primary potential ET debris sources being evaluated.



Figure 3.2-1-2. ET forward bipod ramp (foam).

Liquid Oxygen (LO₂) Feedline Bellows Background

Three ET LO₂ feedline sections incorporate bellows to allow feedline motion. The bellow shields (figure 3.2-1-3)

are covered with Thermal Protection System (TPS) foam, but the ends are exposed. Ice and frost form when moisture in the air contacts the cold surface of the exposed bellows. Although Space Shuttle Program (SSP) requirements include provisions for ice on the feedline supports and adjacent lines, ice in this area presents a potential source of debris in the critical debris zone—the area from which liberated debris could impact the Orbiter.

Protuberance Airload (PAL) Ramps Background

The ET PAL ramps are designed to reduce adverse aerodynamic loading on the ET cable trays and pressurization lines (figure 3.2-1-4). The only PAL ramp foam loss event in the flight history occurred on STS-4. The cause of this foam loss was determined to be associated with a repair operation, which has been precluded by limiting repairs allowed on all PAL ramps. However, the PAL ramps are large, thick, manual-spray applications (using a less

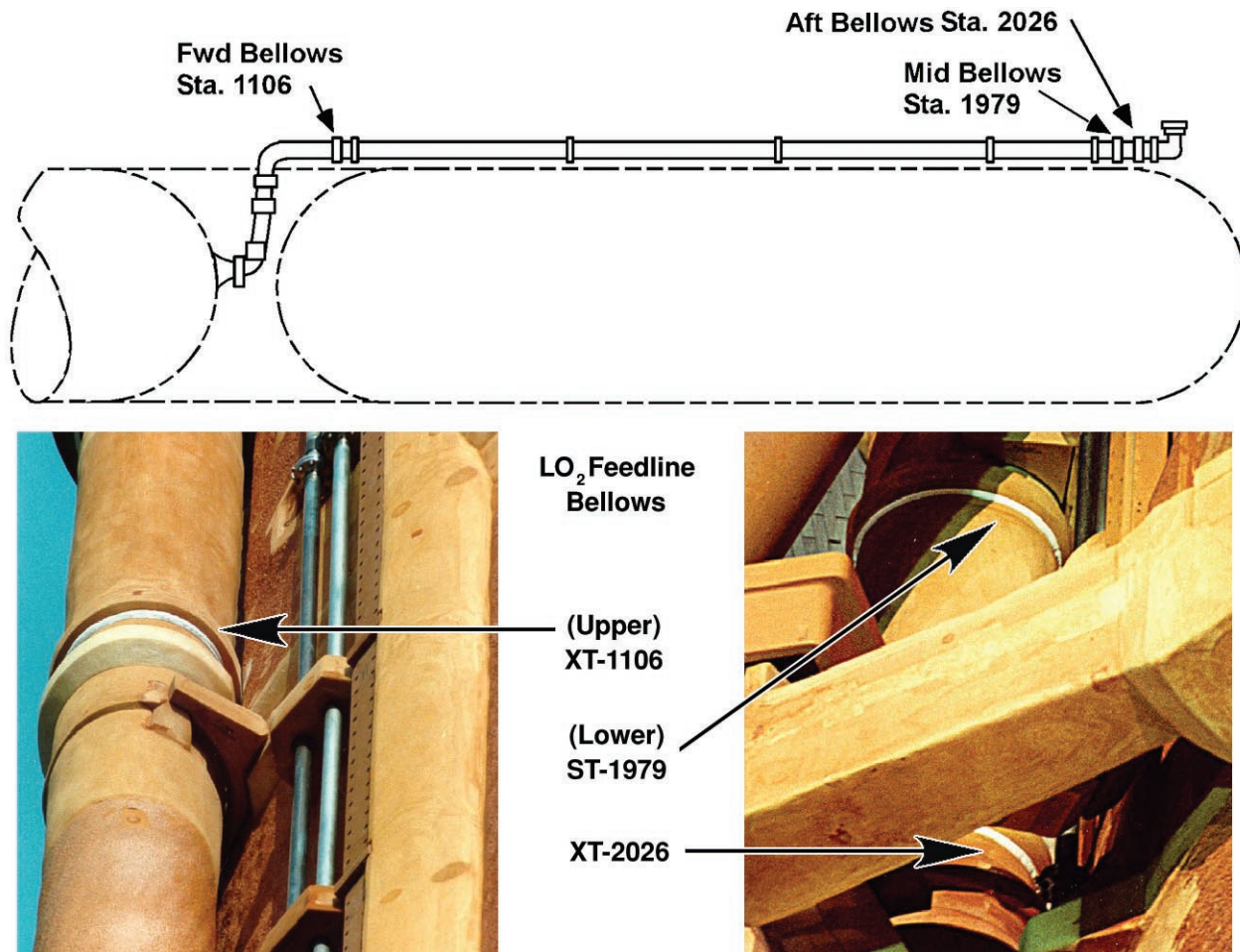


Figure 3.2-1-3. LO₂ feedline bellows.

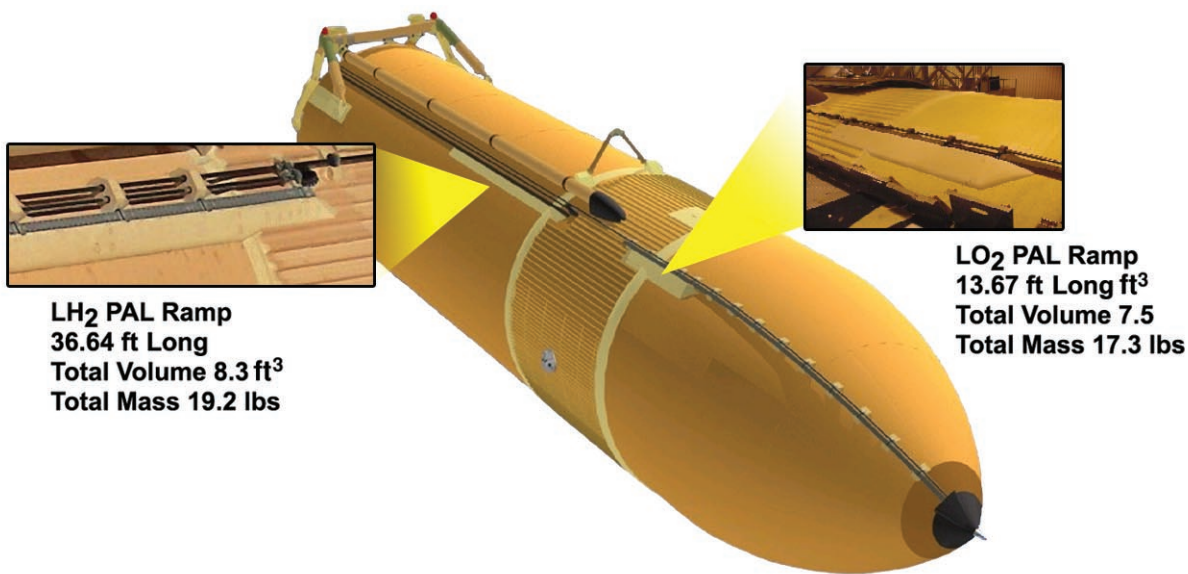


Figure 3.2-1-4. PAL ramp locations.

complex manual spray process than that used on the bipod) and could, if liberated, become the source of large debris.

ET Liquid Hydrogen (LH₂) Intertank Flange Background

The ET LH₂/intertank flange (figure 3.2-1-5) is a manually fastened mechanical joint that is closed out with a two-part manual spray foam application.

Photographic evidence documents a history of foam loss events from this area. The divots from the LH₂/intertank flange area are typically less than 0.1 lb and emanate from within the critical debris zone, which is the area of the ET where debris loss could adversely impact the Orbiter or other Shuttle elements.

NASA IMPLEMENTATION

A three-phase approach to eliminate the potential for debris loss from the ET has been initiated. Phase 1 represents those activities that will be performed before return to flight.

Phase 2 includes debris elimination enhancements that can be incorporated into the ET production line as the enhancements become available but are not considered mandatory for RTF. Phase 3 represents long-term development activities that will be examined to achieve the ultimate goal of eliminating the potential for debris loss. A major ET redesign activity is required to achieve Phase 3.

As part of the Phase 1 effort, NASA is enhancing or redesigning the areas of known critical debris sources (figure 3.2-1-1). This includes redesigning the forward bipod fitting, eliminating ice from the LO₂ feedline bellows, and eliminating debris from the LH₂/intertank flange closeout. In addition to these known areas of debris, NASA is reassessing all TPS areas to validate the TPS configuration, including both automated and manual spray applications. Special consideration is being given to the LO₂ and LH₂ PAL ramps due to their size and location. This task includes assessing the existing verification data, establishing requirements for additional verification data (test, dissections, plug pulls, etc.), and evaluating methods to improve process control of the TPS application.

NASA is pursuing a comprehensive testing program to understand the root causes of foam shedding and develop alternative design solutions to reduce the debris loss potential. Research is being conducted at Marshall Space Flight Center, Arnold Engineering and Development Center, Eglin Air Force Base, and elsewhere.

NASA is also pursuing the development of TPS nondestructive investigation (NDI) techniques to determine the optimal means of prelaunch ET TPS inspection that do not damage the fragile insulating foam. The Phase 1 focus is to implement NDI for the LO₂ and LH₂ PAL ramps and the LH₂ intertank flange manual closeout.

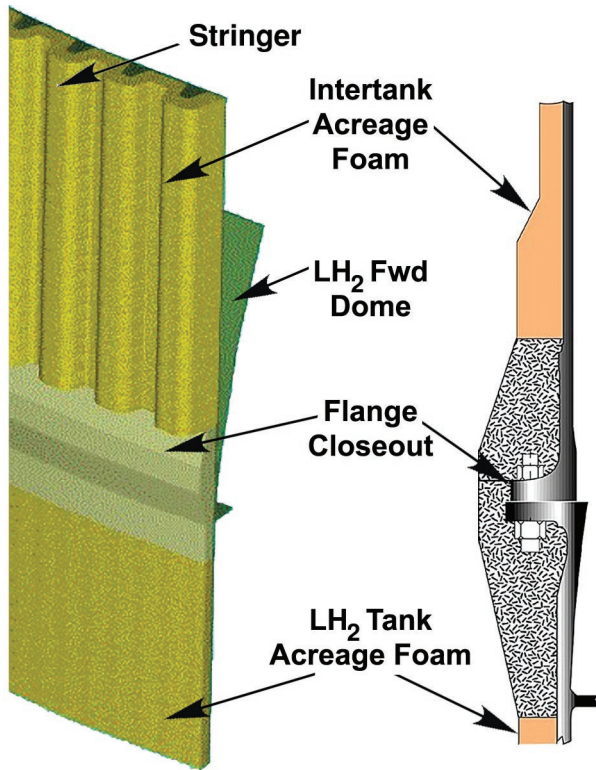


Figure 3.2-1-5. ET LH₂ flange area.

The Phase 2 effort will include pursuing the automation of critical manual TPS spray processes, redesigning or eliminating the LO₂ and LH₂ PAL ramps, and enhancing the NDI screening tool. Efforts will also be made to enhance the TPS material to reduce its debris loss potential and enhance the TPS thermal analysis tools to better size and potentially reduce the amount of TPS on the vehicle.

The Phase 3 effort will examine redesigning the ET to eliminate the debris shedding potential at the source. This will include items such as developing a “smooth” LO₂ tank where there are no external cable trays or pressurization lines, developing a “smooth” intertank where an internal orthogrid eliminates the need for external stringers, and implementing a protuberance tunnel in the LH₂ tank. These changes could provide a tank with a smooth outer mold line that eliminates the need for complex TPS closeouts and manual sprays.

ET Forward Bipod Implementation Approach

NASA has initiated a redesign of the ET forward bipod fitting (figure 3.2-1-6). The baseline design change eliminates the need for large bipod foam ramps. The bipod fittings have been redesigned to incorporate redundant heaters in the base of the bipod to prevent ice formation as a debris hazard.

LO₂ Feedline Bellows Implementation Approach

NASA evaluated three concepts to eliminate ice formation on the bellows and will select one for RTF retrofit. Initial analysis and testing has eliminated the flexible bellows boot as a potential solution. NASA is now focusing on heated gaseous nitrogen (GN₂) or gaseous helium purge, and incorporation of a condensate drain “drip lip” (figure 3.2-1-7) to eliminate ice formation. NASA will use a combination of analysis and testing to verify the design solution’s effectiveness.

LH₂/Intertank Flange Closeout Implementation Approach

NASA will conduct tests to determine the cause of foam

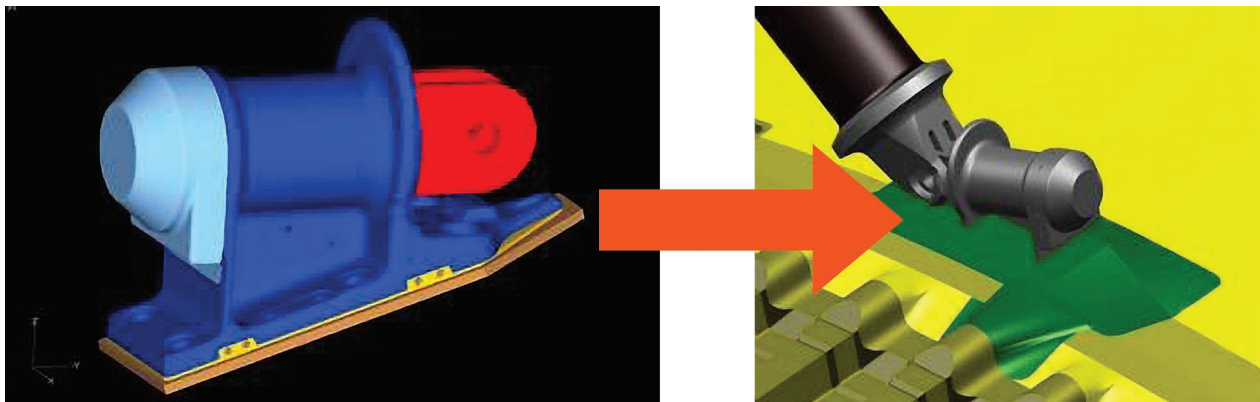
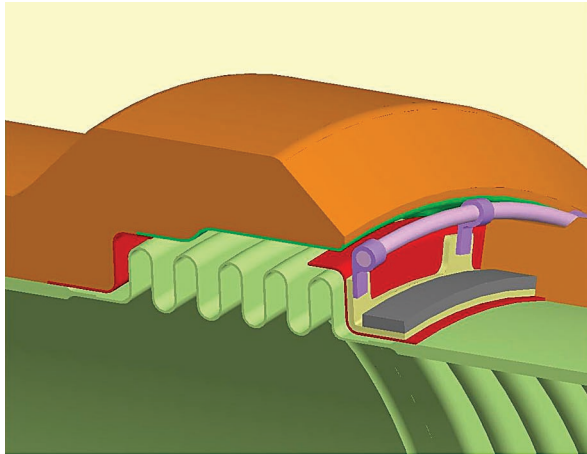
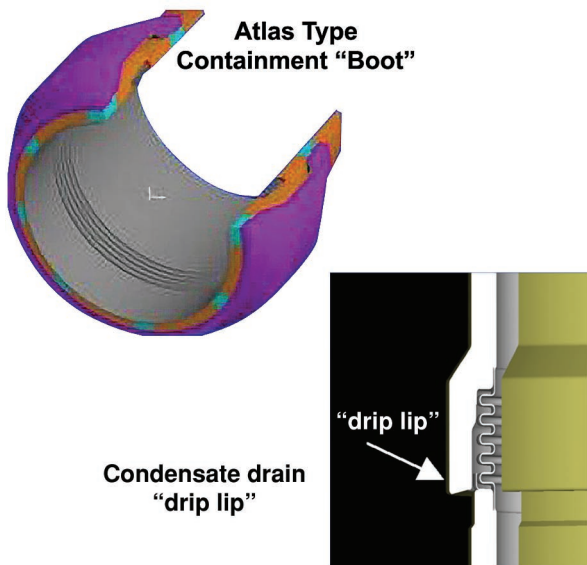


Figure 3.2-1-6. ET forward bipod redesign.



Heated GN₂ Purge



Atlas Type Containment "Boot"

Condensate drain "drip lip"

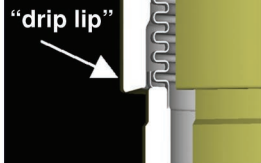
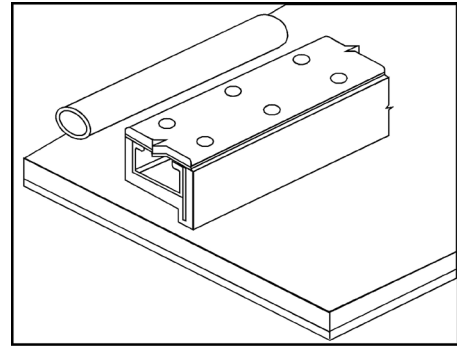


Figure 3.2-1-7. LO₂ feedline bellows design concepts.

liberation from the LH₂/intertank flange area. Several design concepts are being evaluated that will ensure the LH₂/intertank flange closeouts will not generate critical debris in flight. These concepts range from active purge of the intertank crevice to enhanced foam application procedures.

PAL Ramps Implementation Approach

There has been only one PAL ramp foam loss event in the history of the Shuttle (STS-4). The cause of this event was related to a repair operation, which has been precluded by limiting the allowable repairs on all PAL



Leading Edge Fence LO₂ Tray Concept

Figure 3.2-1-8. Leading edge fence LO₂ tray concept.

ramps. However, the ET PAL ramp configurations will also be assessed to reduce or eliminate them as potential sources of TPS debris.

Due to the size and location of the PAL ramps, NASA has placed them at the top of the priority list for TPS verification reassessment and NDI (see figure 3.2-1-9 for task descriptions). NASA will work to first increase confidence in the existing design before RTF. Phase 2 implementation will remove or reduce the size of the PAL ramps. The goal is to reduce or eliminate the potential debris source without adding further risk to the hardware that the PAL ramps are designed to protect. Three options are being evaluated for redesign: no ramps, foam mini-ramp, and leading edge fence (figure 3.2-1-8).

TPS (Foam) Verification Reassessment Implementation Approach

NASA's immediate focus for RTF is on critical manual TPS applications, such as the PAL ramps, identified during the STS-107 investigation. Manually applied TPS is more likely to have imperfections that might result in foam debris. As a result, it requires a higher level of scrutiny. NASA will accomplish the TPS verification assessment by creating a prioritized list of debris-critical TPS applications, assessing existing verification data, and establishing requirements for data to provide added confidence (figure 3.2-1-9). Included with this assessment will be a review and update of the process controls applied to foam applications, especially the manual spray applications. As part of this update, NASA will ensure that at least two employees attend all final closeouts and critical hand-spraying procedures to ensure proper processing (ref Recommendation 4.3-3).

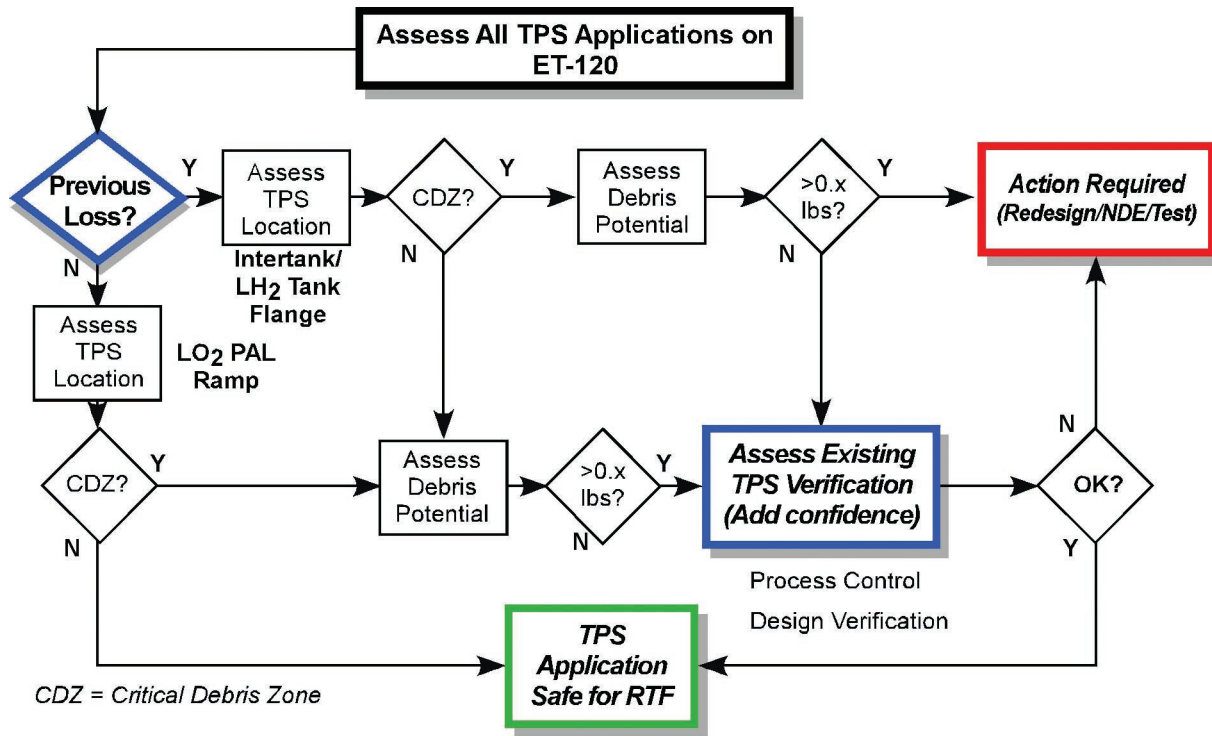


Figure 3.2-1-9. TPS verification reassessment logic.

NDI of Foam Implementation Approach

The development of TPS NDI techniques is being pursued to improve our confidence in the foam application processes. If successful, advanced NDI will provide an additional level of process verification. The initial focus of RTF will be on PAL ramp and LH₂ intertank flange manual applications.

During Phase 1, NASA will survey state-of-the-art technologies, evaluate their capabilities, down-select, and develop a system that will detect critical flaws in ET insulation systems. As an initial screening, test articles with known defects, such as voids and delaminations (figure 3.2-1-10)) will be provided to determine detection limits of the various NDI methods.

After the initial screening, NASA will select those technologies that show promise and conduct more comprehensive probability of detection (POD) for those applicable NDI methods. The Phase 2 activities will optimize and fully certify the selected technologies for use on the External Tank.

STATUS

NASA has completed an initial assessment of debris sources on the ET, including both credible size and frequency or probability of liberated debris.

ET Forward Bipod Status

NASA has successfully completed a systems design review and a Preliminary Design Review (PDR). The Critical Design Review (CDR) is planned for late October 2003. Verification testing is under way, which consists of the following tests:

- Thermal verification test to verify prelaunch ice prevention;
- Structural verification test to verify modified fitting in-flight environments;
- Wind tunnel testing to verify TPS closeouts exposed to ascent aerodynamic and thermal environments.

Preliminary results of testing to date are positive.

TERAHERTZ IMAGING

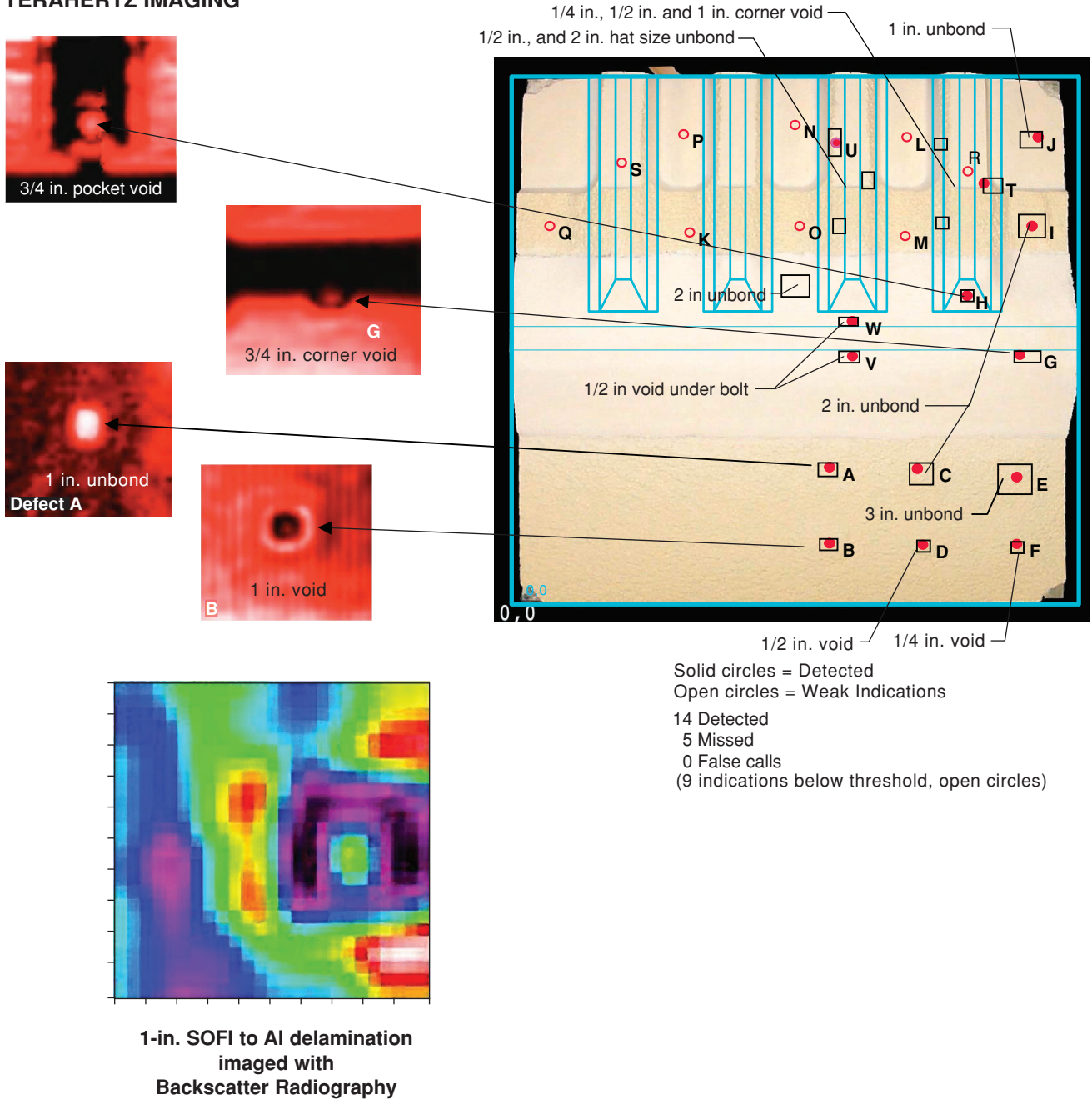


Figure 3.2-1-10. Terahertz images.



Figure 3.2-1-11. LO₂ feedline bellows 'drip lip' with foam insert.

LO₂ Feedline Bellows Status

Analysis and testing of three candidate design solutions was initiated to eliminate the potential for ice debris from the LO₂ feedline bellows area. The preliminary debris transport and Orbiter impact assessments have determined that all bellows need to be addressed by the redesign. Proof-of-concept testing was performed at the Eglin Air Force Base environmental chamber to down-select the design concept for the LO₂ feedline bellows. The Atlas boot was eliminated based on test and analysis results that indicated the boot could not prevent ice formation. Multiple heated GN₂ purge system concepts were tested at various environmental conditions and successfully eliminated ice formation. However, this testing showed that purge effectiveness was sensitive to the purge ring location. In addition, this purge system has multiple integration complexities when applied to the aft bellows locations since a purge is not currently available for this area of the ET.

The TPS "drip lip" is an extension of the current LO₂ feedline TPS closeout that diverts condensate from the bellows and significantly reduces ice formation. The initial testing demonstrated ice elimination for all conditions except for the maximum environment design case (99°F, 95% relative humidity). In this case, cold venting from within the bellows cavity caused a small ice buildup. However, subsequent testing demonstrated ice reduction but not total ice elimination at lower temperature and lower humidity conditions than the maximum environment test point. Follow-on testing demonstrated that inserting a foam strip in the bellows cavity gap reduced, and might eliminate, cavity venting and ice formation. This "drip lip" concept (figure 3.2-1-11) was chosen as the baseline option due to the reduced implementation complexity and the ability to support both forward and aft bellows. The purge system development will continue as a back-up solution.

Longer-term Phase 2 design solutions are also being pursued with the supplier of the feedline bellows assembly to eliminate the icing concern.

LH₂/Intertank Flange Closeout Status

The LH₂/intertank closeout design is being evaluated to minimize potential debris from that area (figure 3.2-1-5). Several design concepts are being evaluated pending determination of foam liberation cause, including incorporating an active purge of the intertank crevice to eliminate the formation of liquid nitrogen (LN₂), and developing enhanced foam application procedures.

Testing is under way to replicate foam debris seen during flight in order to understand the foam loss mechanism and to define a critical defect size. NASA subjected a series of 1'x1' aluminum substrate panels with induced voids of varying diameters and depths below the foam surface to the vacuum and heat profiles experienced during launch. Some of the panels were also subjected to a cryogenic temperature backface to simulate the flight conditions. These tests were successful at producing divots in a predictable manner depending on void size. Divots were significantly more likely to form when subjected to vacuum and heat alone. The cryogenic backface (without the presence of cryopumping) tended to reduce the likelihood of divot formation for a given void size, indicating the thermal boundary conditions play a significant role in divot formation.

Follow-on testing has been conducted on 3'x5' panels that simulated the LH₂ intertank flange geometry and TPS closeout configuration in order to replicate divot formation in a flight-like configuration. The panels that did not have induced voids did not produce divots and no cracks in the insulation were observed. One of the 3'x5' panels with induced voids did successfully create a 0.07 lb, 8" diameter divot. A second 0.08 lb, 8" diameter foam defect

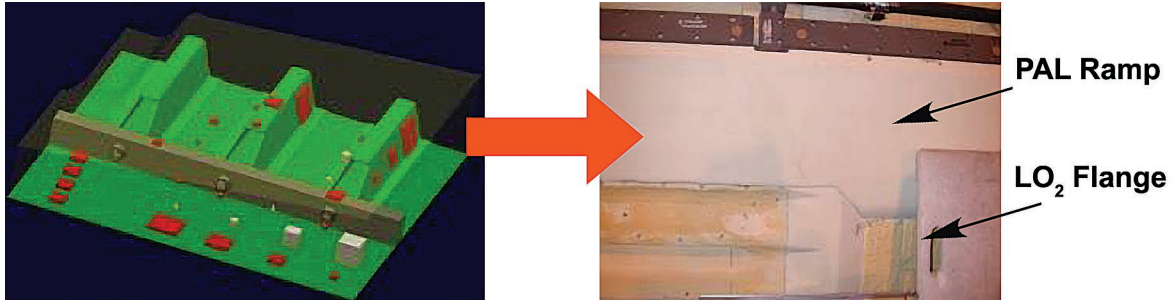


Figure 3.2-1-12. PAL ramp/flange test panel.

was also formed that was apparently only held in place by a test thermocouple wire. Multiple cracks were seen in this panel and other panels around the areas with induced defects. While the divot replication results are not yet conclusive and further testing is planned, there has been considerable progress in being able to replicate and understand the root cause of foam loss in this intertank area.

Testing is also under way to evaluate the feasibility of using a targeted heated gaseous nitrogen (GN_2) or gaseous helium (GHe) purge in the intertank crevice or “y-joint” region to eliminate formation of LN_2 . The concern is that LN_2 formed within the intertank region will migrate or be cryopumped to subsurface voids within the foam. Subsequent heating during launch would lead to substantial buildup in pressure within the foam, contributing to the potential for foam debris loss. The preliminary testing indicated that the targeted GHe purge was successful at eliminating this LN_2 formation, while the directed GN_2 purge did not completely eliminate LN_2 formation. In addition, testing was conducted to determine if an internal y-joint volume displacement system would eliminate LN_2 formation. Preliminary test results using halocarbon oil indicated this was a feasible solution.

Progress has also been made in enhancing the TPS closeout in the LH_2 intertank area to reduce the presence of defects within the foam. An injection mold approach has shown excellent capability of filling the stringer area of the intertank flange (figure 3.2-1-5) without defects. The flange bolts attaching the intertank and LH_2 tank sections have been reversed, taking advantage of the stringer fill injection mold to eliminate a susceptible area for voids under the flange bolt without impacting the structural integrity of the External Tank. If successfully implemented, this approach will greatly reduce or eliminate void formations in the most susceptible area of the

LH_2 intertank flange TPS closeout. In addition, a study has been performed at both KSC and the Michoud Assembly Facility to reduce the potential for TPS damage during ground processing. A series of recommendations has been identified, including reducing access to critical areas of the ET, installing debris safety barriers, improving the work platforms in the area, and investigating a topcoat that would more readily show handling damage.

PAL Ramps Status

Concept design activities are in work to eliminate the PAL ramps as part of the Phase 2 activity. Subscale wind tunnel testing of the candidates is under way. Because the PAL ramps (figure 3.2-1-12) have an excellent flight history, the baseline approach for RTF is to develop sufficient confidence to accept the debris risk of the existing design by evaluating the available verification data and augmenting it with additional test, analysis, and/or inspection data. Removal and replacement of the PAL ramp with an improved process manual spray application is also under consideration for RTF. A backup plan is in place to evaluate redesign solutions that include eliminating the PAL ramps, implementing smaller mini-ramps, or incorporating a cable tray aero block fence. NASA will decide whether to implement an alternative approach after completing a comprehensive testing and analysis program on these options.

TPS (Foam) Verification Reassessment Status

NASA has created a prioritized list of debris-critical TPS applications. NASA used discrete criteria—including flight history, debris potential, design verification, and materials processing—and scoring to prioritize the ET TPS applications for assessment. The summary scores provided a relative comparison of verification confidence between the

highest debris risk (bipod) and lowest debris risk (LH₂ tank acreage application). This assessment was used to target high impact options to reduce debris risk and increase confidence before RTF. The majority of the debris risk concerns are associated with process control and capability to minimize and/or detect critical internal defects. A Manual Spray Enhancement Team has been established to provide recommendations for improving the TPS closeout of manual spray applications. A Critical Defect Team has also been established to build on the results of the LH₂ intertank flange debris replication testing to determine the critical defect size for debris generation.

NDI of Foam Status

Activities have been initiated to develop NDI techniques for use on ET TPS. The following prototype systems under development by industry and academia were evaluated:

- Backscatter Radiography: University of Florida
- Microwave/Radar: Marshall Space Flight Center, Pacific Northwest National Labs, University of Missouri, Ohio State
- Shearography: Kennedy Space Center, Laser Technology, Inc.
- Terahertz Imaging: Langley Research Center, Picometrix, Inc., Rensselaer
- Laser Doppler Vibrometry: Marshall Space Flight Center, Honeywell

The Terahertz Imaging and Backscatter Radiography systems were selected for further probability of detection testing based on the results of the initial proof-of-concept tests. The microwave system will still be evaluated during the Phase 2 development activity.

FORWARD WORK

- Determine critical debris characteristics that could cause catastrophic damage to the Orbiter. Use these results to evaluate LO₂ feedline bellows, LH₂ intertank flange foam closeout, and LH₂/LO₂ PAL ramp redesign options.
- Complete CDR of bipod fitting redesign and complete verification testing.
- Implement the 'drip lip' design option for the LO₂ feedline bellows.

- Assess confidence in current PAL ramps design and develop concept designs for PAL ramps. Determine PAL ramp approach for RTF.
- Complete testing to determine the cause of foam liberation from the LH₂ intertank flange foam closeout and evaluate implementation approaches.
- Assess existing data and establish requirements for data to provide added confidence (tests, dissections, etc.) for TPS (foam) verification.
- Determine detection limits of the various NDI methods and conduct more comprehensive POD and qualification testing on selected technologies.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Nov 03	Implementation of bipod and LO ₂ bellows redesigns
SSP	Dec 03	TPS verification reassessment of critical areas
SSP	Nov/Dec 03	LH ₂ flange process enhancement definition and redesign decision
SSP	TBD	ET RTF design certification review
SSP	TBD	Delivery of RTF ET



Columbia Accident Investigation Board Recommendation 3.3-2

Initiate a program designed to increase the Orbiter's ability to sustain minor debris damage by measures such as improved impact-resistant Reinforced Carbon-Carbon and acreage tiles. This program should determine the actual impact resistance of current materials and the effect of likely debris strikes. [RTF]

BACKGROUND

The STS-107 accident demonstrated that the Space Shuttle Thermal Protection System (TPS) design is vulnerable to impact damage for conditions outside the current design criteria. Identification of all sources of debris and potential modifications to the design of the TPS, referred to as Orbiter hardening, are expected to make the Orbiter less vulnerable to this risk.

NASA IMPLEMENTATION

A Program Requirements Control Board (PRCB) action authorizes assessment of potential TPS modifications for Orbiter hardening. As part of this action, NASA is defining candidate redesigns that will reduce impact damage risk to vulnerable TPS areas and is also developing an assessment plan for other steps to improve Orbiter hardening.

In March 2003, a planning team integrated concepts for Orbiter hardening into the following seven candidate TPS design families: landing gear and External Tank (ET) door TPS and structure; wing leading edge (WLE) subsystem; vehicle carrier panels and attachments; critical area lower surface tile; elevon gap and cove TPS and seals; critical Orbiter maneuvering system pod and vertical tail areas; and nose cap and chin panel subsystem.

Within these seven design families (figure 3.3-2-1), 17 conceptual design candidates were developed in April 2003. These candidates ranged from near-term (one year or less implementation time) with low technical risk to very long-term (greater than three-year implementation time) with high technical risk. NASA directed the planning team to continue working with problem-resolution teams to define study and implementation priorities, with focus on near-term options.

In May 2003, a TPS enhancement Orbiter hardening technical interchange meeting addressed all 17 conceptual design candidates. The results of this meeting were presented to the PRCB in June 2003, including forward

action plan recommendations for the following TPS/WLE enhancement redesign options (listed in order of priority):

- **WLE Redesign**—Options include WLE carrier panel and fastener redesign, spar insulation, and new WLE surface coating materials to provide additional protection against impact and plasma flow vulnerability.
- **Durable Tile**—Complete development of tougher lower surface landing gear door and ET door periphery tiles, elevon leading edge and wing trailing edge carrier panel tiles and window frames, and acreage tile. Also, complete development of ballistic strain isolation pad material.
- **Landing Gear Door and ET Door Redesign**—Options include upgrade of thermal barrier materials to provide better protection against high temperatures, and multiple thermal barrier backup capability to main landing gear doors (MLGDs).
- **Carrier Panel Upgrades to Eliminate Bonded Studs and Elevon Leading Edge Carrier Panel Installation Redesign**—Redesign of carrier panel attachments to eliminate failure mode of structural bonds to ensure positive margins. Redesign access panels to improve protection against impacts and provide additional protection from plasma flow due to impact damage.
- **TPS Instrumentation**—Define additional instrumentation needs, sensor types, and avionics modifications; determine requirements for data trending. Installation of an impact penetration instrumentation system to provide monitoring capability for potential ascent/micrometeoroid and orbital debris impacts.
- **White Toughened Unipiece Fibrous Insulation (TUFI) Tiles**—Lessen impact damage susceptibility of certain upper surface tiles by replacing existing tile with white TUFI tile.
- **Vertical Tail Advanced Flexible Reusable Surface Insulation (AFRSI) High-Emittance Coating**—Add high-emittance coating to existing AFRSI blankets to expand contingency low-alpha reentry trajectory limits.

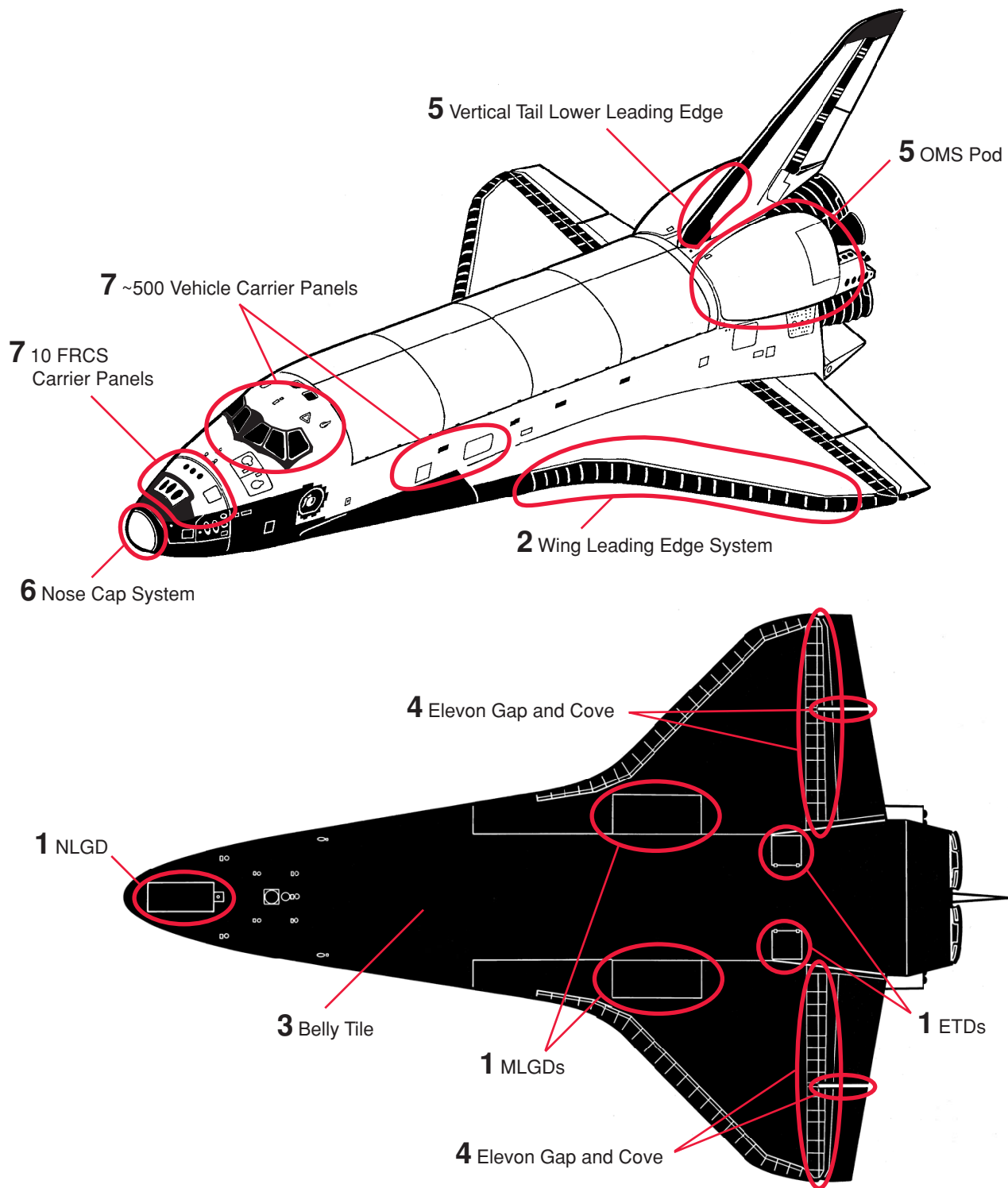


Figure 3.3-2-1. Seven critical TPS families targeted for enhancement.

- Robust Reinforced Carbon-Carbon (RCC) Replacement Study—Apply new technologies to develop a more debris-tolerant material for the nose cap, chin panel, and WLE panels.

The Space Shuttle Program (SSP) has established a plan to determine the impact resistance of both RCC and tiles in their current configurations. The SSP is also working to identify all debris sources from all Space Shuttle elements including the ET, the Solid Rocket Boosters, and the Orbiter. The SSP Systems Engineering and Integration Office is providing transport analyses to identify potential velocity, impact location, and impact angle for the debris sources. In parallel, an impact test program is being conducted to determine the impact resistance of RCC and tile using various debris sources under conditions that encompass the full range of parameters provided by the transport analysis. The data generated from this testing will be used to correlate an accurate set of analytical models to further understand the damage threat. Further testing will be conducted on specific Orbiter insulation configurations that were identified during the investigation, including the leading edge structural subsystem access panels (located directly behind the RCC) and the edge tile configuration of the MLGD.

STATUS

For each of the eight redesign options listed above, NASA is developing detailed feasibility assessments that will include cost and schedule for either full implementation or for the next proposed phase of the project. The Orbiter hardening options have been grouped into three categories based on the implementation phasing. Phase I options will be implemented before return to flight. Phase II includes potential constraints to flight; additional tests and analyses may require some of these options to be moved to Phase I. Phase III consists of the long-term options that will increase the Orbiter's impact resistance capability. The qualification and certification of one Phase III option, tougher lower and upper surface tiles, has been approved by the SSP. This and the other modifications will be implemented as material development is completed and opportunities become available.

Debris sources are being identified, and test plans are being generated for the TPS impact tests. Three full-scale impact tests of RCC were conducted at Southwest Research Institute. The first test used a foam projectile of 0.1 lb. mass at 700 ft/sec (fps), and the second test doubled the kinetic energy of the initial test by using a 0.2 lb. projectile at 700 fps. Neither test resulted in damage to the RCC panel.

The third test again doubled the kinetic energy by using a 0.16 lb. projectile at 1167 fps. This test resulted in multiple through cracks and permanent deflections in the RCC panel.

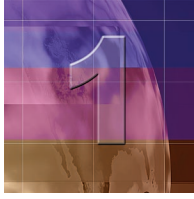
FORWARD WORK

We will continue to implement the plan according to the schedule below. Decision packages for each redesign option will be brought to the PRCB for disposition.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 03 (Complete)	Initial plan reported to PRCB
SSP	Aug 03 (Complete)	Initial Test Readiness Review held for Impact Tests
SSP	Nov 03 (Complete)	Phase I Implementation Plans to PRCB (MLGD corner void, Forward Reaction Control System (FRCS) carrier panel redesign—bonded stud elimination, and WLE impact detection instrumentation)
SSP	Jan 04	Phase II Implementation Plans to PRCB (WLE front spar protection and horse collar redesign, MLGD redundant thermal barrier redesign)
SSP	TBD	Phase III Implementation Plans to PRCB (included robust RCC, ET door thermal barrier redesign, advanced WLE instrumentation, elevon cove leading edge carrier panel redesign, etc.)





Columbia Accident Investigation Board

Recommendation 3.3-1

Develop and implement a comprehensive inspection plan to determine the structural integrity of all Reinforced Carbon-Carbon system components. This inspection plan should take advantage of advanced non-destructive inspection technology. [RTF]

BACKGROUND

Current on-vehicle inspection techniques are determined to be inadequate to assess the structural integrity of Reinforced Carbon-Carbon (RCC) components and attachment hardware. There are two aspects to the problem: (1) how we assess the structural integrity of RCC components and attach hardware throughout their service life, and (2) how we verify that the flight-to-flight RCC mass loss caused by aging does not exceed established criteria. At present, structural integrity is assured by wide design margins; comprehensive nondestructive inspection (NDI) is conducted only at the time of component manufacture. Mass loss is also monitored through a destructive test program that periodically sacrifices flown RCC panels to verify by test that the actual material properties of the panels are within the predictions of the mission life model.

The RCC NDI techniques currently certified include X-ray, ultrasound (wet and dry), eddy current, and computer-aided tomography (CAT) scan. Of these, only eddy current can be done without removing components from the vehicle. While eddy current testing is useful for assessing the health of the RCC outer coating and detecting possible localized subsurface oxidation and mass loss, it reveals little about a component's internal structure. Since the other certified NDI techniques require hardware removal, each presents its own risk of unintended damage. Only the vendor is fully equipped and certified to perform RCC X-ray and ultrasound, even with hardware removed from the Orbiter.

Shuttle Orbiter RCC components are pictured in figure 3.3-1-1.

NASA IMPLEMENTATION

The Space Shuttle Program (SSP) is pursuing inspection capability improvements using newer technologies to allow comprehensive NDI of the RCC without removing it from the vehicle. A technical interchange meeting held in May 2003 included NDI experts from across the

country. This meeting highlighted five techniques with potential for near-term operational deployment: flash thermography, ultrasound (wet and dry), advanced eddy current, shearography, and radiography. The SSP must still assess the suitability of commercially available equipment and standards for flight hardware. Once an appropriate in-place inspection method is fielded, the Program will be able to positively verify the structural integrity of RCC hardware without risking damage by removing the hardware from the vehicle.

NASA is committed to clearing the RCC by certified inspection techniques before return to flight (RTF). The near-term plan calls for removing all RCC components and returning them to the vendor for comprehensive NDI. For the long term, a Shuttle Program Requirements Control Board (PRCB) action was assigned to review inspection criteria and NDI techniques for all Orbiter RCC nose cap, chin panel, and wing leading edge (WLE) system components. Viable NDI candidates were reported to the PRCB in January 2004 and specific options were chosen.

RCC structural integrity and mass loss estimates will be validated by off-vehicle NDI of RCC components. All WLE panels, seals, nose caps, and chin panels will be removed from Orbiter Vehicles (OV)-103, OV-104, and OV-105 and returned to the vendor's Dallas, Texas, facility for comprehensive NDI. Inspections will include a mix of ultrasonic, X-ray, and CAT scan techniques. In addition, NASA has introduced off-vehicle flash thermography for all WLE panels and accessible nose cap and chin panel surfaces; any questionable components will be subjected to CAT scan for further evaluation. Data collected will be used to support development of future in-place NDI techniques.

The health of RCC attach hardware will be assessed using visual inspections and NDI techniques appropriate to the critical flaw sizes inherent in these metallic components. This NDI will be performed on select components from OV-103 and OV-104 with priority given to OV-104. Destructive evaluation of select attach hardware from both vehicles will also be undertaken. Additional requirements

will be established, if necessary, upon completion of initial inspections.

STATUS

Advanced On-Vehicle NDI: Near-term advanced NDI technologies were presented to the PRCB in January 2004. Thermography, contact ultrasonics, eddy current, and radiography were selected as the most promising techniques to be used for on vehicle inspection that could be developed in less than 12 months. The PRCB approved the development of these techniques.

OV-104: The nose cap, chin panel, and all WLE RCC panel assemblies have been removed from the vehicle and shipped to the vendor for complete NDI. Completion of the data analysis from this suite of inspections is planned in March 2004. Inspection of all WLE panels is complete, and completion of the analysis of the final panel is expected in February 2004. Eddy current inspections of the nose cap and chin panel were completed before these components were removed; and the results compare favorably to data collected when the components were manufactured, indicating mass loss and coating degradation are within acceptable limits. Off-vehicle vendor inspection is expected to confirm this assessment.

OV-103: As part of the OV-103 Orbiter maintenance down period (OMDP), WLE panels were removed from the vehicle, inspected by visual and tactile means, and then shipped to the vendor for NDI. The analysis of the inspection results will be completed in May 2004. X-ray inspection of the RCC nose cap, which was already at the vendor for OMM coating refurbishment, revealed a previously undocumented 0.025 in. x 6 in. tubular void in the upper LH expansion seal area. While this discrepancy does not meet manufacturing criteria, it is located in an area of the panel with substantial design margin (900% at end of panel life) and is acceptable for flight. The suite of inspections performed on the OV-103 nose cap has confirmed the Orbiter’s flight worthiness and, to date, revealed nothing that might call into question the structural integrity of any other RCC component.

OV-105: All OV-105 RCC components (WLE, nose cap, and chin panel) will be removed and inspected during its OMDP, which began in July 2003.

RCC Attach Hardware: The RCC Problem Resolution Team was given approval for a plan for attach hardware NDI and destructive evaluation.

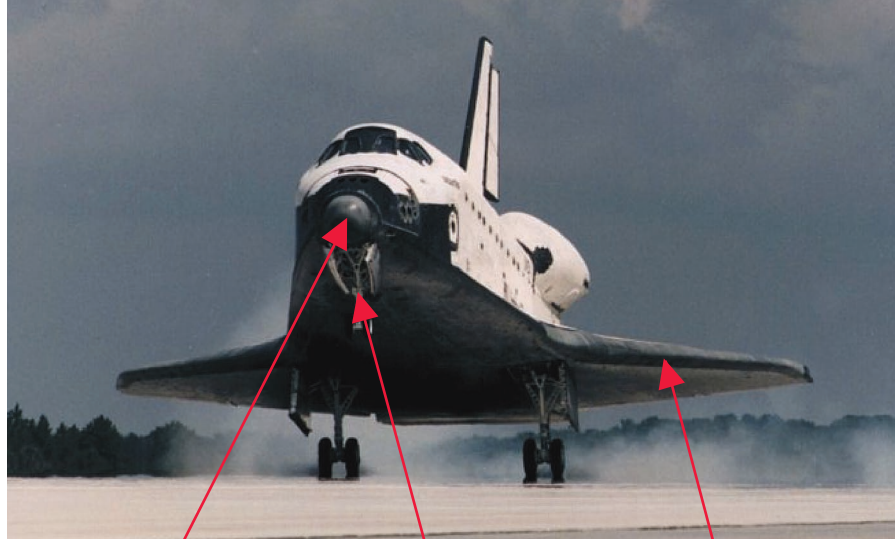
FORWARD WORK

OV-104 RCC system readiness for flight will be based on results of ongoing WLE, nose cap, and chin panel inspections, and NDI.

The near-term advanced on-vehicle NDI techniques are in development, as well as the process and standards for their use. Decisions on long-term NDI techniques (those requiring more than 12 months to develop) will be made after inspection criteria are better established.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Sep 03 (43 of 44 panels complete, last panel complete in Feb 04)	OV-104 WLE RCC NDI analysis complete
SSP	Oct 03 (Complete)	Completion of NDI on OV-104 WLE attach hardware
SSP	Dec 03 (Complete)	OV-103 chin panel NDI
SSP	Jan 04 (Complete)	Report viable on-vehicle NDI candidates to the SSP
SSP	Jan 04 (Complete)	Completion of NDI on OV-103 WLE attach hardware
SSP	Feb 04	OV-103 nose cap NDI analysis complete
SSP	Feb 04	OV-104 chin panel NDI analysis complete
SSP	Mar 04	OV-104 nose cap NDI analysis complete
SSP	May 04	OV-103 WLE RCC NDI analysis complete



Nose Cap,
Chin Panel,
and Seals

Forward External
Tank Attachment
"Arrowhead" Plate

Wing Leading
Edge Panels
and Seals

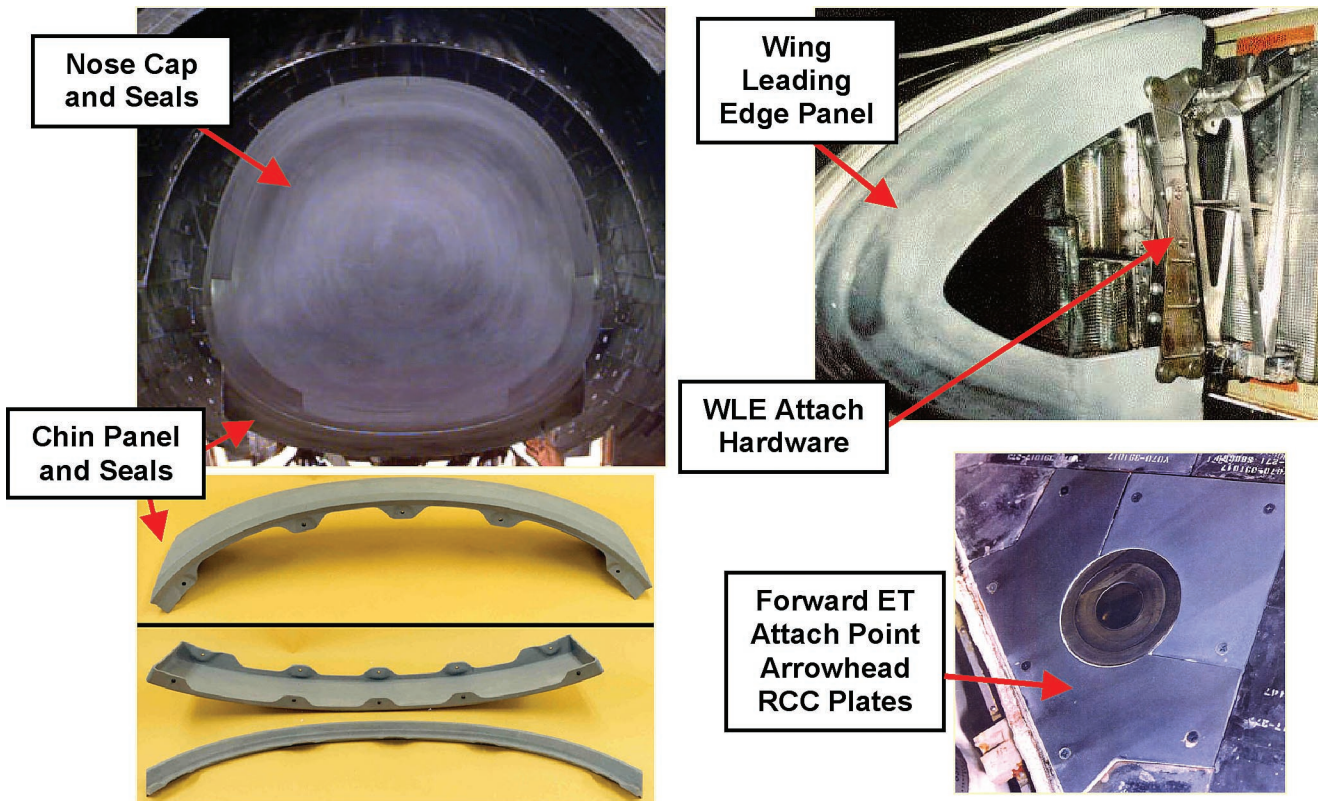
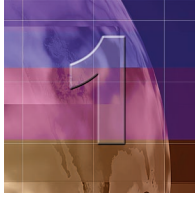


Figure 3.3-1-1. Shuttle Orbiter RCC components.





Columbia Accident Investigation Board

Recommendation 6.4-1

For missions to the International Space Station, develop a practicable capability to inspect and effect emergency repairs to the widest possible range of damage to the Thermal Protection System, including both tile and Reinforced Carbon-Carbon, taking advantage of the additional capabilities available when near to or docked at the International Space Station.

For non-Station missions, develop a comprehensive autonomous (independent of Station) inspection and repair capability to cover the widest possible range of damage scenarios.

Accomplish an on-orbit Thermal Protection System inspection, using appropriate assets and capabilities, early in all missions.

The ultimate objective should be a fully autonomous capability for all missions to address the possibility that an International Space Station mission fails to achieve the correct orbit, fails to dock successfully, or is damaged during or after undocking. [RTF]

BACKGROUND

The Board determined, and NASA concurs, that an on-orbit Thermal Protection System (TPS) inspection and repair capability is an important part of the overall TPS risk mitigation plan.

The ultimate objective is to provide a fully autonomous capability for all missions, both International Space Station (ISS) and non-ISS.

NASA IMPLEMENTATION

NASA's near-term TPS risk mitigation plan calls for Space Shuttle vehicle modifications to eliminate the liberation of critical debris, improved ground- and vehicle-based cameras for debris detection and damage assessment, on-orbit TPS surveys using the Shuttle Remote Manipulator System (SRMS) and Space Station Remote Manipulator System (SSRMS) cameras, and ISS crew observations during Shuttle approach and docking. Techniques for repairing tile and Reinforced Carbon-Carbon (RCC) by extravehicular activity (EVA) are under development. The combination of these capabilities will help to ensure a low probability that critical damage will be sustained, while increasing the probability any damage that does occur can be detected and the consequences mitigated in flight.

NASA's long-term TPS risk mitigation steps will refine and improve all elements of the near-term plan, ensuring an effective inspection and repair capability not reliant upon the ISS is in place in time to support the next Hubble Space Telescope servicing mission.

Damage Inspection Criteria

NASA has defined preliminary critical damage inspection criteria that form the basis for TPS inspection and repair development work. The detailed criteria are evolving based on recent and ongoing tests and analyses. Our goal is to define damage thresholds for all TPS zones below which no repair is required before entry. These criteria are a function of the damage surface dimensions, depth, and entry heating at each location on the vehicle. The preliminary criteria are shown in figure 6.4-1-1.

Inspection and Repair Plan for ISS Missions

TPS Inspection: A combination of the existing Shuttle and ISS cameras can image critical damage in the majority of TPS zones, with some gaps in coverage on the leading edges; NASA is developing the capability to resolve critical TPS damage in all areas. Although current capabilities do not measure damage depth, EVAs can be used in the short term to measure depth in tile damage locations that exceed the surface dimension thresholds. NASA's longer-term goal is to develop a sensor that is capable of measuring damage in three dimensions. In pursuit of this goal, NASA has tested at Kennedy Space Center two lasers flown on previous Shuttle missions and has shown these lasers are capable of building three-dimensional maps of an Orbiter's exterior at the required resolutions.

Because of the low visual and color contrast on the RCC, imagery is not expected to suffice for detecting surface damage and small penetrations in RCC. To overcome this condition, we are investigating using optical filters to highlight low-contrast damage. The scanning laser

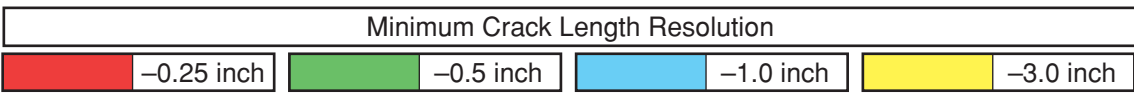
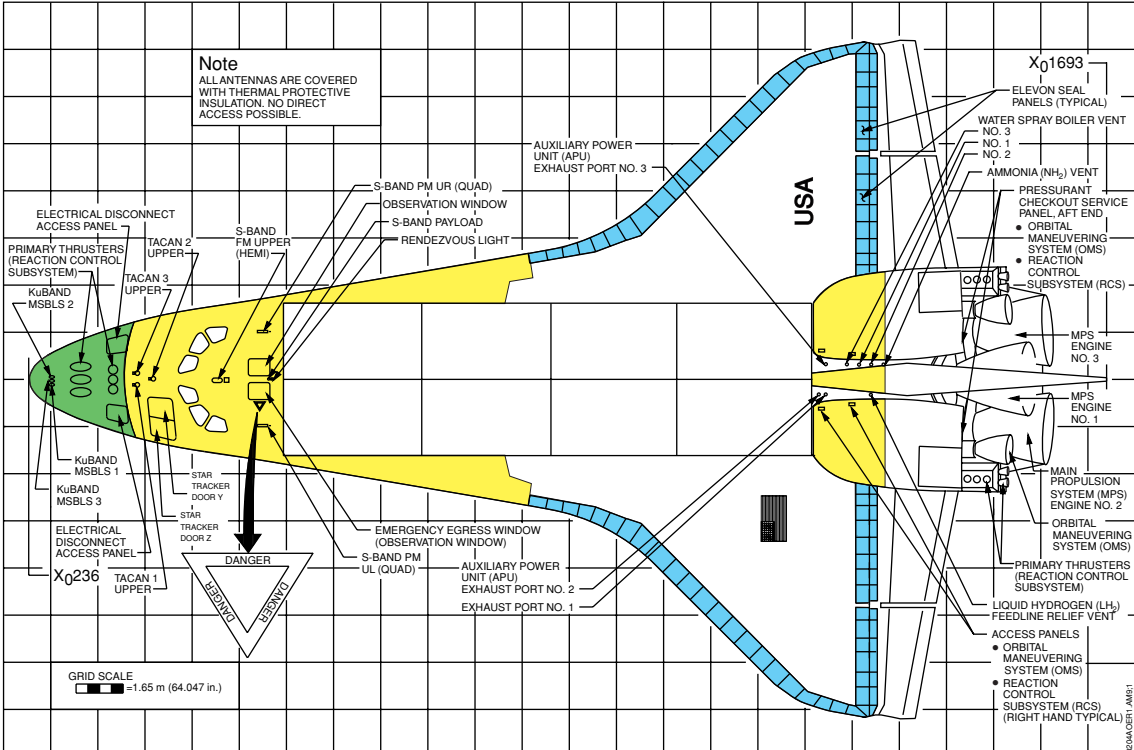
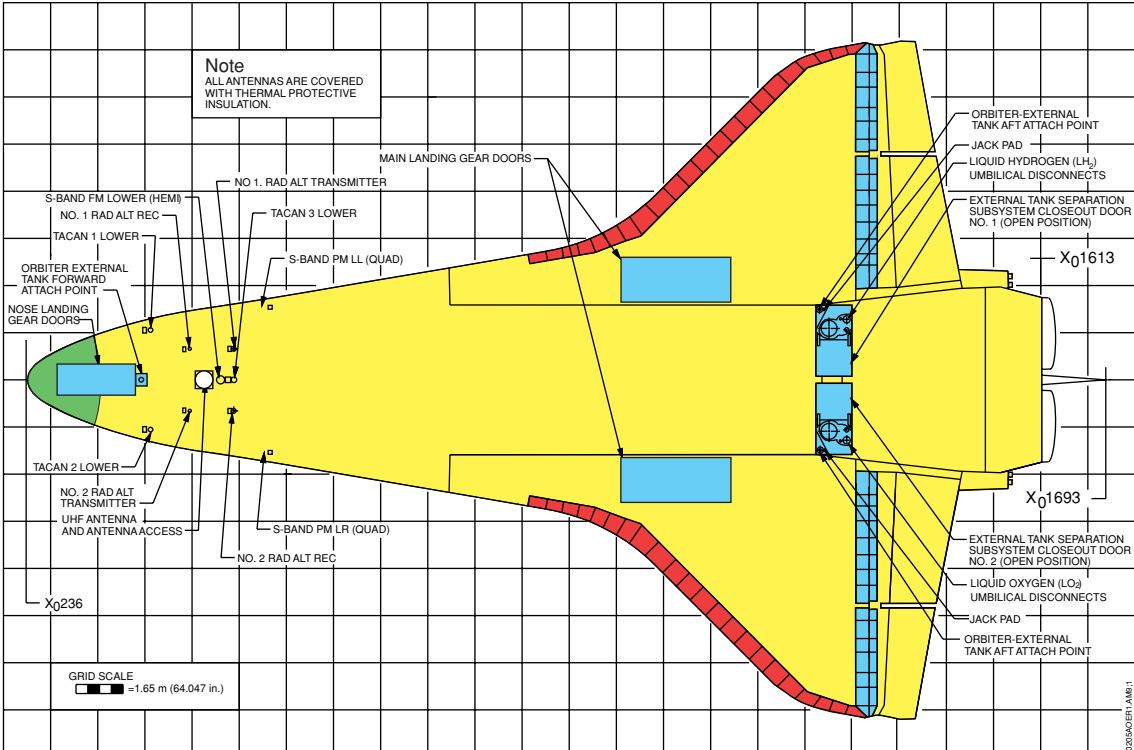


Figure 6.4-1-1. Preliminary TPS damage inspection criteria.

described for depth measurement will also solve this problem.

A comprehensive in-flight inspection, imagery analysis, and damage assessment strategy will be implemented through the existing flight-planning process. The best available cameras and laser sensors suitable for detecting critical damage in each TPS zone will be used in conjunction with digital still photographs taken from ISS during

the Orbiter's approach. The pitch-around maneuver required to facilitate this imagery has been developed and is pictured in figure 6.4-1-2.

EVA Access for Repair: A combined SRMS and SSRMS operation was developed to allow TPS repairs while the Shuttle is docked to the ISS through ISS flight 1J (Japanese Experiment Module). This technique provides access to all TPS surfaces without the need for new equipment. After ISS flight 1J, the ISS grapple fixture required to support this technique will be blocked and an Orbiter stand-alone solution will be used while docked.

As depicted in figure 6.4-1-3, the SRMS grapples the ISS while docked. The docking mechanism hooks are then opened, and the SRMS rotates the Orbiter into a position that presents the lower surface to the ISS. The EVA crew then works from the SSRMS, with the SSRMS essentially used in a "cherry picker" capacity to reach any TPS surface needing repair. After the repair, the SRMS maneuvers the Orbiter back into position and reattaches the Orbiter to the docking mechanism.

Formal procedure development is in work. Most system analyses are complete and have shown this technique to be within specification for all Shuttle and ISS systems.

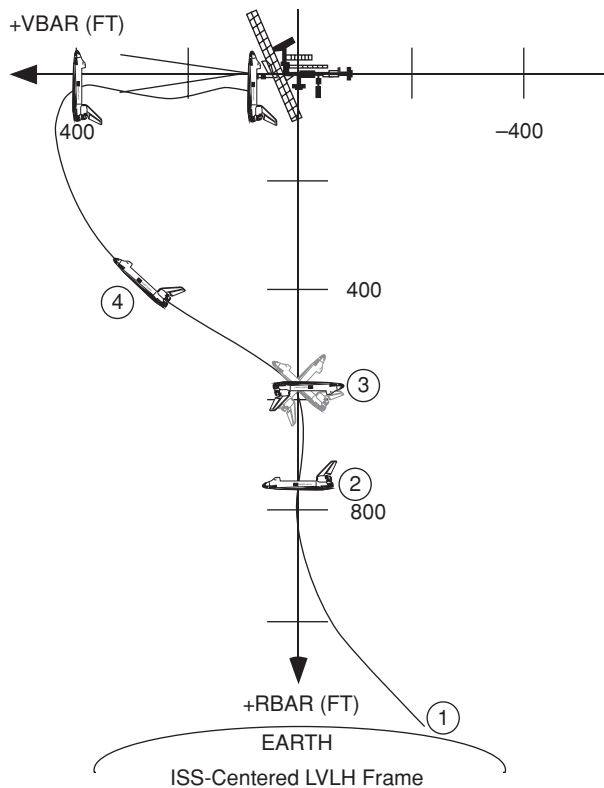
Inspection and Repair Plan for Non-ISS Missions

TPS Inspection: SRMS views are not sufficient to detect critical damage, particularly for the aft, lower surface tiles and most RCC. The solutions described above for detection of tile damage depth and RCC damage will provide a stand-alone, three-dimensional Orbiter inspection capability. A range of SRMS extensions and free-flyer robots is under investigation.

EVA Access for Repair: The SRMS alone cannot provide EVA access to most TPS surfaces for stand-alone repairs. Concepts reviewed that would resolve this deficiency include SRMS extensions, Simplified Aid for EVA Rescue (SAFER) flight, and erectable trusses. The boom concept is in work to provide full inspection capability and will be further developed for use as an EVA platform with access to all TPS surfaces.

Tile Repair Materials

An existing, silicone-based, cure-in-place ablator has shown positive results in development testing. A manufacturing process change appears to control a foaming problem observed during those tests when applying this material



EVENT	
1	1000 FT RANGE RATE GATE (RDOT = -1.3 FPS) TRANSITION TO LOWZ
2	ORBITER ACQUIRES RBAR
3	600 FT (RDOT = -0.1 FPS) BEGIN 1 DEG/SEC POSITIVE PITCH AUTO MNVR: MODE TO FREE DRIFT TO PROTECT ISS FROM ORBITER PLUME LOADS AND CONTAMINATION
	ISS PHOTOGRAPHIC SURVEY OPPORTUNITY FROM U.S. LAB WINDOW
	RESUME ATTITUDE HOLD AS ORBITER RETURNS TO RBAR ATTITUDE AND PILOT BACK TO NOMINAL APPROACH PROFILE
4	TORVA (TWICE ORBITAL RATE RBAR TO VBAR APPROACH)

Figure 6.4-1-2. Orbiter pitch-around for inspection and approach to ISS.

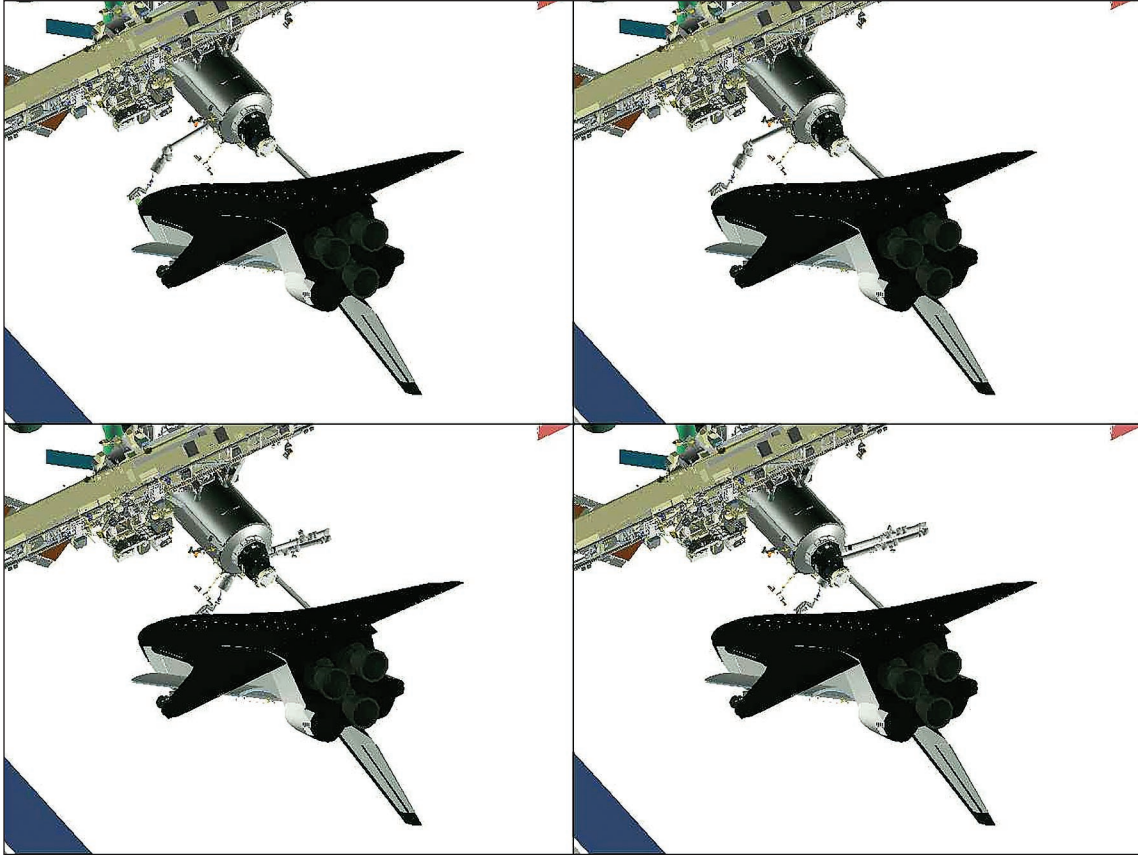


Figure 6.4-1-3. Proposed method for providing EVA access during TPS repair on an ISS flight.

in vacuum. The material adheres to aluminum, primed aluminum, tile, strain isolation pads, and tile adhesive in vacuum and cures in vacuum. Detailed thermal analyses and testing are under way to confirm that this material can be applied and cured in the full range of orbit conditions.

The photos in figure 6.4-1-4 show a test sample of this material before, during, and after an arc jet test run to

2300°F. Additional tests are in work, focusing on the material's performance in tile in the entry environment.

EVA tool and repair techniques based on this material are being developed in parallel with material testing. Additional arc jet, radiant heating, thermal-vacuum, and KC-135 zero-G tests are scheduled to confirm that this material will survive the entry environment when applied using the

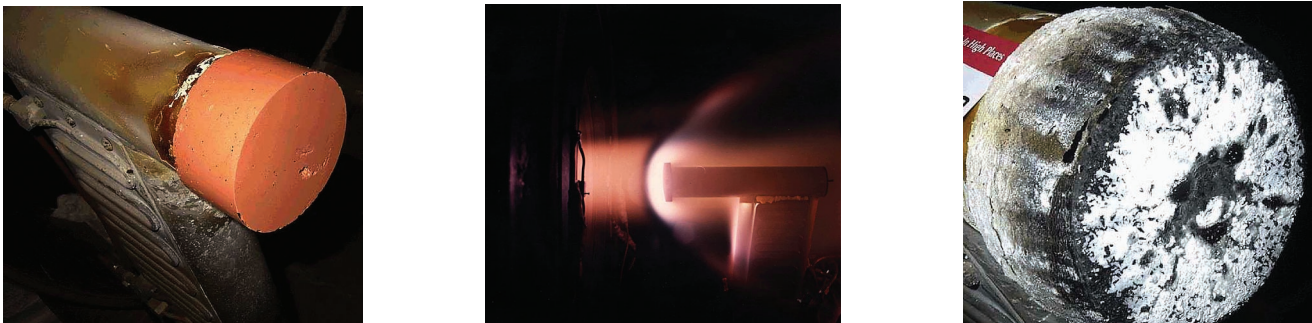


Figure 6.4-1-4. Tile repair material before, during, and after arc jet testing at 2300°F.

proposed repair techniques. This tile repair material has now transitioned to validation testing and certification through the normal certification process used for all Orbiter modifications for flight. Assuming the continued testing of the existing ablator is successful, the tile repair materials and tools should be ready in the December 2003–March 2004 timeframe.

Although other candidate materials have been identified, detailed engineering development of these materials was deferred based on the positive results of the existing ablator.

RCC Repair Materials

This effort is still in the concept definition phase and is much less mature than the tile repair material study. We are evaluating concepts across six NASA centers, 11 contractors, and the United States Air Force Research Laboratory. Although we are aggressively pursuing RCC repair, it is too early in development to forecast a completion date.

The main challenges to repairing RCC are maintaining a bond to the RCC coating during entry heating and meeting very small edge step requirements. The options in work are cure-in-place ablators similar to the tile repair material, variations of patches, sleeves that fit over an entire RCC panel, and filled wings.

RCC test samples are being manufactured with coatings to match Shuttle RCC. These will be damaged to simulate debris impacts at the Johnson Space Center (JSC) and distributed to participating organizations for candidate material and repair technique testing.

STATUS

The following actions have been completed:

- Quantified SRMS, SSRMS, and ISS digital still camera inspection resolution
- Feasibility analyses for docked repair technique using SRMS and SSRMS
- Air-bearing floor test of overall boom to RMS interface

- Simple boom conceptual development
- Engineering assessment for lower surface radio frequency communication during EVA repair
- SAFER technique conceptual development and testing
- Feasibility testing on tile repair material
- Tile repair material transition from concept development to validation tests
- 1-G suited tests on tile repair technique
- Initial KC-135 tile repair technique evaluations

FORWARD WORK

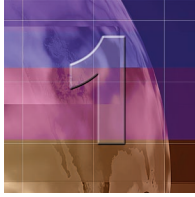
High-level material and concept screening began in September 2003 using facilities at JSC, Ames Research Center, Langley Research Center (LaRC), and Lockheed Martin. We are prepared to use other facilities at LaRC; Marshall Space Flight Center; Glenn Research Center; Lockheed Martin; Boeing; Arnold Engineering Development Center at Arnold Air Force Base, Tennessee; University of Texas; and CIRA PWT in Italy as required to avoid test delays. Candidates that pass the screening tests will then be tested more rigorously for feasibility in entry-like conditions to facilitate down-selection to the preferred solutions. As with the tile repair material, RCC repair material final candidates will then transition to validation testing and certification through the normal engineering process.

The Space Shuttle Program (SSP) has approved for return to flight the implementation (provided it is feasible) of an extension boom grappled by the SRMS with laser sensor and camera packages attached to evaluate any damage to the TPS discovered on orbit.

In addition to planned TPS repair capability, special on-orbit tests are under consideration for STS-114 to further evaluate TPS repair materials, tools, and techniques.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Complete)	1-G suited testing begins on tile repair technique
SSP	Aug 03 (complete)	Generic crew and flight controller training begins on inspection maneuver during approach to ISS
SSP	Aug 03 (Complete)	KC-135 testing of tile repair technique
SSP	Oct 03	Start of RCC repair concept screening tests
SSP	Nov 03	Human thermal-vacuum, end-to-end tile repair tests
SSP	Nov 03	Tile repair material selection
SSP	Dec 03	Baseline ISS flight repair technique and damage criteria
Space Shuttle and ISS Programs	Jan 04	All Shuttle and ISS systems analyses complete for docked repair technique
JSC/Mission Operations Directorate	Feb 04	Formal procedure development complete for inspection and repair
SSP	TBD	Tile repair materials and tools delivery
SSP	TBD	RCC repair material selection



Columbia Accident Investigation Board

Recommendation 3.3-3

To the extent possible, increase the Orbiter's ability to successfully re-enter Earth's atmosphere with minor leading edge structural sub-system damage.

BACKGROUND

The STS-107 accident demonstrated that the Space Shuttle Leading Edge Structural Subsystem (LESS) is vulnerable, and damage to the LESS can cause the loss of the Orbiter. The Space Shuttle Program (SSP) is developing and implementing a comprehensive test and analysis program to redefine the maximum survivable LESS damage for entry. This information will support the requirements for inspection and ultimately the boundaries within which a Thermal Protection System (TPS) repair can be performed. In addition, the SSP is already pursuing LESS improvements that will increase the Orbiter's capability to reenter the Earth's atmosphere with "minor" damage to the LESS. These improvements are only mentioned here, since they are covered in recommendations R3.3-1, R3.3-2, and R6.4-1.

NASA IMPLEMENTATION

NASA will define minor and critical damage using Reinforced Carbon-Carbon (RCC) foam impact tests, arc jet tests, and wind tunnel tests. We will also evaluate existing and contingency flight design options.

We will redefine "minor" damage through an evaluation of the micrometeoroid and orbital debris study results, which defined the allowable quarter-inch and one-inch hole sizes in the wing leading edge panels. Advanced analytical techniques will be used to determine the limiting level of RCC damage that can be successfully flown during entry. A key aspect of the planned work is expanding the existing aero-thermal test database with additional arc jet testing of damaged RCC specimens and additional hypersonic wind tunnel testing. The investigation will also be expanded to include the nose cap and chin panel.

The SSP will evaluate operational adjustments in vehicle or trajectory design within existing certification limits for

reducing thermal effects on the LESS during entry. Possibilities include weight reduction, cold-soaking the Orbiter, lowering the orbit before de-orbit, and trajectory shaping. Additionally, contingency flight design options being considered include expanding entry design constraints and increasing the angle-of-attack profile.

STATUS

In each of the above areas, NASA is developing detailed implementation plans and feasibility assessments.

| A draft of the preliminary RCC damage assessment test and analysis plan was presented to the Orbiter Project Office in September 2003. The goal of this plan is to develop acceptable criteria of damage by considering RCC thermo-chemical response combined with residual strength and damage growth issues. The schedule for this testing will be determined by facility and RCC coupon availability. Evaluation of potential damage caused by micrometeoroid/orbital debris is also being planned. An outcome of this evaluation will be an experimental database, which will be used to develop engineering models and calibration of numerical analysis tools.

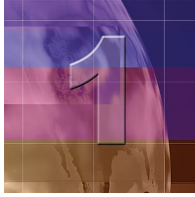
| Potential entry trajectory design adjustments are being considered beginning with STS-107 investigation evaluations.

FORWARD WORK

Additional analysis will be required before incorporating the results of these assessments in flight rules and flight design. Implementation strategies, which are needed to balance the risk of changes in these areas, will be developed as a part of this analysis. Decision packages for studies will be brought to the Program Requirements Control Board.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Dec 03	Vehicle/trajectory design operational adjustment recommendation
SSP	Jun 04	Completion of damaged RCC specimen tests
SSP	Sep 04	Analysis report of maximum RCC damage allowed
SSP	Sep 04	Contingency flight design options recommendation



Columbia Accident Investigation Board

Recommendation 3.3-4

In order to understand the true material characteristics of Reinforced Carbon-Carbon components, develop a comprehensive database of flown Reinforced Carbon-Carbon material characteristics by destructive testing and evaluation.

BACKGROUND

The only material properties data for flown Reinforced Carbon-Carbon (RCC) components is from two panels, both of which were destructively tested by the Shuttle Program (SSP). Both panels were removed from Orbiter Vehicle (OV)-102. One panel, 10 left (10L), was tested after 19 flights and the other panel, 12 right (12R), was tested after 15 flights. The results from these tests were compared to the analytical model and indicated that the model was conservative.

NASA IMPLEMENTATION

An RCC material characterization program is under way using existing flight assets to obtain data on strength, stiffness, stress-strain curves, and fracture properties of RCC for comparison to earlier testing data. The SSP has established a plan to determine the impact resistance of RCC in its current configuration using previously flown panels, those with 26-30 flights. In addition, tension, compression, in-plane shear, interlaminar shear, and high strain rate properties will be developed. Data on the attachment lug mechanical properties, corner mechanical properties, and coating adherence will also be obtained. NASA will maintain a comprehensive database developed with the information from these evaluations and characterization programs.

STATUS

Panel 8L (OV-104 with 26 flights) is being dissected now to provide test articles to several teams performing the analysis of material properties. Panel 6L (OV-103 with 30 flights) will be used to perform thermal and mechanical testing for material susceptibility to crack propagation during the flight envelope. Panels 9L (OV-103 with 27 flights) and 10L (OV-103 with 30 flights) will be used to determine the impact capability of the RCC. Panel 9R (with 30 flights) from OV-103 will be destructively tested, using methods similar to those used on Panels 10L and 12R, to compare its material properties to the analytical model and to add to the database.

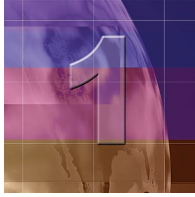
FORWARD WORK

- The study of materials and processes will be central to understanding and cataloging the material properties and their relation to the overall health of the subsystem. Materialography and material characteristics (porosity, coating/substrate composition, etc.) for RCC panels are being evaluated with the objective of correlating mechanical property degradation to microstructural/chemical changes and nondestructive inspection results. Once developed, the database will be used to direct design upgrades, mission/life adjustments, and other critical concerns as long as the leading edge structural subsystem continues to be used. The long-term plan will include additional RCC assets as required to ensure that the database is fully populated (reference R3.8-1).

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Sep 03 (Complete)	Section of Panel 8L test specimens for material property testing
SSP	Sep 03 (Complete)	Panel 9L impact test number 1
SSP	Sep/Oct 03 (Complete)	Material property testing of Panel 8L specimens
SSP	Oct 03 (Complete)	Panel 9L impact test number 2 and 3
SSP	June 04	Panel 9R mission life material properties testing for comparison to the analytical model





Columbia Accident Investigation Board

Recommendation 3.3-5

Improve the maintenance of launch pad structures to minimize the leaching of zinc primer onto Reinforced Carbon-Carbon components.

BACKGROUND

Zinc coating is used on launch pad structures to protect against environmental corrosion. “Craze cracks” in the Reinforced Carbon-Carbon (RCC) panels allow rain water and leached zinc to penetrate the panels and cause pinholes.

NASA IMPLEMENTATION

Before return to flight (RTF), Kennedy Space Center (KSC) will enhance the launch pad structural maintenance program to reduce RCC zinc oxide exposure to prevent zinc-induced pinhole formation in the RCC (figure 3.3-5-1). The enhanced program has four key elements. KSC will

1. Enhance the postlaunch inspection and maintenance of the structural coating system, particularly on the rotating service structure. Exposed zinc primer will be recoated to prevent liberation and rainwater transport of zinc-rich compounds.
2. Assess postlaunch pad structural wash-downs to determine if they can be enhanced to minimize the corrosive effects of acidic residue on the pad structure. This will help prevent corrosion-induced damage to the topcoat and prevent exposure of the zinc primer.
3. Investigate options to improve the physical protection of Orbiter RCC hardware.
4. Implement a sampling program to monitor the effectiveness of efforts to inhibit zinc oxide migration on all areas of the pad structure.

STATUS

NASA is pursuing enhanced inspection, structural maintenance, wash-down, and sampling options to reduce zinc leaching. Changes to applicable work authorization documents are being formulated and will be incorporated before RTF.

NASA is developing options for enhanced physical protection. The options developed will be presented to the Program Requirements Control Board (PRCB) when available.

FORWARD WORK

The RCC Problem Resolution Team will continue to identify and assess potential mechanisms for RCC pinhole formation. Options for enhanced physical protection of RCC will be implemented as soon as they are approved and design is complete.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Dec 03 (Complete)	Complete enhanced inspection, maintenance, wash-down, and sampling plan
SSP	Feb 04	Present to the PRCB options for enhanced physical protection of RCC hardware at the launch pads
SSP	May 04	Incorporate required Work Authorization Document changes

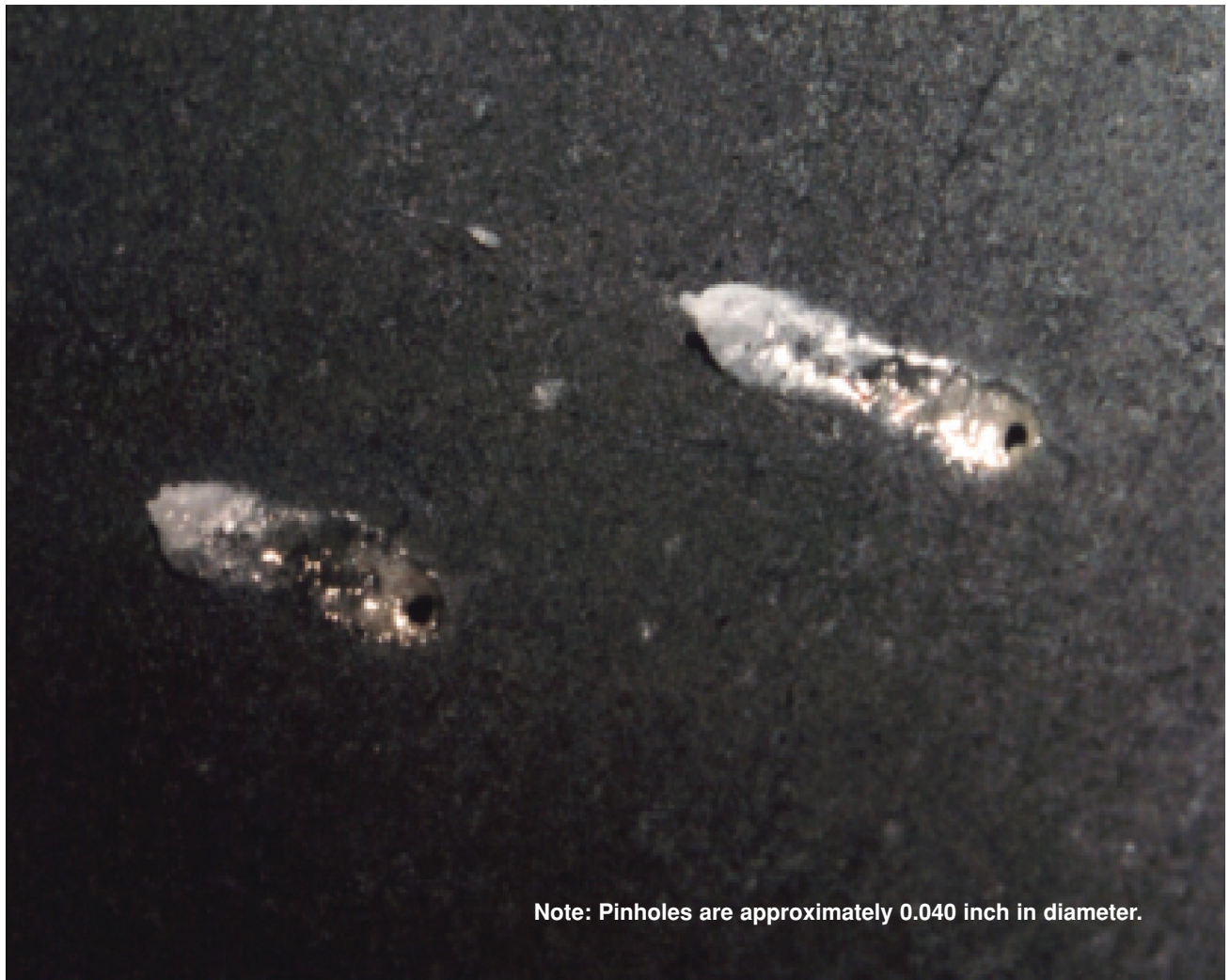
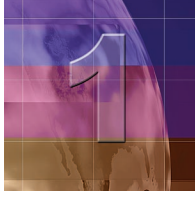


Figure 3.3-5-1. RCC pinholes.



Columbia Accident Investigation Board

Recommendation 3.8-1

Obtain sufficient spare Reinforced Carbon-Carbon panel assemblies and associated support components to ensure that decisions related to Reinforced Carbon-Carbon maintenance are made on the basis of component specifications, free of external pressures relating to schedules, costs, or other considerations.

BACKGROUND

There are 44 wing leading edge (WLE) panels installed on an Orbiter. All of these components are made of Reinforced Carbon-Carbon (RCC). The panels in the hotter areas, panels 6 through 17, have a useful mission life of 50 flights or more. The panels in the cooler areas, panels 1 through 5 and 18 through 22, have longer lives extending as high as 100 flights depending on the specific location. The “hot” panels (6–17) are removed from the vehicle every other Orbiter maintenance down period and are shipped to the original equipment manufacturer, Lockheed Martin, for refurbishment. Because these panels have a long life span, we have determined that a minimum of one spare ship-set is sufficient for flight requirements.

Since few panels have required replacement, few new panels have been produced since the delivery of Orbiter Vehicle (OV)-105. Currently, Lockheed Martin is the only manufacturer of these panels.

NASA IMPLEMENTATION

NASA’s goal is to maintain a minimum of one spare ship-set of RCC WLE panel assemblies. To achieve this goal, four additional panel assemblies are required to have a complete spare ship-set.

- | The last of these panels will be available no later than January 2005.

STATUS

- | The buildup of RCC panels requires the use of carbonized rayon fabric, silicon carbide, tabular alumina, silicon metal, tetraethylorthosilicate [TEOS], Prepreg, and Sermabond 487. In addition to the four panels needed to complete one entire ship-set, there are enough raw materials currently available to build up to four additional ship-sets of RCC panels.

FORWARD WORK

- | The Space Shuttle Program (SSP) is developing a prioritized list of additional spare panels that will be ordered through United Space Alliance after the initial four panels are delivered.

Research is ongoing to determine if there are options for increasing the robustness of the RCC panels. The decision to build RCC panels in addition to those needed to complete the minimum of one ship-set will be delayed until this research is complete.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 03 (Complete)	Authorization to build four panels to complete ship-set
SSP	Jan 05	Delivery of four additional panels
SSP	TBD	Decision on additional space RCC panels (pending SSP decision on RCC enhancements)





Columbia Accident Investigation Board

Recommendation 3.8-2

Develop, validate, and maintain physics-based computer models to evaluate Thermal Protection System damage from debris impacts. These tools should provide realistic and timely estimates of any impact damage from possible debris from any source that may ultimately impact the Orbiter. Establish impact damage thresholds that trigger responsive corrective action, such as on-orbit inspection and repair, when indicated.

BACKGROUND

Foam impact testing, sponsored by the *Columbia* Accident Investigation Board (CAIB), proved that some current engineering analysis capabilities require upgrading and improvement to adequately predict vehicle response during certain events. In particular, the CAIB found that NASA's current impact analysis software tool, Crater, failed to correctly predict the level of damage to the Thermal Protection System (TPS) due to the External Tank foam impact to *Columbia* during STS-107 ascent and contributed to an inadequate debris impact assessment.

NASA IMPLEMENTATION

NASA has already started implementing this recommendation. The Space Shuttle Program (SSP) assigned an action to all Program elements to evaluate the adequacy of all preflight and in-flight engineering analysis tools, including Crater and Bumper. These are just two examples of numerous math models and analysis tools that provide results critical to the determination of mission safety and success.

The SSP elements will investigate the adequacy of existing analysis tools to ensure limitations or constraints on use are defined and documented, and formal configuration management control is maintained. Additionally, tools that are used less frequently, primarily those used to clear mission anomalies, will undergo a more detailed assessment that includes a review of the requirements and verification activities. Results of these element reviews will be briefed in detail at the SSP Integration Control Board (ICB) prior to briefing the specific findings and recommendations to the SSP Manager at the Program Requirements Control Board (PRCB). From these efforts, NASA will have a set of validated physics-based computer models for assessing items like damage from debris impacts.

STATUS

The SSP is currently working with the Boeing Company, Southwest Research Institute, Glenn Research Center, Langley Research Center, Johnson Space Center (JSC) Engineering Directorate, and other organizations to develop and validate potential replacement tools for Crater. Each model offers unique strengths and promises significant improvements beyond the current analysis capability.

An integrated analysis and testing approach is being used for development of the tools for Reinforced Carbon-Carbon (RCC) components. The analysis is based on comprehensive dynamic impact modeling. Testing will be performed on RCC coupons, subcomponents, and wing leading edge panels to provide basic inputs to and validation of these models. Testing to characterize various debris materials will be performed as part of model development. An extensive TPS tile impact testing program will be performed to increase this knowledge base. A hydrocode-type model will be correlated to the database and available for analysis beyond the testing database.

In parallel with the model development and its supporting testing, an integrated analysis is being developed involving debris source identification, transport, and impact damage, and resulting vehicle temperatures and margins. This integrated analysis will be used to establish impact damage thresholds that the Orbiter can safely withstand without requiring on-orbit repair. Insight from this work will be used to identify Shuttle modifications (e.g., TPS hardening, trajectory changes) to eliminate unsafe conditions. In addition, this information will be used as part of the on-orbit repair work, identifying potential types of damage and allowing a risk/benefit trade among return, repair, and rescue.

During future Shuttle missions requiring real-time impact analysis, we anticipate that a suite of models offering a range of predictive accuracies balanced against computer run times will be available for use. Relatively quick analyses with conservative assumptions may be used for initial analysis. This analysis will be augmented with longer-run, more specific models that will provide more detailed results.

FORWARD WORK

All SSP elements presented initial findings and a plan for completing their assessments to the ICB in July, and are

presently evaluating the adequacy of their math models and tools. We will assess the adequacy of Bumper (reference R4.2-4) to perform risk management associated with micrometeoroid and orbital debris (MMOD). We will verify and validate this model to ensure that key components (e.g., debris environment, model assumptions, algorithms, vehicle failure criteria, magnitude of uncertainties) assessments are based on the best available technical data.

Foam impact tests will provide empirical data that will be inserted into the analytical models to define the limits of the models' applicability.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Complete)	Report math models and tools assessment initial findings and plans to ICB and PRCB
SSP	Sep 03 (Complete)	Integrated plan for debris transport, impact assessment, and TPS damage modeling
SSP	Aug 03 – Mar 04	Report math models and tools assessment final findings and recommendations to ICB and PRCB
SSP	Dec 03	Reverification/validation of MMOD risk models
SSP	Mar 04	TPS impact testing and model development
SSP	Apr 04	Verification/validation of new impact analysis tools



Columbia Accident Investigation Board

Recommendation 3.4-1

Upgrade the imaging system to be capable of providing a minimum of three useful views of the Space Shuttle from liftoff to at least Solid Rocket Booster separation, along any expected ascent azimuth. The operational status of these assets should be included in the Launch Commit Criteria for future launches. Consider using ships or aircraft to provide additional views of the Shuttle during ascent. [RTF]

BACKGROUND

NASA has decided to develop an integrated suite of improved imagery capabilities that will serve the Space Shuttle through launch, on-orbit operations, and landing. This will allow us to take advantage of the combination of these capabilities to expeditiously address any problems identified over the course of a mission. Our response to each of the *Columbia* Accident Investigation Board imagery recommendations will be a component of the larger integrated system.

The combination of assets to be held as constraints to launch is under review, but the selection criteria will ensure damage detection and improved engineering assessment capability. The integrated system will include, but is not limited to

- Ground-based ascent imagery
- Aircraft and ship-based ascent imagery
- On-vehicle (External Tank (ET), Solid Rocket Booster (SRB)) ascent imagery
- Orbiter umbilical well imagery of ET separation
- Shuttle crew handheld still and video imagery of the separated ET
- Shuttle remote manipulator system cameras
- Space Station remote manipulator system cameras
- Imagery from ISS during the Orbiter's approach and docking
- Extravehicular activity inspection imagery using wireless video system

Evaluation of the STS-107 ascent debris impact was hampered by the lack of high-resolution, high-speed cameras. The current tracking camera assets at the Kennedy Space Center (KSC) (figure 3.4-1-1) and on the Air Force Eastern Range will be improved to provide the



Figure 3.4-1-1. KSC long-range tracker.

best possible engineering data during Shuttle ascent. For all future launches, NASA will provide the capability for three complementary views of the Shuttle that will allow us to pinpoint the location of any potential damage.

Ground cameras provide visual data suitable for detailed analysis of vehicle performance and configuration from prelaunch through SRB separation. Images can be used to assess debris shed in flight, including origin, size, and trajectory. In addition to providing information about debris, the images will provide detailed information on Shuttle systems used for trend analysis that will allow us to further improve the Shuttle.

NASA and the U.S. Air Force are improving ground assets for viewing launch activities. These evaluations include various still and motion imagery capabilities, the best location for each camera, day versus night coverage, and minimum weather requirements.

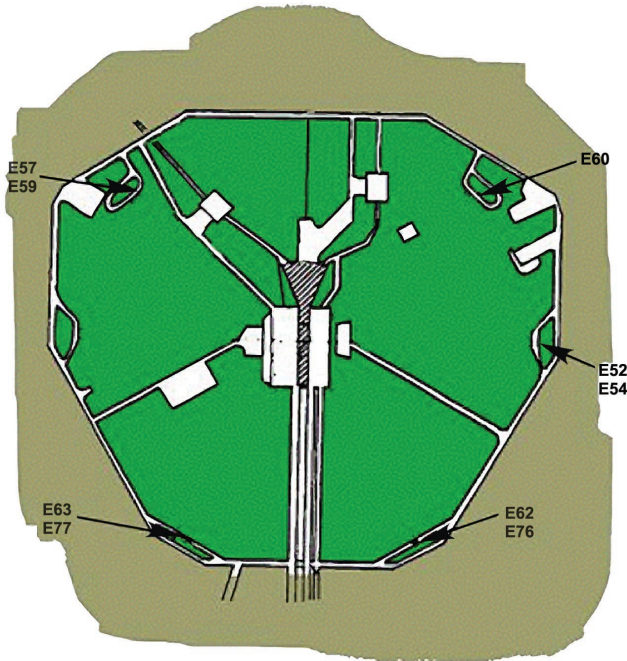


Figure 3.4-1-2. Short-range camera sites.

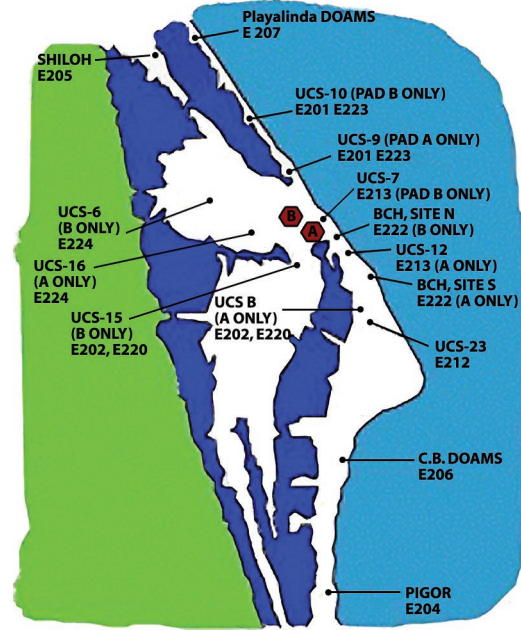


Figure 3.4-1-3. Medium- and long-range tracker sites.

NASA IMPLEMENTATION

To ensure that we can obtain three useful views of the Shuttle vehicle during ascent, for the time being NASA will launch in daylight at a time of day in which sufficient lighting for the ET separation is provided. This will maximize imagery capability for engineering assessment of the ET modifications.

Obtaining three useful views in the dynamic imaging environment from liftoff through SRB separation requires dividing this time into three overlapping periods:

- Short-range images (T-10 seconds through T+57 seconds)
- Medium-range images (T-7 seconds through T+100 seconds)
- Long-range trackers (T-7 or vehicle acquisition through T+165 seconds)

These time periods provide for steps in lens focal lengths to improve image resolution as the vehicle moves away from each camera location. Some cameras are at fixed locations, and other cameras are mounted on mobile

trackers. NASA and the U.S. Air Force will optimize the camera configuration for each flight. We will evaluate the location of the cameras to ensure that the images provide the necessary resolution and coverage to support our analysis requirements.

The locations at Launch Complex 39-B for short-range tracking cameras are as shown in figure 3.4-1-2. The locations for medium-range and long-range cameras are shown in figure 3.4-1-3. Existing cameras will be moved, modernized, and augmented to comply with new requirements.

STATUS

NASA is procuring additional cameras to provide increased redundancy and refurbishing existing cameras. For instance, the optics for the Cocoa Beach, Florida, camera (the "fuzzy camera" on STS-107) have been returned to the vendor for repair. Additional locations for the cameras are under evaluation. Additional operator training will be provided to improve tracking, especially in difficult weather conditions.

FORWARD WORK

NASA is evaluating current and new camera locations, improving optics, upgrading tracking capabilities, and adjusting camera settings.

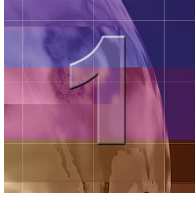
The Space Shuttle Program (SSP) will address hardware upgrades, operator training, and quality assurance of ground-based cameras per the integrated imagery requirements assessment.

NASA will develop appropriate launch commit criteria and pre-countdown camera operability checks. The launch commit criteria must be carefully chosen considering risk and safety of flight concerns because the cameras begin to function less than ten seconds before launch—after the two propellant tanks are pressurized, the auxiliary power units are activated, and just as the Shuttle’s main engines are starting.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Dec 03 (Complete)	Refurbish 14 existing trackers
SSP	Mar 04	Acquire new optics and cameras
SSP	Mar 04	Baseline revised Launch Commit Criteria
SSP	Oct 04	Evaluate and recommend additional camera locations
SSP	Nov 04	Acquire seven additional trackers, optics, cameras, and spares for all systems
SSP	Oct 05	Install remote control capability
SSP	Oct 05	Report options for upgrading timing distribution system
SSP	Oct 06	Investigate options and select optimum configuration for advanced tracking technologies





Columbia Accident Investigation Board

Recommendation 3.4-2

Provide a capability to obtain and downlink high-resolution images of the External Tank after it separates. [RTF]

BACKGROUND

The Shuttle currently has two on-board cameras that photograph the External Tank (ET) after separation; however, the images from these cameras are available only postflight and are not downlinked to the Mission Control Center (MCC) during the mission. Therefore, no real-time imaging of the ET is currently available to provide engineering insight into potential debris during the mission.

NASA IMPLEMENTATION

To provide the capability to downlink images of the ET after separation to the MCC in Houston, NASA is assessing options for modifying the cameras in the Orbiter umbilical well. These images may be downlinked in real time or shortly after safe orbit is achieved, depending on which option is selected. Beginning with STS-114 and until these modifications are complete, the flight crew will use handheld digital still imagery to document the ET separation and downlink the images to the MCC.

STATUS

NASA is enhancing our ability to downlink images of the separating ET. This capability will be in place in time to support return to flight.

FORWARD WORK

NASA will select an option to downlink the images from the Shuttle's umbilical well cameras to the MCC and pursue expanding our downlink capabilities to include all Shuttle missions at all orbital inclinations. We will research options to improve camera resolution, functionality in reduced light conditions, and alternate camera mounting configurations.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Sep 03 (Complete)	Initiate Orbiter umbilical well feasibility study
SSP	Nov 03	Complete preliminary design review/critical design review on approved hardware
SSP	May 04	Begin Orbiter umbilical well installations





Columbia Accident Investigation Board

Recommendation 3.4-3

Provide a capability to obtain and downlink high-resolution images of the underside of the Orbiter wing leading edge and forward section of both wings' Thermal Protection System. [RTF]

BACKGROUND

The damage to the left wing of *Columbia* occurred shortly after liftoff, but went undetected for the entire mission. Although there was ground photographic evidence of debris impact, we were unaware of the extent of the damage. Therefore, NASA is adding on-vehicle cameras that will help us to detect and assess damage.

NASA IMPLEMENTATION

To meet the requirement to assess the health and status of the Orbiter Thermal Protection System (TPS), NASA will rely primarily on on-orbit inspections which will be augmented by on-vehicle ascent cameras. On-orbit inspections will provide better imagery resolution than on-vehicle cameras. On flight day two of STS-114, the Shuttle crew will perform the first inspection of the wing leading edge (WLE) and nose cap Reinforced Carbon Carbon (RCC) using cameras and laser sensors. These sensors will be mounted on the end of a 50-foot extension boom which will be carried in the Shuttle payload bay and grappled by the Shuttle's robotic arm. The extension boom, which is currently under development, will allow the crew to view the WLE and nose cap RCC. The ISS crew will perform a subsequent inspection of Shuttle tile by taking digital photos of the Shuttle during rendezvous as it performs a rotation maneuver about 600 feet from the ISS. Both sets of high-resolution imagery will be downlinked to the ground for evaluation. On-orbit inspection techniques are discussed in detail in our response to R6.4-1.

In addition to the primary on-orbit inspection techniques, NASA will use a suite of cameras in various locations on the Space Shuttle. These cameras will supplement ground-based imagery until Solid Rocket Booster (SRB) separation and provide the primary views through External Tank (ET) separation. Before return to flight, a camera with downlink capability will be added to the ET to view the bipod area and Orbiter lower tile acreage. In addition, cameras are installed on each SRB to view the ET intertank area. In the

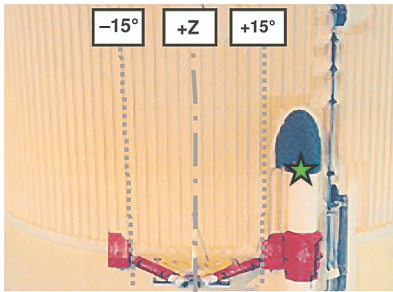
future, as new technologies become available, NASA will evaluate the capability of on-vehicle cameras to assess total impact damage.

STATUS

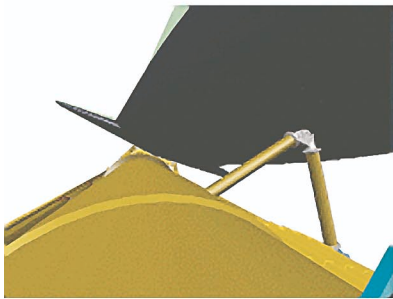
The advantages and disadvantages of externally mounted camera options on the ET and SRBs were presented to the Program Requirements Control Board (PRCB) on July 24, 2003. The approved configuration for STS-114 (figure 3.4-3-1) includes cameras mounted on the (1) ET liquid oxygen (LO₂) feedline fairing location and (2) SRB forward skirt location.

Furthermore, NASA has approved design and installation of additional and better cameras on the ET and SRBs for the earliest possible implementation (figures 3.4-3-2 and 3.4-3-3). These configurations widen the scope and improve the resolution of the available imagery. This will improve coverage of the Orbiter wing leading edge and forward section of both wings' TPS. In addition, the planned system will provide imagery of the tiles on the majority of the underside of the Orbiter, which includes critical landing gear door and umbilical door areas. Ongoing analyses will define other options for additional or alternative camera placements, newer imagery capabilities, and a wider range of lighting conditions.

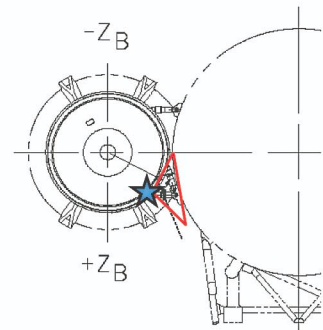
ET Mounted Camera



★ = Image for location (STS-114)



SRB Mounted Cameras

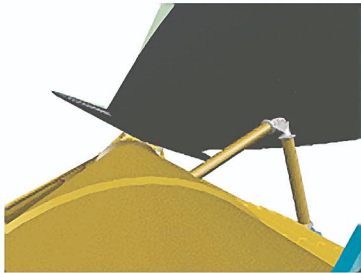


★ = Image for location (STS-114)



Figure 3.4-3-1. ET flight cameras (STS-114 configuration).

ET Mounted Camera



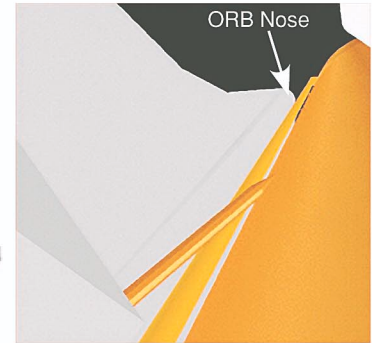
★ = Image for location (STS-115)

SRB Mounted Cameras



★ = Image for location (STS-115)

SRB Mounted Cameras (new)



★ = Image for location (STS-115)

View from RH ETAR;
Boeing model
80 field of view

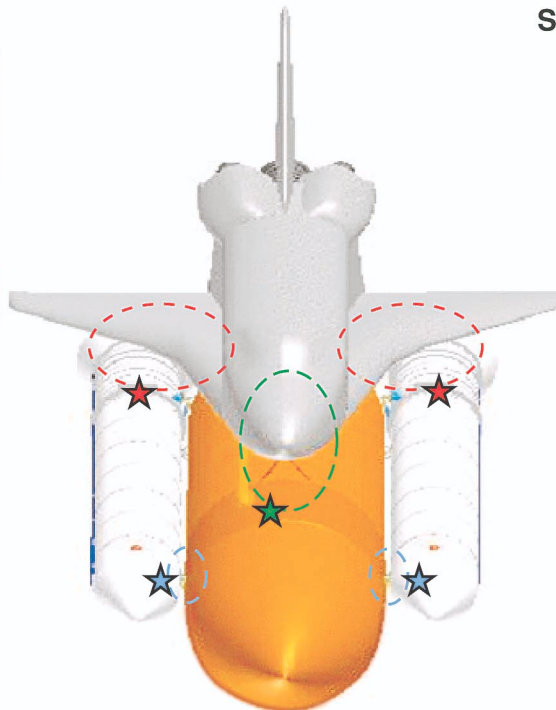
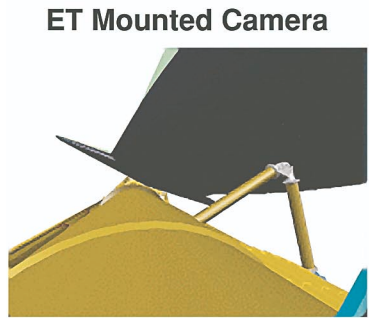
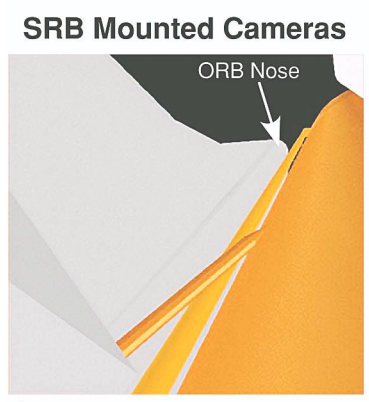


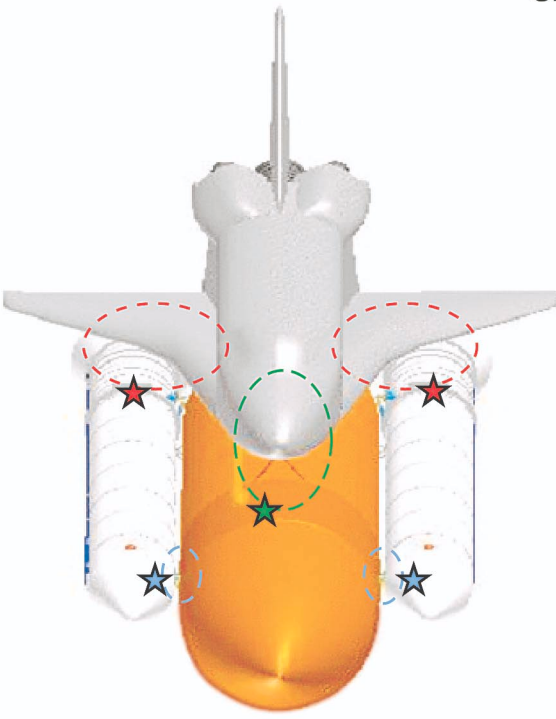
Figure 3.4-3-2. ET flight cameras (TBD configuration).



★ = Image for location (STS-116)

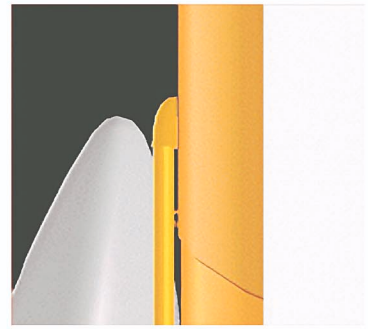


★ = Image for location (STS-116)



SRB Mounted Cameras (new)

exact location & field of view TBD



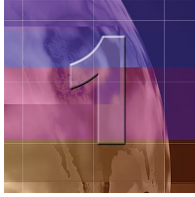
OR



Figure 3.4-3-3. ET flight cameras (TBD configuration).

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	May 03 (Completed)	Start ET hardware modifications
SSP	Jul 03 (Completed)	Authority to proceed with ET LO ₂ feedline and SRB forward skirt locations
SSP	Aug 03 (Completed)	Start SRB hardware modifications
SSP	Sep 03 (Ongoing)	Begin SRB Forward Skirt Camera Installation
SSP	Oct 03	Systems Requirements Review
SSP	Nov 03	Implementation Approval for ET Camera
SSP	Dec 03	Begin ET camera installations
SSP	Jan 04	Review SRB Camera Enhancements for Mission Effectivity



Columbia Accident Investigation Board

Recommendation 6.3-2

Modify the Memorandum of Agreement with the National Imagery and Mapping Agency (NIMA) to make the imaging of each Shuttle flight while on orbit a standard requirement. [RTF]

BACKGROUND

The Board found, and NASA concurs, that the full capabilities of the United States to assess the condition of the *Columbia* during STS-107 should have been used but were not.

NASA IMPLEMENTATION

NASA has already concluded a Memorandum of Agreement with the National Imagery and Mapping Agency that provides for on-orbit assessment of the condition of each Orbiter vehicle as a standard requirement. In addition, NASA has initiated discussions across the interagency community to explore the use of appropriate national assets to evaluate the condition of the Orbiter vehicle.

Since this action may involve receipt and handling of classified information, the appropriate security safeguards will be observed during its implementation.

NASA has determined which positions/personnel will require access to data obtained from external sources. NASA will ensure that all personnel are familiar with the general capabilities available for on-orbit assessment and that the appropriate personnel are familiar with the means to gain access to that information.

FORWARD WORK

- NASA has already begun the process to obtain all required clearances.
- The operational teams will develop standard operating procedures to implement any agreements with the appropriate government agencies at the Headquarters level.

SCHEDULE

An internal NASA process is being used to track clearances and training of personnel.





Columbia Accident Investigation Board

Recommendation 3.6-1

The Modular Auxiliary Data System instrumentation and sensor suite on each Orbiter should be maintained and updated to include current sensor and data acquisition technologies.

BACKGROUND

The Modular Auxiliary Data System (MADS), which is also referred to in the CAIB Report as the “OEX recorder,” is a platform for collecting engineering performance data. The MADS records data that provide the engineering community with information on the environment experienced by the Orbiter during ascent and entry, and with information on how the structures and systems responded to this environment. The repair and/or upgrade of sensors has not been a formal Program requirement because MADS was intended to be only a supplemental package, not used for flight critical decisions. This lack of formal requirements will be reassessed.

The MADS hardware is 1970s technology and is difficult to maintain. NASA has recognized the problem with its sustainability for some time. The available instrumentation hardware assets can only support the existing sensor suite in each Orbiter. If any additional sensors are required, their associated hardware must be procured.

NASA IMPLEMENTATION

The Space Shuttle Program (SSP) agrees that MADS needs to be maintained until a replacement system is developed and implemented (reference 3.6-2). The Instrumentation Problem Resolution Team (PRT) will be reviewing sensor requirements for various Orbiter systems to determine appropriate action for sensors. The PRT will also ensure proper maintenance of the current MADS hardware.

STATUS

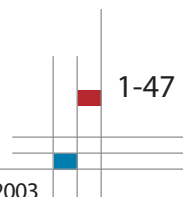
NASA has acquired MADS wideband instrumentation tape and certified it for flight. This will extend the operational availability of the MADS recorder. NASA has also extended the recorder maintenance and skills retention contract with the MADS vendor, Sypris. The MADS avionics sustaining engineering contracts are in place.

FORWARD WORK

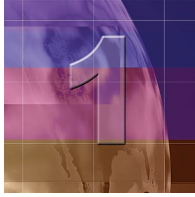
The SSP will maintain the current MADS, including flight hardware and ground support equipment and sensor and data acquisition components, until a replacement system is operational. Upgrades to the current system and additional sensor requirements are covered under the vehicle health monitoring system project (reference R3.6-2) as part of the Shuttle Service Life Extension activities. Implementation proposals will be brought to the Shuttle Program Requirements Control Board for approval.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	TBD	TBD







Columbia Accident Investigation Board

Recommendation 3.6-2

The Modular Auxiliary Data System should be redesigned to include engineering performance and vehicle health information and have the ability to be reconfigured during flight in order to allow certain data to be recorded, telemetered, or both, as needs change.

BACKGROUND

The Modular Auxiliary Data System (MADS)* provides limited engineering performance and vehicle health information postflight—not during the mission. There are two aspects to this recommendation: (1) redesign for additional sensor information, and (2) redesign to provide the ability to select certain data to be recorded and/or telemetered to the ground during the mission. To meet these two recommendations, a new system must be developed to replace MADS. The evaluation of this replacement is currently in progress to address system obsolescence issues and also provide additional capability.

Requirements are being baselined for the Vehicle Health Monitoring System (VHMS), which is being developed to replace the existing MADS with an all-digital industry standard instrumentation system. VHMS will provide increased capability to enable easier sensor addition that will lead to significant improvements in monitoring vehicle health.

NASA IMPLEMENTATION

The VHMS project will provide the capability to collect, condition, sample, time-tag, and store all sensor data. The collected data can be downlinked to the ground during flight operations and downloaded from the vehicle for use by ground operations. VHMS will provide an easy growth path for additional sensor data and other instrumentation systems.

STATUS

The VHMS project is in pre-formulation phase, nearing the completion of the Program Requirements Review (PRR). The Systems Requirements Document (SRD) is currently being developed and will include requirements that address this recommendation.

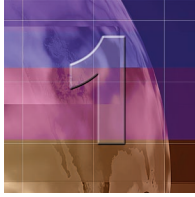
FORWARD WORK

The Space Shuttle Program (SSP) will continue development of the VHMS project requirements and obtain authority to proceed for implementation.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03	PRR held
SSP	Oct 03	Program Requirements Document baselined at Space Shuttle Upgrades Program Requirements Control Board
SSP	Dec 03	SRD baselined

*Note that the *Columbia* Accident Investigation Board Report alternately refers to this as the OEX Recorder.



Columbia Accident Investigation Board

Recommendation 4.2-2

As part of the Shuttle Service Life Extension Program and potential 40-year service life, develop a state-of-the-art means to inspect all Orbiter wiring, including that which is inaccessible.

BACKGROUND

A significant amount of Orbiter wiring is insulated with Kapton, a polymer film used as electrical insulation. Kapton insulated wire has many advantages; however, several disadvantages have been identified. As a result, Space Shuttle Program (SSP) has had Kapton wiring concerns that have been, and continue to be, addressed. Extensive multifaceted remedial and corrective actions have been implemented across the Orbiter fleet to address Kapton wiring concerns.

While technology-based wire damage identification techniques are available to the Orbiter workforce, the most effective method used to date has been visual inspection. Techniques such as Hipot, a high-potential dielectric verification test, and time domain reflectometry (TDR), a test that identifies changes in the impedance between conductors, are rarely effective for detecting damage that does not expose the conductor or where a subtle impedance change is present. Neither is an effective method for detecting subtle damage to wiring insulation. While current technologies may be relatively ineffective in detecting subtle wire damage, we recognize that visual inspection in all areas is impractical. The Orbiters contain some wire runs, such as those installed beneath the crew module, that are completely inaccessible to inspectors during routine ground processing. Even where wire is installed in accessible areas, not every wire segment is available for inspection due to bundling and routing techniques.

NASA IMPLEMENTATION

NASA is continuing the assessment and establishment of state-of-the-art wire integrity techniques. A TDR derivative, the proposed Hybrid Reflectometer, is being investigated by an Ames Research Center team. The Hybrid Reflectometer is based on technology that could make current TDR technology more sensitive to subtle wire discrepancies.

Current military and civilian aircraft are being used beyond their original design lives. As a result, continual research is conducted to safely extend the life of these aircraft and their systems. In addition to NASA activity, we will leverage the efforts of industry, military, and other governmental agencies to find the means most effective to address these concerns.

Synergies are also being sought with non-aircraft industries. National research centers are seeking methods of establishing the integrity of wiring applications in both nuclear power and weapons industries. Scrutinizing the findings and results of this research may prove invaluable to NASA.

STATUS

NASA is collaborating with industry and other government agencies to find the most effective means to address these concerns. NASA is creating a roadmap for developing a state-of-the-art Shuttle wire inspection capability.

FORWARD WORK

NASA will continue to seek solutions to this difficult technical issue.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Ongoing	Present recommendations to PRCB





Columbia Accident Investigation Board

Recommendation 4.2-1

Test and qualify the flight hardware bolt catchers. [RTF]

BACKGROUND

The External Tank (ET) is attached to the Solid Rocket Boosters (SRBs) at the forward skirt thrust fitting by the forward separation bolt. The pyrotechnic bolt is actuated at SRB separation by fracturing the bolt in half at a predetermined groove, releasing the SRBs from the ET thrust fittings. The bolt catcher attached to the ET fitting retains the forward half of the separation bolt. The other half of the separation bolt is retained within a cavity in the forward skirt thrust post (figure 4.2-1-1).

The STS-107 bolt catcher design consisted of an aluminum dome welded to a machined aluminum base bolted to both the left- and right-hand ET fittings. The inside of the bolt catcher was filled with a honeycomb energy absorber to decelerate the ET half of the separation bolt (figure 4.2-1-2).

Static and dynamic testing demonstrated that the manufactured lot of bolt catchers that flew on STS-107 had a factor of safety of approximately 1. The factor of safety for the bolt catcher assembly should be 1.4.

NASA IMPLEMENTATION

The new bolt catcher assembly and related hardware will be designed and qualified by testing as a complete system to demonstrate compliance with factor-of-safety requirements. The bolt catcher housing will be fabricated from a single piece of aluminum forging (figure 4.2-1-3) that removes the weld from the original design (figure 4.2-1-4). Further, a new energy-absorbing material will also be selected; the thermal protection material is being reassessed (figure 4.2-1-5); and the ET attachment bolts and inserts (figure 4.2-1-6) are being redesigned and resized.

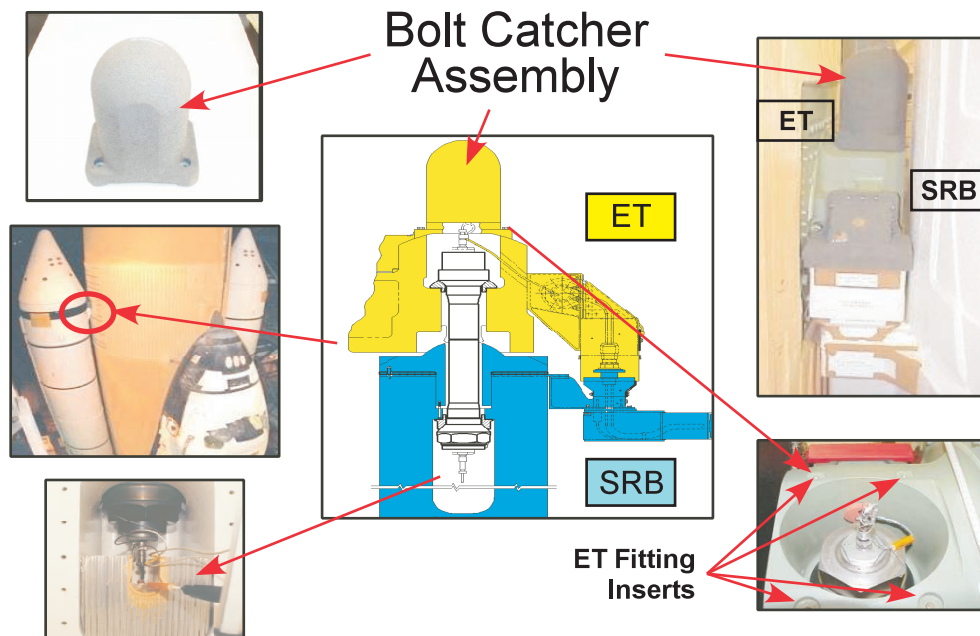
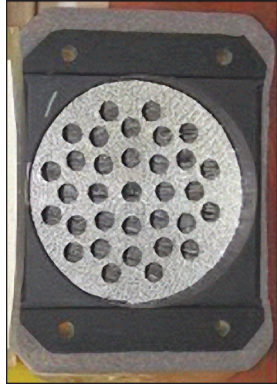


Figure 4.2-1-1. SRB/ET forward attach area.



Bolt catcher energy absorber



Bolt catcher energy absorber after bolt impact

Figure 4.2-1-2. Bolt catcher impact testing.



Figure 4.2-1-3. New one-piece forging design.

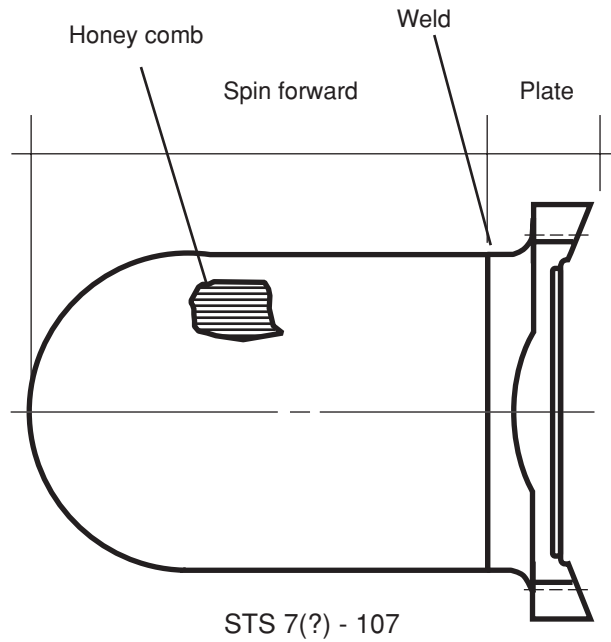


Figure 4.2-1-4. Original two-piece welded design.

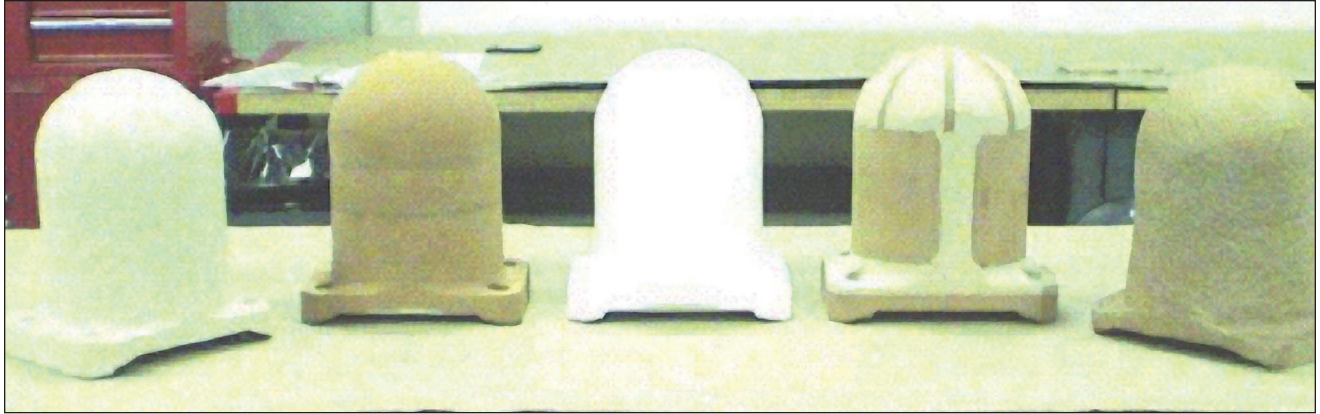


Figure 4.3-1-5. Thermal protection concepts.

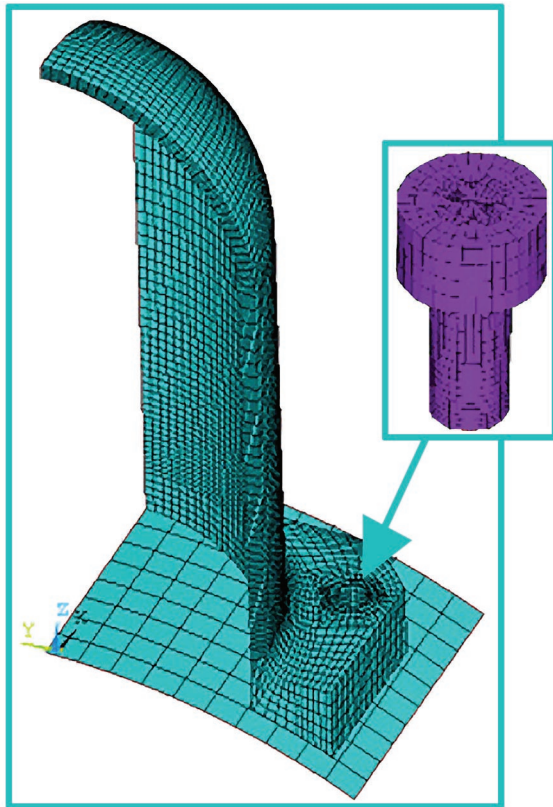


Figure 4.2-1-6. ET bolt/insert finite element model.

STATUS

The redesign of the bolt catcher assembly is under way. Redesign and resizing of the ET attachment bolts and inserts are being worked jointly by the SRB and ET Projects. Testing is ongoing to characterize the energy

absorber material, determine the design loads, and demonstrate that the assembly complies with the 1.4 factor-of-safety requirement. Qualification testing is under way on the various thermal protection materials, including natural environmental (weather) exposure followed by combined environment testing, including random vibration, acoustic, first stage thermal, pyrotechnic shock, and first stage thermal testing.

FORWARD WORK

- Complete structural development.
- Perform structural qualification testing.
- Complete thermal protection material qualification testing.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Nov 03	Complete Critical Design Review
SSP	Jan 04	Complete Qualification
SSP	Jan 04	Deliver First Flight Article





Columbia Accident Investigation Board

Recommendation 4.2-3

Require that at least two employees attend all final closeouts and intertank area hand-spraying procedures. [RTF]

BACKGROUND

External Tank (ET) final closeouts and intertank area hand-spraying processes typically require more than one person in attendance to execute procedures. Those closeout processes that can currently be performed by a single person did not necessarily specify an independent witness or verification.

NASA IMPLEMENTATION

NASA has established a Thermal Protection System (TPS) verification team to verify, validate, and certify all future foam processes. The verification team will assess and improve the TPS applications and manual spray processes. Included with this assessment is a review and an update of the process controls applied to foam applications, especially the manual spray applications. Spray schedules, acceptance criteria, quality, and data requirements will be established for all processes during verification using a Material Processing Plan (MPP). The plan will define how each specific part closeout is to be processed. Numerous TPS processing parameters and requirements will be enhanced, including additional requirements for observation and documentation of processes. In addition, a review is being conducted to ensure the appropriate quality coverage based on process enhancements and critical application characteristics.

The MPPs will be revised to require, at a minimum, that all ET critical hardware processes, including all final closeouts and intertank area hand-spray procedures, be performed in the presence of two certified Production Operations employees. The MPPs will also include a step to require technicians stamp the build paper to verify their presence and validate the work was performed according to plan. Additionally, quality control personnel will witness and accept each manual spray TPS application. Government oversight of TPS applications will be determined upon completion of the revised designs and the identification of critical process parameters.

STATUS

The Space Shuttle Program (SSP) has approved the revised approach for ET TPS certification and the Space Flight Leadership Council approved it for Return to Flight Task Group (RTFTG) review. TPS verification activities are under way and specific applicable ET processing procedures are under review.

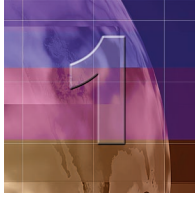
FORWARD WORK

Complete the TPS verification activities and implement the modifications, including modifying the MPPs to reflect the requirement that a minimum of two certified Production Operations employees be present for critical hardware processes.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Dec 03 (Complete)	Review revised processes with the RTFTG
SSP	Feb 04	Update TPS processes and procedures to incorporate recommendations





Columbia Accident Investigation Board

Recommendation 4.2-4

Require the Space Shuttle to be operated with the same degree of safety for micrometeoroid and orbital debris as the degree of safety calculated for the International Space Station (ISS). Change the micrometeoroid and orbital debris safety criteria from guidelines to requirements.

BACKGROUND

Micrometeoroid and orbital debris (MMOD) is recognized as a continuing concern. The current differences between the International Space Station (ISS) and Orbiter MMOD risk allowances for a critical debris impact are based on the original design specification for each of the two vehicles. The ISS was designed for long-term MMOD exposure, whereas the Orbiter was designed for short-term MMOD exposure. The debris impact factors that are considered when determining the MMOD risks for a spacecraft are mission duration, attitude(s), altitude, inclination, year, and the on-board payloads.

The current Orbiter impact damage guidelines dictate that there will be no more than a 1 in 200 risk for loss of vehicle for any single mission. This recommendation suggests that the Orbiter meet the same degree of safety that the ISS meets in regards to MMOD risks. The ISS currently has a 5 percent catastrophic risk of MMOD debris impact over ten years. If we assume that there will be five Space Shuttle flights per year, this would require that the Orbiter meet an average MMOD critical damage risk of 1 in 1000 for any single mission.

NASA uses a computer simulation and modeling tool called BUMPER to assess the risk from MMOD impact to the Orbiter during each flight and takes into account the mission duration, attitude variation(s), altitude, and other factors. BUMPER has been certified for use on both the ISS and the Orbiter. BUMPER has also been examined during numerous technical reviews and deemed to be the world standard for orbital debris risk assessment. Optimized trajectories, vehicle changes, results from trade studies, and more detailed ballistic limit calculations are used to improve the fidelity of the BUMPER results.

NASA IMPLEMENTATION

To comply with the recommendation to operate the Orbiter to the same degree of safety for MMOD as calculated for ISS, NASA is evaluating:

- Orbiter vehicle design upgrades to decrease vulnerability to MMOD.
- Operational changes (i.e., modify Orbiter orientation after docking to the ISS).
- Development of an inspection capability to detect and repair critical damage.
- Add an on-board impact damage detection sensor system to detect critical damage that may occur to the Thermal Protection System during ascent or while on orbit.

In addition to the above, NASA will change the MMOD safety criteria from guidelines to requirements.

NASA intends to lower MMOD risk through an integrated, time-phased approach of operations changes, addition of damage detection sensors to the vehicle, and additional vehicle upgrades.

STATUS

Impact Testing is being conducted and will provide data to support the development of more effective vehicle hardening techniques for both low-velocity (ascent debris) and hypervelocity (MMOD) impact threats. The test results are an important component in verifying the ballistic limit equations used in the BUMPER code.

The current methods for collecting debris impact data from an Orbiter during its postflight inspection are being evaluated for completeness and adequacy. These post-flight data are useful for tracking trends in MMOD damage to the vehicle and are used to update the MMOD environment definition models that are imbedded in BUMPER code. NASA's objective is to continually improve the accuracy of the code used for MMOD risk assessments by using both ground-based and on-orbit data sources.

Progress is being made on evaluating the benefits, costs, and time required for implementing each of the potential

components in the MMOD risk reduction strategy. These evaluations are focusing on changing operations, verifying Thermal Protection System (TPS) integrity before entry, developing a TPS inspection and repair capability, improving vehicle hardening for TPS tile and wing leading edge, creating operational and hardware modifications to the ISS that would improve Orbiter MMOD protection, and improving BUMPER analysis capabilities. A combination of these items will help to ensure that the Orbiter meets the requirement for reduced risk of critical damage from MMOD in the most efficient and effective manner.

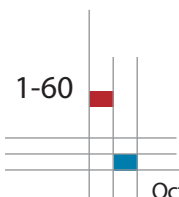
FORWARD WORK

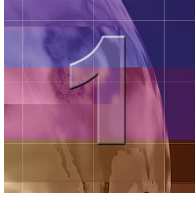
Investigations will continue on potential vehicle modifications, such as new impact debris sensors, next-generation tiles and toughened strain isolation pad materials, improved Reinforced Carbon-Carbon, and improved crew module aft bulkhead protection. Additionally, a study is under way to

assess the advantages afforded by alternative docking locations on ISS, as well as other ISS modifications that reduce the Orbiter’s exposure to MMOD while docked to the ISS. Hypervelocity impact tests will continue to be performed and BUMPER code updated to support the risk reduction effort.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Dec 03	Assess adequacy of MMOD requirements
SSP	Dec 03	Update risk management practices





Columbia Accident Investigation Board

Recommendation 4.2-5

Kennedy Space Center Quality Assurance and United Space Alliance must return to the straight-forward, industry standard definition of “Foreign Object Debris,” and eliminate any alternate or statistically deceptive definitions like “processing debris.” [RTF]

BACKGROUND

Beginning in 2001, foreign object debris (FOD) work at Kennedy Space Center was divided into two categories, “processing debris” and “FOD.” FOD was defined as debris found during the final or flight-closeout inspection process. All other debris was labeled processing debris. The categorization and subsequent use of two different definitions of debris led to the perception that processing debris was not a concern.

NASA IMPLEMENTATION

NASA will stop using the term “processing debris.” A team of NASA and United Space Alliance (USA) employees will benchmark similar industry and Department of Defense (DoD) processing facilities. Afterwards, a consistent definition of FOD will be developed and implemented across all processing activities. NASA and USA Shuttle processing operating procedures will be updated and metrics will be developed to reflect the definition change.

Approximately two months after the development of the improved FOD control program, NASA will perform a baseline audit. In addition, NASA will include FOD as an element of surveillance activities (e.g., hardware surveillance, process surveillance, and process sampling activities). NASA management will also participate in periodic walk-downs of processing areas for all three shifts.

The new FOD control program will be rolled out to all employees. And the FOD training and the FOD Web site will be updated and improved.

STATUS

The team completed both benchmarking trips, visiting four installations, and is documenting the results and comparing them with the KSC FOD Program. A preliminary definition has been developed, but will not be

finalized until late January. In addition, the contractor and NASA managers are conducting inspection walkdowns.

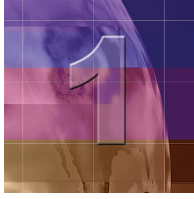
FORWARD WORK

Remaining work includes documenting the FOD Program as an operating procedure, implementing increased NASA surveillance, and performing a baseline audit of the improved FOD Program.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Ongoing	Review and trend metrics
SSP	Oct 03 (Complete)	Initiate NASA Management Walkdowns
SSP	Dec 03 (Complete)	FOD Control Program benchmarking
SSP	Jan 04	Revised FOD definition
SSP	Feb 04	USA Operating Procedure developed
SSP	Mar 04	Implement FOD surveillance
SSP	Apr 04	Baseline audit of Implementation of FOD definition, training, and surveillance





Columbia Accident Investigation Board

Recommendation 6.2-1

Adopt and maintain a Shuttle flight schedule that is consistent with available resources. Although schedule deadlines are an important management tool, those deadlines must be regularly evaluated to ensure that any additional risk incurred to meet the schedule is recognized, understood, and acceptable. [RTF]

BACKGROUND

Schedules are integral parts of program management and provide for the integration and optimization of resource investments across a wide range of connected systems. The Space Shuttle Program (SSP) is just such a system, and it needs to have a visible schedule with clear milestones to effectively achieve its mission. However, NASA will not compromise system safety in our effort to optimize integration. Schedules associated with all activities generate very specific milestones that must be completed for mission success. If these milestones can be accomplished safely, the scheduled activities occur on time. If a milestone is not accomplished, the schedules are extended consistent with the needs of safety.

NASA IMPLEMENTATION

NASA's priorities will always be flying safely and accomplishing our missions successfully. To do this, NASA will adopt and maintain a Shuttle flight schedule that is consistent with available resources. Schedule risk will be regularly assessed, and unacceptable risk will be mitigated. NASA will develop a process for Shuttle launch schedules that incorporates all of the manifest constraints and allows adequate margin to accommodate a normalized amount of changes. This process will entail launch margin, cargo/logistics margin, and crew timeline margin. The SSP will enhance and strengthen the existing risk management system that assesses technical, schedule, and programmatic risks. Additionally, the SSP will examine the risk management process that is currently used by the International Space Station (ISS). The data will be placed in the One NASA Management Information System so that the senior managers in the Space Flight Enterprise can virtually review schedule performance indicators and risk assessments on a real-time basis.

The changes coming from the *Columbia* accident will result in new requirements that must be factored into the manifest. The ISS Program and the SSP are working together to incorporate return to flight (RTF) changes into the ISS assembly sequence. A systematic review of the currently

planned flights is being performed. After all the requirements have been analyzed and identified, a launch schedule and ISS manifest will be established. NASA will add margin that will allow some changes without having those changes ripple throughout the manifest.

STATUS

Currently, all the appropriate manifest owners have initiated work to identify their requirements. SSP is coordinating with the ISS Program to create an RTF integrated schedule. The current manifest launch dates are all NET [no earlier than] and will be determined once an RTF date is established. A set of tools is being developed to manage the schedule margin and flexibility that is in the manifest.

FORWARD WORK

Development will continue on the tools to manage the manifest schedule margin and flexibility.

SSP will be benchmarked against a very effective system that currently exists and is well proven within the ISS Program for dealing with similar issues.

Until all of the RTF recommendations and implementations plans are identified, a firm STS-114 Shuttle launch schedule cannot be established. In this interim period, the STS-114 launch schedule will be considered a no earlier than (NET) schedule and subsequent launch schedules will be based on milestones. The ISS on-orbit configuration is stable and does not drive any particular launch date.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03 (Complete)	Baseline the RTF constraints schedule
SSP	TBD	Establish STS-114 baseline schedule





Columbia Accident Investigation Board

Recommendation 6.3-1

Implement an expanded training program in which the Mission Management Team faces potential crew and vehicle safety contingencies beyond launch and ascent. These contingencies should involve potential loss of Shuttle or crew, contain numerous uncertainties and unknowns, and require the Mission Management Team to assemble and interact with support organizations across NASA/Contractor lines and in various locations. [RTF]

BACKGROUND

- | The Mission Management Team (MMT) is responsible for making Space Shuttle Program (SSP) decisions regarding preflight and in-flight activities and operations that exceed the authority of the launch director or the flight director. Responsibilities are transferred from the prelaunch MMT chair to the flight MMT chair once a stable orbit had been achieved. The flight MMT is operated during the subsequent on-orbit flight, entry, landing, and postlanding mission phases through crew egress from the vehicle.
- | When the flight MMT is not in session, all MMT members are on call and required to support emergency MMTs convened because of anomalies or changing flight conditions.
- | Previously, MMT training, including briefings and simulations, concentrated on the prelaunch and launch phases, including launch aborts.

NASA IMPLEMENTATION

- | Formal training for MMT members will be revised to include the following:
 1. Following review and baselining of the MMT requirements, a training class for all MMT members will be developed and conducted prior to the start of simulations. This training class will describe in detail the processes and each MMT member's responsibilities in the MMT.
 2. MMT simulations will be conducted at least twice a year to exercise the team's response to off-nominal scenarios. MMT simulations are currently scheduled for November 2003 (flight MMT), December 2003 (flight MMT), January 2004 (flight MMT), February 2004 (prelaunch MMT), and March 2004 (prelaunch MMT). These simulations will bring together the flight crew, flight control team, launch control team, engineering staff, outside agencies,

and MMT to improve communication and to teach better problem-recognition and reaction skills.

3. Training classes in human factors and decision making will become a regular part of MMT membership training. As a first step, a class on Crew Resource Management for all MMT members has been scheduled for November 2003. A training plan for the longer term is under development.
- | NASA determined through an in-depth review of the processes and functions of STS-107 and previous flight MMTs that additional rigor and discipline are required in the flight MMT process. An essential piece of strengthening the MMT processes is ensuring all safety, engineering, and operations concerns are heard and dispositioned appropriately. As a result, NASA will expand processes for the review and dispositioning of on-orbit anomalies and issues. The flight MMT meeting frequency and the process for requesting an emergency MMT meeting have been more clearly defined. NASA has reconfirmed and will enforce the requirement to conduct daily MMT meetings.

STATUS

- | The MMT training team is developing simulation scenarios.

The SSP is reviewing the flight MMT process and will revise Program documentation (NSTS 07700, Volume VIII, Operations, Appendix D) accordingly. Proposed process changes are:

1. Membership, organization, and chairmanship of the preflight and in-flight MMT will be standardized. The SSP Deputy Manager will chair both phases of the MMT, in contrast to the previous organization where the preflight MMT was chaired by a different manager than the in-flight MMT.

2. Flight MMT meetings will be formalized through the use of standardized agenda formats, presentations, action item assignments, and a readiness poll. Existing SSP meeting support infrastructure will be used to ensure MMT meeting information is distributed as early as possible before scheduled meetings, as well as timely generation and distribution of minutes subsequent to the meetings.
3. Responsibilities for the specific MMT membership will be defined. MMT voting membership will be expanded. MMT membership for each mission is established by each participating organization in writing prior to the first preflight MMT.
4. Each MMT member will define internal processes for MMT support and problem reporting.
5. Formal processes will be established for review of findings from ascent and on-orbit imagery analyses, postlaunch hardware inspections, and ascent reconstruction and any other flight data reviews to ensure a timely, positive reporting path for these activities.
6. A process will be established to review and disposition mission anomalies and issues. All anomalies will be identified to the flight MMT. For those items deemed significant by any MMT member, a formal flight MMT action and office of primary responsibility (OPR) will be assigned. The OPR will provide a status of the action to all subsequent flight MMT meetings. The MMT will require written requests for action closure. The request must include a description of the issue (observation and potential consequences), analysis details (including employed models and methodologies), recommended actions and associated mission impacts, and flight closure rationale (if applicable).

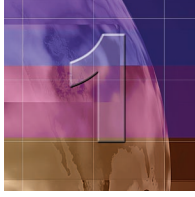
FORWARD WORK

Revisions to project and element processes will be established consistent with the new MMT requirements and will follow formal Program approval. Associated project and element activities in development include, but are not limited to, the following:

1. Development of MMT training.
2. A mission evaluation room console handbook that specifies MMT reporting requirements.
3. A flight MMT reporting process for postlaunch pad debris assessment findings.
4. A flight MMT reporting process for launch imagery analysis findings.
5. A flight MMT reporting process for Solid Rocket Booster/Reusable Solid Rocket Motor post-recovery hardware assessment findings.
6. A flight MMT reporting process for on-orbit vehicle inspection findings.
7. MMT meeting support procedures.
8. MMT simulation procedures.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Oct 03	MMT process changes to Program Requirements Change Board
SSP	Oct 03	Project/element process changes
SSP	Nov 03 Dec 03 Jan 04 Feb 04 Mar 04	MMT simulations
SSP	Oct 03	MMT Interim training plan
SSP	Dec 03	MMT Final training plan
SSP	Nov 03	MMT training



Columbia Accident Investigation Board

Recommendations 7.5-1, 7.5-2, and 9.1-1

R7.5-1 Establish an Independent Technical Engineering Authority that is responsible for technical requirements and all waivers to them, and will build a disciplined, systematic approach to identifying, analyzing, and controlling hazards throughout the life cycle of the Shuttle System. The independent technical authority does the following as a minimum:

- Develop and maintain technical standards for all Space Shuttle Program projects and elements
- Be the sole waiver-granting authority for all technical standards
- Conduct trend and risk analysis at the subsystem, system, and enterprise levels
- Own the failure mode, effects analysis and hazard reporting systems
- Conduct integrated hazard analysis
- Decide what is and is not an anomalous event
- Independently verify launch readiness
- Approves the provisions of the recertification program called for in Recommendation 9.1-1

The Technical Engineering Authority should be funded directly from NASA Headquarters and should have no connection to or responsibility for schedule or program cost.

R7.5-2 NASA Headquarters Office of Safety and Mission Assurance should have direct line authority over the entire Space Shuttle Program safety organization and should be independently resourced.

R9.1-1 Prepare a detailed plan for defining, establishing, transitioning, and implementing an independent Technical Engineering Authority, independent safety program, and a reorganized Space Shuttle Integration Office as described in R7.5-1, R7.5-2, and R7.5-3. In addition, NASA should submit annual reports to Congress, as part of the budget review process, on its implementation activities. [RTF]

INTRODUCTION

Prior to return to flight (RTF), as called for in recommendation 9.1-1, NASA will develop a comprehensive plan with concrete milestones leading us to a revised organizational structure and improved management practices, and implementing *Columbia Accident Investigation Board* (CAIB) recommendations 7.5-1 through 7.5-3. Over the next several months, we will report to Congress our progress on development of options and milestones.

NASA is committed to change the Agency's organizational structure to facilitate a culture that ensures that we can manage and operate the Space Shuttle Program safely for years to come. Our organization's culture did not successfully embrace a robust set of practices that promoted safety and mission assurance as priorities. As stated within the CAIB report, there was evidence that

safety was compromised by leadership and communication problems, technical optimism, emphasis on schedule over safety, and funding problems.

Changing NASA's culture is a significant and critical undertaking. We must put in place structures and practices that continually emphasize the critical role of safety and mission assurance while we adhere to sound engineering practices, and move toward a long-term cultural shift that values these practices. We must have the ability to search for vulnerabilities and anticipate risk changes. The character of our culture will be measured by the strength of NASA's leadership commitment to continuously improve safety and engineering rigor, and to share and implement lessons-learned. This will allow us to improve safety by asking probing questions and elevating and resolving issues. Our culture must be institutionalized in an organizational structure that assures robust and sustainable checks and balances.

The resulting organizational and cultural changes will balance the roles and responsibilities of Program management, technical engineering, and safety and mission assurance, while clarifying lines of authority for requirements. We must institutionalize an engineering quality and safety culture that will become embedded in our human space flight program even as personnel or organizations changes. This cultural transformation will require changes to the way we manage all of our programs, institutions, budgets, and human capital.

Although implementation will be as rapid as possible, we must take the time necessary to understand and address the risk posed by introducing changes into complex problems. As the CAIB report states, "Changes in organizational structure should be made only with careful consideration of their effect on the system and their possible unintended consequences."

NASA is committed to assessing our options, understanding the risks, selecting the appropriate option, and implementing the needed change. We will dedicate the resources to accomplish these tasks.

NASA IMPLEMENTATION

Recognizing the need to make significant managerial and organizational changes to address the deficiencies that led to the *Columbia* accident, NASA has already begun to implement a number of improvements. Guided by the CAIB report, we will analyze and create an implementation strategy to ensure each of the CAIB's recommendations is met. The Office of Safety and Mission Assurance has been assigned as the focal point for this recommendation.

STATUS

As a preliminary first step, based on the early recognition of the need for enhanced engineering and safety organizations, NASA recently established the NASA Engineering and Safety Center (NESC) at Langley Research Center to provide independent engineering and safety assessment. The NESC will be operational by November 2003, and

will further augment the Office of Safety and Mission Assurance's independent engineering and safety assessment capabilities. The NESC is the catalyst that will invigorate engineering excellence and strengthen the safety culture within NASA. The Headquarters Office of Safety and Mission Assurance will provide the NESC's budget and policy to assure independence. The NESC's charter includes, but is not limited to, the following:

- A centralized location for the management of independent in-depth technical assessments for safety and mission assurance, engineering, and the Program. This will be supported by expert personnel and state-of-the-art tools and methods.
- Independent testing to determine the effectiveness of problem resolutions or to validate the expected outcomes of models or simulations.
- Independent safety and engineering trend analyses.

In addition, NASA is improving and strengthening current Program management, engineering, and safety processes. However, the criticality of fully understanding all aspects of the CAIB recommendations requires a complete and thoughtful evaluation and response. These recommendations will result in major organizational changes. NASA's priority is to fly safely while successfully executing our mission for the nation.

FORWARD WORK

NASA is committed to making the organizational and cultural changes necessary to respond to the CAIB recommendations 7.5-1 and 7.5-2. The process of implementing and institutionalizing these changes will include investigating funding paths, determining requirement ownership, identifying certification of flight readiness responsibility, and specifying responsibility within the Space Shuttle Program for cost, schedule, and technical issues.

NASA will form an interdisciplinary team to assess these issues to develop a detailed plan prior to RTF as required in recommendation 9.1-1.



Columbia Accident Investigation Board

Recommendation 7.5-3

Reorganize the Space Shuttle Integration Office to make it capable of integrating all elements of the Space Shuttle Program, including the Orbiter.

BACKGROUND

NASA understands that the irregular division of responsibilities between the Shuttle Integration Office and the Space Shuttle Vehicle Engineering Office led to confused responsibilities for systems engineering and integration within the Space Shuttle Program (SSP). This confusion led to loss of an opportunity to recognize the importance of External Tank (ET) bipod ramp shedding and its implication for safe flight.

NASA IMPLEMENTATION

The SSP Manager strengthened the role of the Shuttle Integration Office to make it capable of integrating all of the elements of the SSP, including the Orbiter Project. The Program restructured its Shuttle Integration Office into a Space Shuttle Systems Engineering and Integration Office (SEIO). The SEIO Manager now reports directly to the SSP Manager, thereby placing the SEIO at a level in the Shuttle organization that establishes the authority and accountability for integration of all Space Shuttle elements.

The new SEIO charter clearly establishes that it is responsible for the systems engineering and integration of flight performance of all Space Shuttle elements. To sharpen the focus of the SEIO onto flight vehicle systems engineering and integration, the Cargo Integration function (and personnel) from the old Shuttle Integration Office are now relocated to the Mission Integration Office within SEIO. With this move, the number of civil service personnel performing analytical and element systems engineering and integration in the SEIO was doubled by acquiring new personnel from the Johnson Space Center (JSC) Engineering and Mission Operations Directorates and from outside of NASA.

STATUS

The Space Shuttle Vehicle Engineering Office is now the Orbiter Project Office, and its charter is amended to clarify that SEIO is now responsible for integrating all flight elements.

NASA reorganized and revitalized the Integration Control Board (ICB). This board will review and approve element recommendations and actions to ensure the appropriate integration of activities in the SSP. The Orbiter Project Office is now a mandatory member of the ICB. Orbiter changes that affect multiple elements must now go through the ICB process prior to SSP approval. Orbiter changes for return to flight (RTF) that affect multiple elements, which were not previously reviewed and approved by the ICB, will be routed from the Program Requirements Control Board back to the ICB for review and approval prior to implementation.

Functions with multielement integration were relocated from the Orbiter Project to SEIO. The Space Shuttle Flight Software organization is being moved from the Orbiter Project into the SEIO. This reflects the fact that the Shuttle Flight Software Office manages multiple flight element software sources besides the Orbiter. Because many integrated Space Shuttle performance requirements are implemented through flight software, this also provides better visibility into the Space Shuttle as an integrated vehicle. Because almost any change to the Shuttle hardware has a corresponding flight software change, placing the flight software function inside SEIO also improves our ability to detect and control the integration of element design changes. Finally, this move also strengthens the SSP because it places a major integration facility, the Shuttle Avionics Integration Laboratory, within the SEIO.

All Program integration functions at the Marshall Space Flight Center (MSFC), the Kennedy Space Center, and JSC are now coordinated through the SEIO. Those offices receive technical direction from the SSP SEIO.

MSFC Propulsion Systems Integration (PSI) is increasing its contractor and civil servant technical strength and its authority within the Program. Agreements between the PSI Project Office and the appropriate MSFC Engineering organizations are being expanded to enhance anomaly resolution within the SSP. MSFC Engineering personnel will participate in appropriate Program-level integration boards

and panels, such as Structures and Loads, Aerodynamics, Aerothermodynamics, and Guidance, Navigation, and Control (GN&C). PSI will also participate in MSFC Element-level boards (e.g., Configuration Control Board, Element Acceptance Review, and Preflight Review) and will bring a focused systems perspective and enhanced visibility into changes and anomalies that affect multiple Program elements. A PSI Review Board is being established to address the systems issues and ensure that the items are evaluated, tracked, and worked with the Program SEIO.

The role of the System Integration Plan (SIP) and the Master Verification Plans (MVPs) for all design changes with multielement impact has been revitalized. The SEIO is now responsible for all SIPs and MVPs. These tools will energize SEIO to be a proactive function within the SSP for integration of design changes and verification. SIPs and MVPs are being developed for all major RTF design changes that impact multiple Shuttle elements.

The SEIO is also responsible for generation of all natural and induced design environments analyses. Debris is now treated as an integrated induced environment that will result in element design requirements for generation limits and impact tolerance. All flight elements are being reevaluated as potential debris generators. Computations of debris trajectories under a wide variety of conditions will define the induced environment due to debris. The Orbiter Thermal Protection System will be recertified to this debris environment, as will the systems of all flight elements. Specification of debris as an induced design environment will ensure that any change that results in either additional debris generation or additional sensitivity to debris impact will receive full Program attention.

The SSP is evaluating contractor support levels, NASA oversight requirements, and the NASA/contractor relationships needed to support the new SEIO functions. Changes to the Space Flight Operations Contract and other contracts will be incorporated as required.

FORWARD WORK

The changes described above have already been completed or are in advanced stages of implementation. The Space Shuttle Reorganization baselined the organizational changes within the SSP.

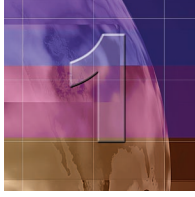
The major challenge will be to determine if the scope and quality of SEIO's work is sufficient to deliver high-quality systems engineering and integration. To assure this, a standing independent assessment team, composed of outside members with experience in integrating large, complex flight systems, will be formed to evaluate the performance of the SEIO function.

In addition, JSC Engineering will assign a Shuttle Chief Integration Engineer. This chief engineer will chair the Space Shuttle Engineering Integration Group to ensure that all technical issues worked by the standing integration boards and panels (such as Structures and Loads, Aerodynamics, Aerothermodynamics, and GN&C) are being properly addressed. The membership of all standing integration boards and panels is being reviewed, and a cochair will be selected from MSFC Engineering to ensure the proper engineering review of integrated products. This will provide an additional mechanism to measure the performance of the SEIO.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP Manager	Aug 03 (Complete)	Approve the SSP Reorganization
SSP Systems Integration	Aug 03 (Complete)	Transition Cargo Integration to Mission Integration
SSP Systems Integration	Aug 03 (Complete)	Reform ICB with Mandatory Orbiter Membership
SSP Systems Integration	Aug 03 (Complete)	Release ET Bipod Redesign Systems Integration Plan
SSP Systems Integration	Oct 03	Release Initial Debris Induced Environment Computations for Use by Projects
JSC Engineering Directorate	Oct 03	Assign Chief Integration Engineer
SSP Systems Integration	Oct 03	Approve ET Bipod Redesign Systems Integration Plan
SSP Systems Integration	Oct 03	Transition Flight Software to SEIO
SSP Systems Integration	Oct 03	Complete Independent Review of Initial Debris Environment Computations
SSP Systems Integration	Dec 03	Review SEIO Quality and Scope Assessment
SSP Systems Integration	Feb 04	Approve Final Debris Environment





Columbia Accident Investigation Board

Recommendation 9.2-1

Prior to operating the Shuttle beyond 2010, develop and conduct a vehicle recertification at the material, component, subsystem, and system levels. Recertification requirements should be included in the Service Life Extension Program.

BACKGROUND

In 2002, NASA initiated Shuttle Service Life Extension to extend the vehicle's useful life. A mid-life recertification program is a foundational element of Shuttle Service Life Extension.

NASA IMPLEMENTATION

NASA has approved funding for work to identify and prioritize additional analyses, testing, or potential redesign of the Shuttle to meet recertification requirements. The findings from these and other efforts will result in specific Shuttle Service Life Extension project requirements. The identification of these requirements puts NASA on track for recertifying the Shuttle.

As a part of our return to flight efforts, NASA has begun the first step in Shuttle recertification, revalidating the operational environments (e.g., loads, vibration, acoustic, and thermal environments) used in the original certification.

STATUS

In May 2003, the Space Flight Leadership Council approved the first Shuttle Service Life Extension package of work, which included funding for Orbiter mid-life

certification and complementary activities on the Orbiter Fleet Leader project, Orbiter Corrosion Control, and an expanded Probabilistic Risk Assessment for the Shuttle.

FORWARD WORK

SSP project and element organizations will compile and develop mid-life certification plans for presentation to the SSP Program Requirements Control Board (PRCB) in December 2003.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Project and Elements	Dec 03	Present mid-life plans to PRCB





Columbia Accident Investigation Board

Recommendation 10.3-1

Develop an interim program of closeout photographs for all critical sub-systems that differ from engineering drawings. Digitize the closeout photograph system so that images are immediately available for on-orbit troubleshooting. [RTF]

BACKGROUND

| Closeout photography is used, in part, to document differences between actual hardware configuration and the engineering drawing system. The *Columbia* Accident Investigation Board (CAIB) recognized the complexity of the Shuttle drawing system and the inherent potential for error and recommended an upgrade to it (reference CAIB recommendation 10.3-2).

Some knowledge of vehicle configuration can be gained by reviewing photographs maintained in the Kennedy Space Center (KSC) quality data center film database or the digital still image management system (SIMS) database. NASA has transitioned to using primarily digital photography. Photographs are taken to document work that brings hardware to flight configuration or to document vehicle configuration after completion of major modifications. These photographs are typically taken in areas that are closed for flight, and usually when planned or unplanned work results in the removal and reinstallation of functional system components. Progressive photographs may be taken when subsequent installations block the view of previous work. Images are typically cross-referenced to the work-authorizing document that specified them.

NASA IMPLEMENTATION

In complying with this recommendation and before return to flight, NASA will identify necessary upgrades to the SIMS database and to storage and retrieval hardware. The existing database will be used to store digital images acquired before the upgraded system comes on line. Database changes will focus on improving retrieval capability by cross-referencing images to top-level drawings or vehicle zone locators. To improve the quality of broad-area closeout imaging, hardware changes may include advanced technology, such as 360° field-of-view cameras and high-definition photography (figure 10.3-1-1).

Photo requirements will be established commensurate with element Project requirements. Components already closed for flight will be documented as access becomes available.

STATUS

The SIMS database exists and currently serves as a repository for digital images. The upgrade plan will be developed and closeout photo requirements set by the projects before return to flight.

FORWARD WORK

We will improve and expand the SIMS database. The collection of digital photographs will be part of an ongoing process, and the database of available photographs will grow as components are accessed.

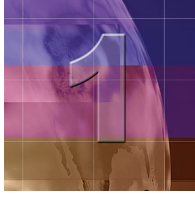
SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Sep 03 (Complete)	Projects transmit photo requirements to KSC Ground Operations
SSP	Oct 03	Present SIMS upgrade plan
SSP	Dec 03	Implement required changes to operating procedures



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Figure 10.3-1-1. Typical closeout photograph, OV-102 left-hand wing cavity.



Columbia Accident Investigation Board

Recommendation 10.3-2

Provide adequate resources for a long-term program to upgrade the Shuttle engineering drawing system including

- Reviewing drawings for accuracy
- Converting all drawings to a computer-aided drafting system
- Incorporating engineering changes

BACKGROUND

This recommendation contains two related but distinct parts. The Shuttle engineering drawings have accumulated a backlog of unincorporated changes. Also, based on today's technology, there is an advantage in converting drawings to a computer-aided drafting system.

The Digital Shuttle Project (DSP) is an activity to determine the feasibility of converting Space Shuttle drawings to a computer-aided drafting system. The DSP is a joint project between the Space Shuttle Program (SSP) and the Ames Research Center's Engineering for Complex Systems Program.

The SSP created a prioritized schedule for incorporating the outstanding engineering changes on these drawings based on frequency of use and complexity.

NASA IMPLEMENTATION

NASA will accelerate the development of options for consideration by the SSP on upgrading the Shuttle engineering drawing system. This will include prioritizing a range of options that addresses cost, schedule, impact on current processing, and risk. At its most complete implementation for a specific system, DSP has the potential to

- Convert vehicle engineering drawings into geometric solid models.
- Facilitate incorporation of engineering changes.
- Reconcile differences between the as-built and as-designed vehicle configurations.
- Put an infrastructure and process in place to maintain and share engineering data throughout the SSP.

STATUS

To date, the project has

- Completed the conversion of Avionics Bays 1, 2, and 3A drawings into geometric solid models with metadata.
- Started to loft the wing portions of the master dimension specification to solid surfaces.
- Established a scanning capability at Kennedy Space Center to acquire as-built configuration information.
- Developed professional relationships with software vendors to evolve their standard products to meet SSP needs.
- Developed a prototype infrastructure to manage and share engineering data.
- Interviewed key SSP personnel to identify knowledge management issues.

The SSP will continue to incorporate changes into the engineering drawing system.

FORWARD WORK

NASA will develop detailed plans and costs for upgrading the Shuttle engineering drawing system. Currently in the formulation phase, the work that remains to be completed includes assessing current design documentation and developing drawing conversion standards, a concept of operations, a system architecture, and procurement strategies. At the conclusion of this phase, the DSP will present detailed plans and costs for upgrading the Shuttle engineering drawing system and seek authorization from the SSP to proceed with implementation.

| **SCHEDULE**

Responsibility	Due Date	Activity/Deliverable
SSP	Feb 04	System Requirements Review
SSP	Aug 04	System Definition Review
SSP	Sep 04	Autorization to Proceed with Implementation





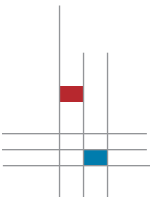
Raising the Bar – Other Corrective Actions

NASA recognizes that we must undertake a fundamental reevaluation of our Agency's culture and processes; this process goes beyond immediate return to flight actions to longer-term work to institutionalize change in the way that we do business. Much of the work needed for this effort was captured in CAIB observations. Part 1 of this plan addressed the CAIB recommendations. Part 2 addresses other corrective actions, including internally generated actions and the observations contained in Chapter 10 of the CAIB report.

(Continued on back)



Subsequent versions of the Space Shuttle Implementation Plan for Return to Flight and Beyond will contain further detail on implementation of the CAIB observations and other suggestions that NASA receives as they are evaluated and implementation plans are developed, including the yet to be released CAIB Report Volume II, Appendix D. We have performed an initial evaluation of Appendix D and have begun addressing the recommendations and findings. Some of these issues are also addressed in the CAIB observations addressed in this section.

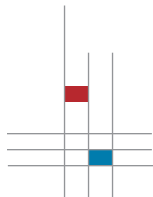




Space Shuttle Program Actions

NASA continues to receive and evaluate inputs from a variety of sources, including those that have been generated from within the Space Shuttle Program.

We are systematically assessing all corrective actions and have incorporated many of these actions in this Implementation Plan. This section contains self-imposed actions and directives of the Space Shuttle Program that are being worked in addition to the constraints to flight recommended by the Columbia Accident Investigation Board.





Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 1

NASA will commission an assessment, independent of the Space Shuttle Program (SSP), of the Quality Planning and Requirements Document (QPRD) to determine the effectiveness of government mandatory inspection point (GMIP) criteria in assuring verification of critical functions before each Shuttle mission. The assessment will determine the adequacy of existing GMIPs to meet the QPRD criteria. Over the long term, NASA will periodically review the effectiveness of the QPRD inspection criteria against ground processing and flight experience to verify that GMIPs are effectively assuring safe flight operations.

BACKGROUND

The *Columbia* Accident Investigation Board report highlighted the Kennedy Space Center (KSC) and Michoud Assembly Facility (MAF) government mandatory inspection point (GMIP) processes as an area of concern. GMIP inspection and verification requirements are driven by the KSC Ground Operations Quality Planning and Requirements Document and the Marshall Space Flight Center Mandatory Inspection Documents.

NASA IMPLEMENTATION

NASA has chartered an Independent Assessment Team (IAT) made up of experts from NASA, the Department of Defense, the aerospace industry, and the Federal Aviation Administration to evaluate the effectiveness of GMIP verification for the Shuttle Processing Directorate at KSC and the External Tank Project at MAF. The team will emphasize the review of policy and the evaluation of hardware processes associated with selected existing GMIPs. After the assessment is complete, its results, along with their potential effect on return to flight, will be provided to the NASA Offices of Space Flight (OSF) and Safety and Mission Assurance (OSMA), and to the Space Shuttle Program (SSP) for disposition.

To ensure the continued validity of the GMIP process, NASA will systematically audit the inspection criteria.

STATUS

In July 2003, OSF reviewed and approved a draft terms of the reference (TOR) document and the proposed membership for the GMIP's IAT. The Assessment Team was formally selected and chartered through a final TOR, signed by the Co-chairs of the Space Flight Leadership Council and the Associate Administrator for OSMA. The team was briefed by, and held discussions with, all levels of management and the safety and mission assurance workforce at

KSC and MAF. The team also performed walkdowns and gathered data at both locations.

The results of the IAT's work is consolidated in a report, released in January 2004, containing findings, recommendations, and observations related to GMIP policy, processes, and workforce. The report links recommendations to specific facts and observations made by the team. Preliminary findings, recommendations, and observations have been briefed to OSMA and OSF.

The IAT determined that the NASA Quality Assurance programs in place today are relatively good based on the ground rules that were in effect when the programs were formulated; however, these rules have changed since the programs' formulation. The IAT recommended that NASA reassess its quality assurance requirements based on the modified ground rules established as a result of the *Columbia* accident. The modified ground rules for the Space Shuttle include an acknowledgement that the Space Shuttle is an aging, relatively high risk development vehicle. As a result, the NASA Safety and Mission Assurance Quality Assurance Program must help to ensure both safe hardware and an effective contractor quality program.

The IAT's findings echo the Observations and Recommendations of the CAIB. Among the recommendations the team identified are

- Strengthen the Agency-level policy and guidance to specify the key components of a comprehensive Quality Assurance Program that includes, among other things, the appropriate application of GMIPs
- Establish a formal process for periodic review of QPRD and GMIP requirements at KSC, and the Mandatory Inspection Documents and GMIPs at MAF, against updates to risk management documentation (Hazard Analyses, Failure Modes and Effects Analyses/Critical Item List) and other system changes

- Continue to define and implement formal, flexible processes for changing the QPRD and adding, changing, or deleting GMIPs
- Document and implement a comprehensive Quality Assurance Program at KSC in support of the Space Shuttle Program activities
- Develop and implement a well defined, systematically deployed Quality Assurance Program at MAF

In response to the CAIB Report, the Marshall Space Flight Center (MSFC) and KSC Shuttle Processing Safety and Mission Assurance initiated efforts to address identified Quality Assurance Program shortfalls. The activities under way at KSC include

- A formal process was implemented to revise GMIPs
- A change review board comprised of the Shuttle Processing Chief Engineer, Safety and Mission Assurance, and, as applicable, contractor engineering representatives has been established to disposition proposed changes
- A new process is under development to document and implement temporary GMIPs while permanent GMIP changes are pending, or as deemed necessary for one-time or infrequent activities
- A pilot project was initiated to trend GMIP accept/reject data to enhance first-time quality determination and identify paths for root cause correction
- Surveillance has been increased through additional random inspections for hardware and compliance audits for processes
- Enhanced Quality Inspector training, based on benchmarking similar processes, is under development

In response to the shortfalls identified at MAF, MSFC initiated the following:

- Application of the CAIB observations and the IAT recommendations to all MSFC propulsion elements
- Formalizing and documenting processes that have been in place for Quality Assurance program planning and execution at each manufacturing location

- Increasing the number of inspection points for External Tank assembly
- Increasing the level and scope of vendor audits (process, system, and supplier audits)
- Improving training across the entire MSFC SMA community, with concentration on the staff stationed at manufacturer and vendor resident management offices

To further strengthen the overall Space Shuttle Quality Assurance Program, a new management position has been established and filled on the Shuttle SMA Manager's staff with a specific focus on Quality.

FORWARD WORK

The final IAT report consisting of observations, findings, and recommendations has been provided to the Space Shuttle Program for implementation.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Headquarters	Jul 03 (Complete)	Assessment begun
Headquarters	Oct 03 (Complete)	Presentation to OSF and OSMA
Headquarters	Jan 04 (Complete)	Final report issued
SSP	TBD	Implement changes to the Quality Process identified in the Final Report



Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 2

The Space Shuttle Program will evaluate relative risk to all persons and property underlying the entry flight path. This study will encompass all landing opportunities from each inclination to each of the three primary landing sites.

BACKGROUND

The *Columbia* accident highlighted the need for NASA to better understand entry overflight risk. In its report, the *Columbia* Accident Investigation Board observed that NASA should take steps to mitigate the risk to all persons and property from Orbiter entries. NASA is dedicated to understanding and diminishing potential risks associated with entry overflight before returning to flight.

NASA IMPLEMENTATION

The overflight risk from impacting debris is a function of three fundamental factors: the probability of vehicle loss of control (LOC) and subsequent breakup, surviving debris, and the population living under the entry flight path. NASA is identifying phases of the entry that present a greater probability of LOC based on increased load factors, aerodynamic pressures, or reduced flight control margins. Several other factors—such as housing, time of day, or debris toxicity—can be factored into the evaluation if they are deemed necessary for a more accurate assessment of risk. It should also be noted that the measures undertaken to improve crew safety and vehicle health will result in a lower probability of LOC, thereby improving the public safety during entry overflight.

NASA is currently studying the relative risks to persons and property associated with entry to its three primary landing sites: Kennedy Space Center (KSC) in Florida; Edwards Air Force Base (EDW) in California; and White Sands Space Harbor/Northrup (NOR) in New Mexico. NASA will evaluate the full range of potential ground tracks for each site and each inclination and conduct sensitivity studies to assess the overflight risk.

The results of these analyses will determine if some ground tracks must be removed from consideration as normal, preplanned, end-of-mission landing opportunities. In addition, NASA will incorporate population overflight, as well as crew considerations, into the entry flight rules that guide the flight control team's selection from the remaining landing opportunities.

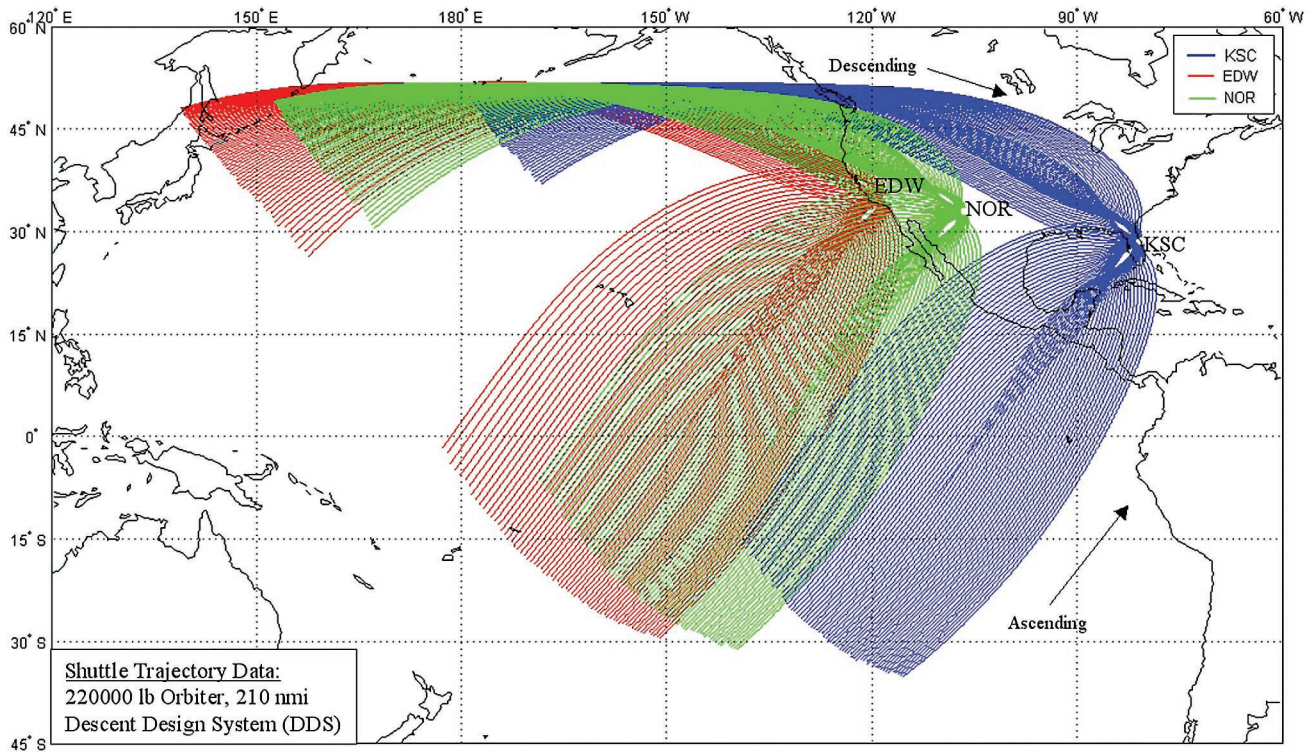
STATUS

The current assessment is aimed at determining which landing opportunities present the most risk. For this preliminary relative risk assessment, more than 1200 entry trajectories were simulated for all three primary landing sites from all of the standard Shuttle orbit inclinations: 28.5° (Hubble Space Telescope), 39.0° (STS-107), and 51.6° (International Space Station). The full range of entry crossrange* possibilities to each site was studied in increments of 25 nautical miles for all ascending entry (south to north) and descending entry (north to south) approaches. Figure SSP 2-1 displays the ground tracks simulated for the 51.6° inclination orbit. Although these preliminary results indicate that some opportunities have an increased public risk compared to others, the uncertainty of the input factors must be reduced further in order to make reliable decisions regarding public risk.

FORWARD WORK

The Space Shuttle Program (SSP) has generated preliminary data to compare public risk among various landing opportunities. These preliminary data will be updated and validated prior to return to flight (RTF). The Johnson Space Center, the Office of Safety and Mission Assurance at NASA Headquarters, and the Agency Range Safety Program will coordinate activities and share all analysis, research, and data obtained as part of this RTF effort. This shared work will be applied to the development of an Agency safety policy for entry operations.

*Entry crossrange is defined as the distance between the landing site and the point of closest approach on the orbit ground track. This number is operationally useful to determine whether or not the landing site is within the Shuttle's entry flight capability for a particular orbit.



**Figure SSP 2-1. Possible entry ground tracks from 51.6° orbit inclination.
 Blue lines are landing at KSC, green at NOR, red at EDW.**

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 Completed	Preliminary results to RTF Planning Team and SSP Program Requirements Control Board (PRCB)
SSP	Sep 03 Completed	Update to RTF Planning Team and SSP PRCB
SSP	Nov 03	Update to RTF Planning Team and SSP PRCB
SSP	Jan 04	Report to RTF Planning Team and SSP PRCB



Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 3

NASA will evaluate the feasibility of providing contingency life support on board the International Space Station (ISS) to stranded Shuttle crewmembers until repair or rescue can be affected.

BACKGROUND

All but one of the currently manifested Shuttle missions is to the International Space Station (ISS). Therefore, it is prudent to examine our options for planning an emergency capability to sustain Shuttle crews on the ISS should the Orbiter become unfit for entry. This Contingency Shuttle Crew Support (CSCS) capability would, in an emergency, sustain a Shuttle crew on board the ISS for as long as possible. It is not intended to mitigate known but unacceptable risks. Rather, CSCS is a generic capability that will provide NASA with a best effort ability to sustain the crew on the ISS should known but remote risks or unforeseen circumstances disable the Shuttle.

NASA IMPLEMENTATION

The ISS Program Office will pursue manifesting additional logistics to enable a more robust CSCS capability. NASA has begun coordination with the ISS International Partners to discuss the concept.

NASA will evaluate current Shuttle and ISS support capabilities for crew rescue during a CSCS situation and explore ways of using all available resources to extend CSCS to its maximum duration. This may involve making recommendations on operational techniques, such as undocking the Orbiter after depletion of usable consumables and having another Shuttle available for launch to rescue the crew within the projected CSCS duration. These actions may be outside of the current flight rules and Orbiter performance capabilities and will need to be fully assessed. Currently NASA is assuming that STS-114 will require no new Shuttle or ISS performance capabilities to enable CSCS.

NASA will also evaluate CSCS options to maximize Shuttle/ISS docked capabilities. These options, such as power-downs and resource-saving measures, will extend the time available for contingency operations including Thermal Protection System inspection and repair.

STATUS

NASA completed a preliminary feasibility assessment of CSCS. The assessment results indicated that for the STS-114 mission, the combined ISS and Shuttle crew can be sustained on the ISS for a period of at least 86 days. This would allow NASA sufficient time to launch a second Shuttle for rescue.

The major assumptions of the initial assessment were

1. STS-114 launch date of March 11, 2004; a revised assessment based upon a no earlier than September 2004 launch date will be developed in early 2004.
2. Nine crew total on ISS (two ISS crew and seven Shuttle crew).
3. ISS systems operate nominally with no degradation/failures (e.g., oxygen generation, carbon dioxide removal, condensate collection); key equipment is zero fault-tolerant.
4. 1,118 liters of Shuttle fuel cell water are successfully transferred to the ISS.
5. Progress resupply vehicles provide critical consumables during the contingency period assuming no acceleration from currently baselined launch dates.

NASA is continuing to assess CSCS options and coordinate with our International Partners.

FORWARD WORK

NASA will pursue the CSCS capability to a best-effort, contingency level. This capability will allow us to support the full joint crew for the duration of the CSCS period, relying only on planned Progress vehicles. CSCS will be designed to rely on a second Shuttle for crew rescue, or to provide capability to sustain the Shuttle crew while on-orbit repairs are made to the damaged Orbiter.

We will coordinate with the Russian Aviation and Space Agency regarding the CSCS concept and its impact to Russian systems and operations.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
ISS Program Office 	Aug 03 Completed	Status International Partners at Multilateral Mission Control Boards
ISS Program Office	Nov 03	Assess ISS systems capabilities and spares plan and provide recommendations to ISS and Space Shuttle Program (SSP)
ISS Program Office	Nov 03	Obtain concurrence on use of Russian systems
ISS Program Office	Mar 04	Develop CSCS Logistics Plan
ISS Program Office and SSP	Jun 04	Develop waste management and water balance plans
ISS Program Office and SSP	Jun 04	Develop ISS Launch Commit Criteria
ISS Program Office	Jun 04	Develop food management plan
ISS Program Office and SSP	Jun 04	Develop crew health and exercise protocols





Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 4

NASA will validate that the controls are appropriate and implemented properly for “accepted risk” hazards and any other hazards, regardless of classification, that warrant review due to working group observations or fault tree analysis.

BACKGROUND

Hazard analysis is the determination of potential sources of danger that could cause loss of life, personnel capability, system, or injury to the public. Hazard analysis is accomplished through: (1) performing analyses; (2) establishing controls; and (3) establishing a maintenance program to implement the controls. Controls and verifications for the controls are identified for each hazard cause.

Accepted risk hazards are those hazards that, based on analysis, have a critical or catastrophic consequence and whose controls are such that the likelihood of occurrence is considered higher than improbable and might occur during the life of the Program. Examples include critical single failure points, limited controls or controls that are subject to human error or interpretation, system designs or operations that do not meet industry or Government standards, complex fluid system leaks, inadequate safety detection and suppression devices, and uncontrollable random events that could occur even with established precautions and controls in place.

All hazards, regardless of classification, will be reviewed if working group observations or fault-tree analysis call into question the classification of the risk or the efficacy of the mitigation controls.

NASA IMPLEMENTATION

Each Space Shuttle Program (SSP) project will perform the following assessment for each accepted risk hazard report and any additional hazard reports indicted by the STS-107 accident investigation findings:

1. Verify proper use of hazard reduction precedence sequence per NSTS 22254, Methodology for Conduct of Space Shuttle Program Hazard Analyses.
2. Review the basis and assumptions used in setting the controls for each hazard and determine whether they are still valid.
3. Verify each reference to launch commit criteria, flight rules, Operation and Maintenance Requirements

Specification Document, crew procedures, and work authorization documents is a proper control for the hazard cause.

4. Verify proper application of severity and likelihood per NSTS 22254, Methodology for Conduct of Space Shuttle Program Hazard Analyses, for each hazard cause.
5. Verify proper implementation of hazard controls by confirming existence and proper use of the control in current Program documentation.
6. Identify any additional feasible controls that can be implemented that were not originally identified and verified.
7. Assure that all causes have been identified and controls documented.

The System Safety Review Panel (SSRP) will serve as the forum to review the project’s assessment of the validity and applicability of controls. To the maximum extent possible, the SSRP will perform actual on-site assessment of the existence and effectiveness of controls. In accordance with SSP requirements, the SSRP will review, process, and disposition updates to baselined hazard reports.

Although the scope of the official return to flight (RTF) action encompasses only the accepted risk hazards, the STS-107 accident has brought into question the implementation and effectiveness of controls in general. As such, the controlled hazards are also suspect. The further evaluation of all hazards, including the controlled hazards, will be included in the RTF plan if the results of the accepted risk hazards review indicate significant problems—such as a recurring lack of effective controls, insufficient technical rationale, or improper classification. Following the completion of the RTF action, all hazard reports (accepted risk and controlled) will be reviewed by the end of calendar year 2004.

In summary, the goal of this review is to reconfirm that the likelihood and severity of each accepted risk hazard

are thoroughly and correctly understood, and that mitigation controls are properly implemented.

STATUS

Each project and element is currently in the process of reviewing its accepted risk hazard reports per the Program Requirements Control Board approved schedules.

FORWARD WORK

Analysis results could drive additional hardware or operational changes. As noted previously, review of controlled risks hazards may be necessary after the results of the accepted risk reviews are reported.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03 (Ongoing)	Identify and review "Accepted Risk" hazard report causes and process impacts
SSP	Sep 03 (Ongoing)	Analyze implementation data
SSRP	Oct 03	SSRP review element hazards and critical items list review processes Kennedy Space Center Sep 9, 11 Reusable Solid Rocket Motor Sep 24, 25 Integration Oct Solid Rocket Booster Sep 8 Space Shuttle main engine Oct 7, 8
SSP	Oct 03	Validate and verify controls and verification methods
SSP	Oct 03	Develop, coordinate, and present results and recommendation



Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 5

NASA will determine critical debris sources, transport mechanisms, and resulting impact areas. Based on the results of this assessment, we will recommend changes or redesigns that would reduce the debris risk. NASA will also review all Program baseline debris requirements to ensure appropriateness and consistency.

BACKGROUND

A review of critical debris potential is necessary to prevent the recurrence of an STS-107 type of failure. NASA is improving the end-to-end process of predicting debris impacts and the resulting damage.

NASA IMPLEMENTATION

NASA will analyze credible debris sources from a wide range of release locations to predict the impact location and conditions. We will develop critical debris source zones to provide maximum allowable debris sizes for various locations on the vehicle. Debris sources that can cause significant damage may be redesigned. Critical impact locations may also be redesigned or debris protection added.

A list of credible ascent debris sources has been compiled for each Space Shuttle Program (SSP) hardware element—Solid Rocket Booster, Reusable Solid Rocket Motor, Space Shuttle main engine, External Tank, and Orbiter. Potential debris sources have been identified by their location, size, shape, material properties, and, if applicable, likely time of debris release. This information will be used to conduct a debris transport analysis to predict impact location and conditions, such as velocities and relative impact angles.

NASA will analyze over one million debris transport cases. These will include debris type, location, size, and release conditions (freestream Mach number, initial velocity of debris piece, etc.).

STATUS

All hardware project and element teams have completed the first step of the analysis to identify known and suspected debris sources originating from the flight hardware.

To support the very large number of debris transport cases required to complete this action, NASA significantly modified its debris transport tools. These modifications will improve the efficiency of the debris transport process.

The tools, along with their underlying limitations, were reviewed by an independent peer review team September 30, 2003 – October 2, 2003. In addition, a comprehensive “Debris Summit” will be held on November 4-5, 2003, to review all activities related to debris generation, debris transport, and impact analyses.

FORWARD WORK

As debris sources are analyzed, the resulting damage will be assessed and critical debris sources will be identified. The Integration Control Board and Program Requirements Control Board (PRCB) will periodically review status. The following actions are in work:

- Systems engineering and integration to deliver impact conditions map to all hardware elements.
- Hardware elements to identify potentially unacceptable damage locations.
- Systems engineering and integration to recommend hardware modifications that will eliminate and/or reduce debris sources, or hardening modifications to increase impact survivability.

SCHEDULE

This is an extensive action that will take a year or more to fully complete. The preliminary schedule, included below, is dependent on use of current damage assessment tools. If additional testing and tool development are required, it may increase the total time required to complete the action.

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	Elements provide debris history/sources
SSP	Nov 03	Begin RTF [Return to Flight] Debris Transport analyses

Continued on page 2-10

| (Concluded from page 2-9)

Responsibility	Due Date	Activity/Deliverable
SSP	Feb 04	Summary Report/ Recommendation to PRCB-RTF cases only
SSP	Jun 04	Begin Other Debris Transport analyses



Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 6

All waivers, deviations, and exceptions to Space Shuttle Program (SSP) requirements documentation will be reviewed for validity and acceptability before return to flight.

BACKGROUND

Requirements are the fundamental mechanism by which the Space Shuttle Program (SSP) directs the production of hardware, software, and training for ground and flight personnel to meet performance needs. The rationale for waivers, deviations, and exceptions to these requirements must include compelling rationale that the associated risks are mitigated through design, redundancy, processing precautions, and operational safeguards. The Program manager has approval authority for waivers, deviations, and exceptions.

NASA IMPLEMENTATION

Because waivers, deviations, and exceptions to SSP requirements contain the potential for unintended risk, the Program has directed all elements to review these exemptions to Program requirements to determine whether the exemptions should be retained.

Each project and element will be alert for items that require mitigation before return to flight. The projects and elements will also identify improvements that should be accomplished as part of Space Shuttle Service Life Extension.

The following instructions were provided to each project and element:

1. Any item that had demonstrated periodic, recurrent, or increasingly severe deviation from the original design intention must be technically evaluated and justified. If there is clear engineering rationale for multiple waivers for a Program requirement, it could mean that a revision to the requirement is needed. The potential expansion of documented requirements should be identified for Program consideration.

2. The review should include the engineering basis for each waiver, deviation, or exception to ensure that the technical rationale for acceptance is complete, thorough, and well considered.
3. Each waiver, deviation, or exception should have a complete engineering review to ensure that incremental risk increase has not crept into the process over the Shuttle lifetime and that the level of risk is appropriate.

The projects and elements were encouraged to retire out-of-date waivers, deviations, and exceptions.

STATUS

Each project and element presented a plan and schedule for completion to the Program Requirements Change Board on June 25, 2003.

FORWARD WORK

Each project and element will identify and review critical items list waivers that could be associated with ascent debris generation.

- | Each project and element has begun implementing its plan and will provide closure to the SSP by January 2004.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP Organizations	Jan 2004	Review of all waivers, deviations, and exceptions





Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 7

The Space Shuttle Program (SSP) should consider NASA Accident Investigation Team (NAIT) working group findings, observations, and recommendations.

BACKGROUND

As part of their support of the *Columbia* Accident Investigation Board, each NASA Accident Investigation Team (NAIT) technical working group compiled assessments and critiques of Program functions. These assessments offer a valuable internal review and will be considered by the Space Shuttle Program (SSP) for conversion into directives for corrective actions.

NASA IMPLEMENTATION

All NAIT technical working groups have an action to present their findings, observations, and recommendations to the Program Requirements Control Board (PRCB). Each project and element will disposition recommendations within their project to determine which should be return to flight actions. They will forward actions that require SSP or Agency implementation to the SSP PRCB for disposition.

STATUS

The following NAIT working groups have reported their findings and recommendations to the SSP PRCB: the Space Shuttle Main Engine Project Office, the Reusable

Solid Rocket Motor Project Office, the Mishap Investigation Team, the External Tank Project, the Solid Rocket Booster Project Office, Space Shuttle Systems integration, and the Early Sightings Assessment Team.

Project and PRCB recommendations currently being implemented include revision of the SSP contingency action plan, modifications to the External Tank, and evaluation of hardware qualification and certification concerns.

FORWARD WORK

The remaining working groups will report their findings and recommendations to the SSP PRCB in October 2003.

SCHEDULE

An implementation schedule will be developed after PRCB approval.





Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 8

NASA will identify certification of flight readiness (CoFR) process changes, including program milestone reviews, flight readiness review (FRR), and prelaunch Mission Management Team (MMT) processes to improve the system.

BACKGROUND

The certification of flight readiness (CoFR) is the fundamental process for ensuring compliance with Program requirements and assessing readiness for proceeding to launch. The CoFR process includes multiple reviews at increasing management levels that culminate with the Flight Readiness Review (FRR), chaired by the Associate Administrator of Space Flight, approximately two weeks before each launch. After successful completion of the FRR, all responsible parties, both Government and contractor, sign a CoFR.

NASA IMPLEMENTATION

To ensure a thorough review of the CoFR process, the Program Requirements Control Board (PRCB) has assigned an action to each organization to review NSTS 08117, Certification of Flight Readiness, to ensure that their internal documentation complies and their responsibilities are properly described.

The action was assigned to each Space Shuttle Program (SSP) supporting organization that endorses or concurs on the CoFR and to each organization that prepares or presents material in the CoFR review process.

Each organization is reviewing the CoFR process in place during STS-112, STS-113, and STS-107 to identify any weaknesses or deficiencies in their organizational plan.

STATUS

Several organizations have completed their initial review.

FORWARD WORK

NASA will revise NSTS 08117, including editorial changes such as updating applicable documents lists; combining previously separate roles and responsibilities within project and Program elements; and increasing the rigor of project-level reviews.

SCHEDULE

Organizations are scheduled to begin reporting to the PRCB by August 1, 2003.

Responsibility	Due Date	Activity/Deliverable
SSP KSC	Nov 03	Baseline NSTS 08117, Certification of Flight Readiness





Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 9

NASA will verify the validity and acceptability of failure mode and effects analyses (FMEAs) and critical items lists (CILs) that warrant review based on fault tree analysis or working group observations.

BACKGROUND

The purpose of failure mode and effects analyses (FMEAs) and critical items lists (CILs) is to identify potential failure modes of hardware and systems and their causes, and to assess their worst-case effect on safe flight. A subset of the hardware analyzed in the FMEA becomes classified as critical based on the risks and identified undesirable effects and the corresponding criticality classification assigned. These critical items, along with supporting retention rationale, are documented in a CIL that accepts the design with additional controls. The controls mitigate the likelihood of the failure mode occurring and/or the ultimate effect and risk occurring.

The analysis process involves the following phases:

1. Perform the design analysis.
2. For critical items, assess the feasibility of design options to eliminate or further reduce the risk. Consideration is given to enhancing hardware specifications, qualification requirements, manufacturing, and inspection and test planning.
3. Formulate operating and maintenance procedures, launch commit criteria, and flight rules to eliminate or minimize the likelihood of occurrence and the effect associated with each failure mode. Formally document the various controls identified for each failure mode in the retention rationale of the associated CIL and provide assurance that controls are effectively implemented for all flights.

NASA IMPLEMENTATION

In preparation for return to flight (RTF), NASA will develop a plan to selectively evaluate the effectiveness of the Space Shuttle Program (SSP) FMEA/CIL process and assess the validity of the documented controls associated with the SSP CIL. Initially, each project and element will participate in this effort by identifying those FMEAs/CILs that warrant revalidation based on their respective criticality and overall

contribution to design element risk. In addition, STS-107 investigation findings and working group observations affecting FMEA/CIL documentation and risk mitigation controls will be assessed, properly documented, and submitted for SSP approval. If the revalidation assessment identifies a concern regarding effective implementation of controls, the scope of the initial review will be expanded to include a broader selection of components.

This plan will vary according to the specific requirements of each project, but all plans will concentrate revalidation efforts on FMEA/CILs that have been called into question by investigation results or that contribute the most significant risks for that Program element. Revalidation efforts include:

1. Reviewing existing STS-107 investigation fault trees and working group observations to identify areas inconsistent with or not addressed in existing FMEA/CIL risk documentation.
 - a. Verifying the validity of the associated design information, and assessing the acceptability of the retention rationale to ensure that the associated risks are being effectively mitigated consistent with SSP requirements.
 - b. Establishing or modifying Program controls as required.
 - c. Developing and revising FMEA/CIL risk documentation accordingly.
 - d. Submitting revised documentation to the SSP for approval as required.
2. Assessing most significant Program element risk contributors.
 - a. Identifying a statistically significant sample of the most critical CILs from each element project. Including those CILs where ascent debris generation is a consequence of the failure mode experienced.

- b. Verifying that criticality assignments are accurate and consistent with current use and environment.
- c. Validating the Program controls associated with each item to ensure that the level of risk initially accepted by the SSP has not changed.
 - 1. Establishing or modifying Program controls as required.
 - 2. Developing and revising FMEA/CIL risk documentation accordingly.
 - 3. Submitting revised documentation to the SSP for approval as required.
- d. Determining if the scope of the initial review should be expanded based on initial results and findings. Reassessing requirements for performance of FMEAs on systems previously exempted from Program requirements, such as the Thermal Protection System, select pressure and thermal seals, and certain primary structure.

The System Safety Review Panel (SSRP) will serve as the forum to review the project assessment of the validity and applicability of the CIL retention rationale. To the maximum extent possible, the SSRP will perform actual on-site assessment to confirm the existence and effectiveness of controls. Additionally, the SSRP will review any updates to baselined CILs.

RTF constraints will be assessed according to this plan, but all FMEAs/CILs will be reviewed by the end of 2005.

STATUS

Each project and element is in the process of reviewing its fault-tree-related FMEAs/CILs according to the Program Requirements Control Board (PRCB) approved schedules.

FORWARD WORK

Should some of the FMEA/CIL waivers not pass this review, NASA may have to address hardware or process changes.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	Projects status reports to PRCB
SSP	Dec 03	Completion of review



Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 10

NASA will review Program, project, and element contingency action plans and update them based on *Columbia* mishap lessons learned.

BACKGROUND

The Space Shuttle Program (SSP) Program Requirements Control Board has directed all Shuttle projects and elements to review their internal contingency action plans for ways to improve processes.

NASA IMPLEMENTATION

The SSP will update its Program-level contingency action plan to reflect the lessons learned from the *Columbia* mishap. SSP projects and elements will prepare their internal contingency action plans in accordance with Program guidelines. In addition, the SSP will recommend changes to the Agency Contingency Action Plan for Space Flight Operations.

The contingency action plan worked well for the *Columbia* accident, but areas that need improvement were identified during the post-accident review.

1. International roles, responsibilities, and relationships in the event of a Shuttle mishap are not well defined. Agreements associated with landing site support are in place, but lines of responsibility for accident response are vague or absent.
2. A particular success of the *Columbia* accident response was the integration of NASA's contingency action plan with a wide variety of Federal, state, and local organizations. To improve the immediate response to any future accident or incident, NASA should capture these lessons in revisions to its plans and formalize them in standing agreements with other agencies (e.g., Federal Emergency Management Agency (FEMA) and Environmental Protection Agency).
3. FEMA provided immediate and indispensable access to communication, computer, and field equipment for the *Columbia* accident response and recovery effort. They also provided transportation, search assets, people, and money for goods and services. NASA should plan on providing these assets for any future

incidents that are not of a magnitude significant enough to trigger FEMA participation.

4. NASA will consider developing or acquiring a generic database to document vehicle debris and handling.
5. NASA and the Department of Defense manager for Shuttle contingency support will review their agreement to ensure understanding of relative roles and responsibilities in accident response.
6. NASA will ensure that a geographic information system (GIS) is available and ready to provide support in the event of a contingency. The GIS capabilities provided during the *Columbia* recovery were of great importance.
7. The Mishap Investigation Team (MIT) is a small group of people from various disciplines. NASA will review MIT membership and supplemental support, and include procedures in its contingency plan for quickly supplementing MIT activities with administrative, computer, and database support and debris management.
8. Since replacing initial responders with volunteers is important, NASA will consider developing a volunteer management plan. For the *Columbia* recovery, an impromptu system was implemented that worked well.
9. NASA will review the frequency and content of contingency simulations for adequacy. The SSP holds useful contingency simulations that include senior NASA managers. An on-orbit contingency simulation will be considered, and attendance by Accident Investigation Board standing members will be strongly encouraged.
10. NASA will include additional contingency scenarios in the contingency action plan. The current plan, which is primarily oriented toward ascent accidents, will be revised to include more orbit and entry scenarios with appropriate responses.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Dec 03	Review and baseline revisions to SSP Contingency Action, NSTS 07700, Vol. VIII, App. R



Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 11

Based on corrosion recently found internal to body flap actuators, NASA will inspect the fleet leader vehicle actuators to determine the condition of similar body flap and rudder speed brake actuators.

BACKGROUND

Internal corrosion was found in OV-104 body flap (BF) actuators in Fall 2002, and subsequently in the OV-103 BF actuators. In addition, corrosion pits were discovered on critical working surfaces of two BF actuators (e.g., planet gears and housing ring gears), and general surface corrosion was found inside other BF actuators.

Since the rudder speed brake (RSB) actuator design and materials are similar to BF actuators, similar internal corrosion in RSB actuators could adversely affect performance of Criticality 1/1 hardware. Any existing corrosion will continue to degrade the actuators. The loss of RSB functionality due to “freezing up” of the bearing or jamming caused by broken gear teeth would cause Orbiter loss of control during entry.

Current RSB actuators have never been inspected, and the operational life of the installed RSB actuators is outside of Orbiter and industry experience. The Space Shuttle Program (SSP) and the Space Flight Leadership Council approved removal and refurbishment of all four of the OV-103 RSB actuators to investigate corrosion concerns. If OV-103 RSB actuators (figure SSP 11-1) are found with severe corrosion, they could affect OV-104 readiness for return to flight.

NASA IMPLEMENTATION

The Space Shuttle Program (SSP) directed the removal and refurbishment of all four OV-103 RSB actuators. Current spares inventory includes four RSB actuators. All spare RSB actuators were returned to the vendor for acceptance test procedure (ATP) revalidation. All passed ATP and were returned to logistics. The spare RSB actuators will be installed in OV-103. Original OV-103 RSB actuators will then be refurbished by the vendor and installed on OV-104 at the next OV-104 Orbiter maintenance down period (OMDP). OV-104 RSB actuators will be removed, refurbished, and installed on OV-105 at the next OV-105 OMDP.

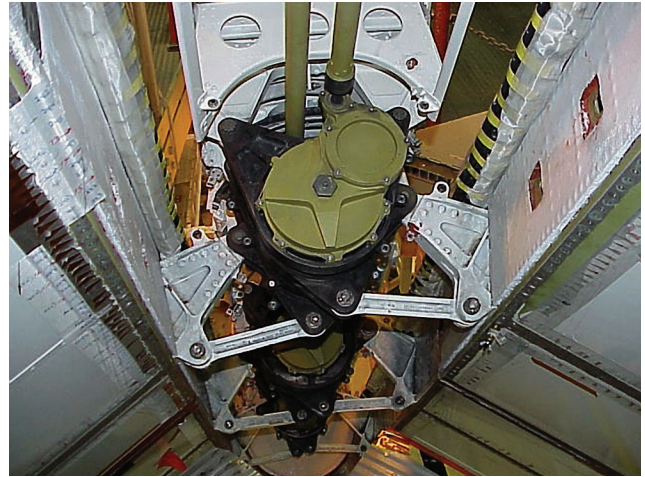


Figure SSP 11-1. OV-103 RSB actuator

STATUS

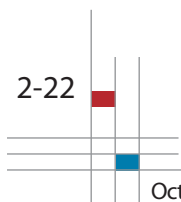
The ground support equipment needed for the removal and refurbishment of the RSB actuators has been procured and made ready for use at the Kennedy Space Center. The RSB actuators were removed from OV-103 and shipped to the vendor where they are being disassembled and inspected.

FORWARD WORK

The SSP will review findings from the inspections of the OV-103 RSB actuators. If the results of the OV-103 RSB actuator inspections are favorable, rationale will be developed for continuing to fly OV-104 four more times before RSB actuator inspection. The rationale will also be based on further different scenarios looking at the sensitivity for observed pit depths as well as determining the worst-case condition.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Complete)	Initial plan reported to SFLC
SSP	Aug 03 (Complete)	ATP Spare RSB actuators at vendor and returned to Logistics
SSP	Sep 03 (Complete)	OV-103 RSB actuators removed and replaced with spares
SSP	Dec 2003	RSB findings and analysis completed





Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 12

NASA will review flight radar coverage capabilities and requirements for critical flight phases.

BACKGROUND

In addition to Shuttle vehicle ascent imaging by photo and visual means, NASA uses radar systems of the Air Force Eastern Range to monitor Space Shuttle launches. There are several C-Band radars and a Multiple Object Tracking Radar (MOTR) used to monitor the ascent trajectory. Although not specifically designed to track debris, these radars have some limited ability to resolve debris separating from the ascending vehicle, particularly between T+30 to T+250 seconds.

During the STS-107 launch, the MOTR, which is specifically intended for the purpose of tracking several objects simultaneously, was unavailable.

NASA IMPLEMENTATION

Launch commit criteria (LCC) will be amended to require the MOTR to be available for all future Space Shuttle launches. Independent of NASA, the Eastern Range is also investigating upgrades to the radars and capabilities of the systems that will be used to monitor Shuttle launches.

The Space Shuttle Systems Engineering and Integration Office has commissioned the Ascent Debris Radar Working Group (ADRWG) to characterize the debris environment during a Space Shuttle launch and to identify/define the return signals seen by the radars. Once the capabilities and limitations of the existing radars for debris tracking are understood, this team will research proposed upgrades to the location, characteristics, and post-processing techniques needed to provide improved radar imaging of Shuttle debris.

Specific technical goals are to improve the radars' ability to resolve, identify, and track potential debris sources. Another goal is to decrease the postlaunch data processing time such that a preliminary radar assessment is available more rapidly, and to more easily correlate the timing of the ascent radar data to optical tracking systems. Successful implementation of a radar debris tracking system will have an advantage over optical

systems as it is not constrained by ambient lighting or cloud interference. It further has the potential to maintain insight into the debris shedding environment beyond the effective range of optical tracking systems.

STATUS

The ADRWG was initiated in August 2003. After a review of existing debris documentation and consultation with radar experts within and outside of NASA, a preliminary presentation of the working group findings and recommendations was provided to the Space Shuttle Program (SSP) office in September 2003.

The ADRWG constructed a composite list of known and not previously known potential debris sources. When coordinated with all Shuttle projects, this list will be the basis for analysis of radar identification capabilities; e.g., radar cross section (RCS) signatures. Analyses will include comparisons against known RCS signatures as a means of correlating results.

FORWARD WORK

NASA is updating the LCC to include the MOTR in support of Shuttle launches. The ADRWG will hold technical interchange meetings over the next three months to determine NASA recommendations and requirements regarding the use of radar for debris tracking in future missions.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
ADRWG	Oct 03	Final list of debris sources
ADRWG	Nov 03	Complete Radar Study
ADRWG	Nov 03	Finalize finding and recommendations
SSP	Dec 03	Baseline requirements and initiate implementation





Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 13

NASA will verify that hardware processing and operations are within the hardware qualification and certification limits.

BACKGROUND

An Orbiter Project Office investigation into several Orbiter hardware failures identified certification environments that were not anticipated or defined during original qualifications. Some examples of these include drag chute door pin failure, main propulsion system flow liner cracks, and environmental control and life support system secondary O₂/N₂ flex hose bellows failure.

Because of these findings by the Orbiter Project Office, all projects and elements are assessing all Space Shuttle hardware operations according to requirements for certification/qualifications. If a finding is determined to be a constraint to flight, the project or element will immediately report the finding to the Program Requirements Control Board (PRCB) for disposition.

NASA IMPLEMENTATION

Before the *Columbia* accident, on December 17, 2002, the Space Shuttle Program (SSP) Council levied an action to all SSP projects and elements to review their hardware qualification and verification requirements, and verify that processing and operating conditions are consistent with the original hardware certification (memorandum MA-02-086). At the SSP Council meeting on April 10 and 11, 2003, each Program project and element identified that

their plan for validating that hardware operating and processing conditions, along with environments or combined environments, is consistent with the original certification (memorandum MA-03-024). The PRCB has reissued this action as a return to flight action.

STATUS

Interim status reports from the SSP project and element organizations have been presented to the SSP PRCB and will continue through November 2003.

FORWARD WORK

The SSP projects and elements will complete their reassessments by December 2003. Actions, if required, to implement the findings will then be as directed by the PRCB.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
All SSP project and element organizations	Dec 03	Present completed plans and schedules to SSP PRCB





Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 14

Determine critical Orbiter impact locations and TPS damage size criteria that will require on-orbit inspection and repair. Determine minimum criteria for which repairs are necessary and maximum criteria for which repair is possible.

BACKGROUND

The Shuttle Thermal Protection System (TPS) consists of various materials applied externally to the outer structural skin of the Orbiter that allow the skin temperatures to remain within acceptable limits during the extreme temperatures encountered during entry. Failure of the TPS can result in the catastrophic loss of the crew and vehicle. The TPS is composed of an assortment of materials that includes Reinforced Carbon-Carbon (RCC), tiles, Nomex-coated blankets, thermal panes, metals, silica cloths, and vulcanizing material.

Failure of the TPS can be caused by debris impact. The debris impact location, energy, impact angle, material, density, and shape are all critical factors in determining the effects of the debris impact on the TPS.

NASA IMPLEMENTATION

NASA is developing models to accurately predict the damage resulting from a debris impact. Efforts to develop a comprehensive damage-tolerance testing plan are in work. NASA is also developing more mature models to determine which damage is survivable and which damage must be repaired before safe entry.

A Program Requirements Control Board (PRCB) action encompasses all efforts related to the testing and analysis necessary to determine the thresholds between damage and no-damage cases, between damage that is safe for entry and damage that must be repaired. This action also addresses the development of models to improve tile and RCC damage prediction and to determine the maximum possible repair capability while in flight.

To fulfill this PRCB action, the Orbiter Debris Impact Assessment Team (ODIAT) was created to integrate all NASA, United Space Alliance, Boeing, and Lockheed efforts necessary to determine the different debris damage thresholds for both tile and RCC and to develop predictive debris damage models. Figure SSP 14-1 shows the interfaces between the ODIAT and various new or

existing teams that are working return to flight (RTF) activities.

The ODIAT effort is comprised of four main activities:

- Impact testing on tile, RCC flat plates, and full RCC panels;
- Material property testing of RCC coupons and potential debris types;
- Analysis and integration of test results into predictive models; and
- Damage tolerance testing and analysis to determine the threshold for damage that must be repaired.

STATUS

Efforts are under way in each of the major focus areas described above. Tile testing is planned for Southwest Research Institute (SwRI) in San Antonio (foam impacts), White Sands (ice impacts), and Kennedy Space Center (ablator impacts). Full-scale RCC panel impact tests are ongoing at SwRI. RCC panel 9L from OV-103 was shot with a 0.1-lb piece of foam at 701 ft/sec. No damage resulted from the impact. Subsequent tests are being planned at greater masses and velocities. Coupon testing for material properties has begun at Southern Research Institute in Birmingham. Data from these tests will be used to verify and modify the current models being used. The production of additional RCC coupon material for testing is under way at Lockheed-Martin in Dallas. Analysis and modeling work is continuing for both the RCC and the tile. The data collected will be used to develop and verify two types of RCC and tile models.

The first type of model will be used in real-time situations where a timely answer is needed. This model will provide a conservative answer to possible damage assessments. The second type of model will be a detailed hydrocode or LSDYNA model that will provide very accurate predictions of possible damage. This model may take several days to code and run and will be used for situations where time is

not a critical factor. The analysis and modeling tasks are being worked in conjunction with Boeing, Langley Research Center, Glenn Research Center, and SwRI. Efforts to develop a comprehensive damage-tolerance testing plan are in work. This effort will show, through structural and thermal testing of damaged RCC and tile samples, exactly how much damage can be allowed while still ensuring a safe return for the crew and vehicle.

FORWARD WORK

NASA will continue to conduct tests that provide the material and physical properties of the TPS. NASA is also developing minor and critical damage criteria for the TPS by performing RCC foam impact tests, arc jet tests, and wind tunnel tests. Results from these tests will also help to determine the location dependencies of the impacting debris. Techniques for repairing tile and RCC are under development. The ability of the International Space

Station crew to provide support to an Orbiter crew during a Shuttle TPS repair scenario or during a crew rescue operation is under investigation. The combination of these capabilities will help to ensure a lower probability that critical damage will be sustained, while increasing the probability that any damage that does occur can be detected and the consequences mitigated during flight.

Additional information related to this action can be found in other sections of this Implementation Plan. Information on the damage that the TPS can sustain, and still allow for successful entry of the Orbiter into Earth's atmosphere, is further explained in NASA's response to Recommendation R3.3-3. Information regarding the TPS inspection and repair capabilities being investigated is further explained in NASA's answer to Recommendations R6.4-1 and R3.3-2.

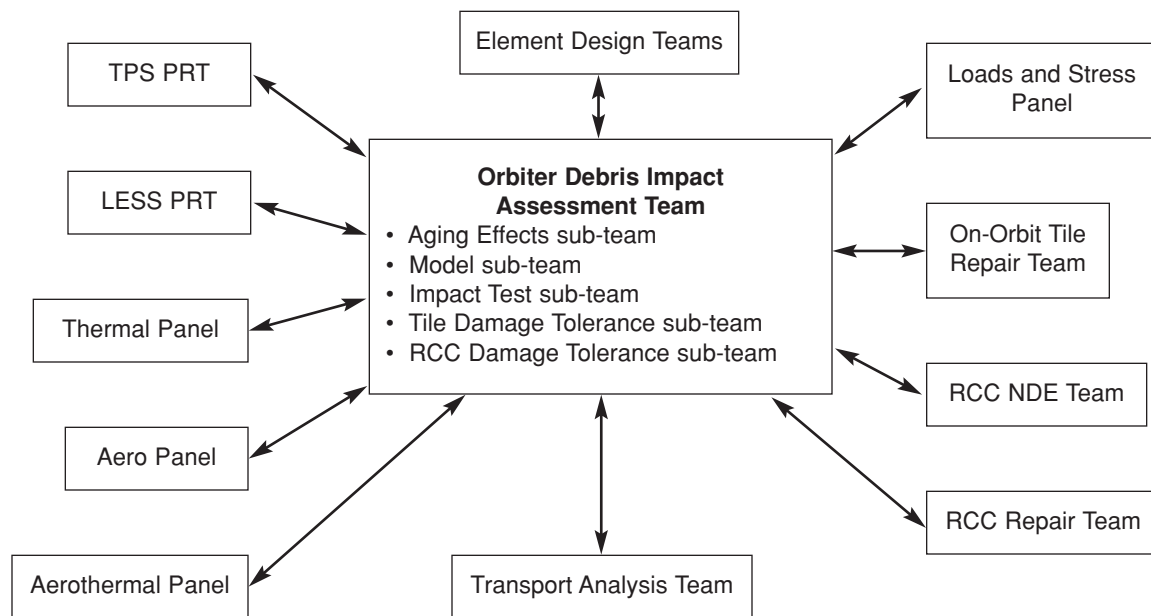
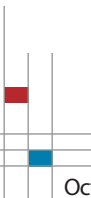


Figure SSP 14-1. Orbiter Debris Impact Assessment Team integrates efforts from other teams

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
ODIAT	Oct 03	Panel 9 Testing Complete
ODIAT	Mar 04	RCC Materials Testing Complete
ODIAT	Apr 04	Tile Impact Testing Complete
ODIAT	Apr 04	RCC Model Correlation Complete
ODIAT	Oct 04	Final RCC Model Verification (Contingency RTF)
ODIAT	TBD	Tile Model Correction Complete
ODIAT	TBD	Damage Tolerance Test and Analysis Complete

2-30



October 15, 2003



Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 15

NASA will identify and implement improvements in problem tracking, in-flight anomaly (IFA) disposition, and anomaly resolution process changes.

BACKGROUND

Bipod ramp foam was released during the launch of STS-112 in October 2002. After the mission, the Space Shuttle Program (SSP) considered this anomaly and directed the External Tank Project to conduct the testing and analysis necessary to understand the cause of bipod foam release and present options to the Program for resolution. The Program did not hold completion of these activities as a constraint to subsequent Shuttle launches because the interim risk was not judged significant. The *Columbia* accident investigation results clearly disclose the errors in that engineering judgment.

NASA IMPLEMENTATION

NASA will conduct a full review of its anomaly resolution processes with the goal of ensuring appropriate disposition of precursor events in the future.

In support of the return to flight activity, the SSP, supported by all projects and elements, began to identify and implement improvements to the problem tracking, in-flight anomaly disposition, and anomaly resolution processes. A team is reviewing SSP and other documentation and processes, as well as audited performance for the past three Shuttle missions. The conclusion is that while clarification of the requirements identified in NSTS 08126, Problem Reporting and Corrective Action (PRACA) System Requirements, is needed, the implementation of those requirements appears to be the area that has the largest opportunity for improvement. Issues identified indicate misinterpretations of definitions,

resulting in misidentification of problems, and noncompliance with tracking and reporting requirements.

The recommended actions are

- (1) Train all SSP elements and support organizations on PRACA requirements and processes. The SSP community is not as aware of the PRACA requirements and processes as they should be to avoid past mistakes.
- (2) Update NSTS 08126 to clarify the in-flight anomaly (IFA) definition, delete “program” IFA terminology, and add payload IFAs and Mission Operations Directorate (MOD) anomalies to the scope of the document.
- (3) Update the PRACA nonconformance system (Web PCASS) to include flight software, payload IFAs, and MOD anomalies. These changes will be incorporated in a phased approach. The goal is to have a single nonconformance tracking system.

STATUS

Initial PRACA process changes have been presented to the PRCB. Additional work is required to complete this activity.

SCHEDULE

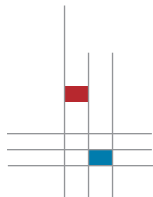
TBS





CAIB Observations

The observations contained in Chapter 10 of the CAIB report expand upon the CAIB recommendations, touching on the critical areas of public safety, crew escape, orbiter aging and maintenance, quality assurance, test equipment, and the need for a robust training program for NASA managers. NASA is committed to examining these observations and has already made significant progress in determining appropriate corrective measures. Future versions of the Implementation Plan will expand to include additional suggestions from various sources. This will ensure that beyond returning safely to flight, we are institutionalizing sustainable improvements to our culture and programs that will ensure we can meet the challenges of continuing to expand the bounds of human exploration.





Columbia Accident Investigation Board

Observation 10.1-1

NASA should develop and implement a public risk acceptability policy for launch and re-entry of space vehicles and unmanned aircraft.

BACKGROUND

Launch and entry¹ of space vehicles and operation of uncrewed aircraft typically involve substantial hazards, which can pose significant risk to the public and operational personnel. In particular, the *Columbia* accident demonstrated that Orbiter breakup during entry has the potential to cause casualties among the general public. As the lead government agency directing or controlling launch, entry, and other range flight operations, NASA is legally responsible for public safety during all phases of the operations.

NASA and the Air Force maintain agreements that provide for the management of safety risk associated with Shuttle launches. The Air Force 45th Space Wing is responsible for consequences within and outside Federal property resulting from Shuttle launch and ascent. This includes risk assessment, risk mitigation, and acceptance/disposition of residual risk to public and operational personnel. The Director of Kennedy Space Center (KSC) is responsible for consequences and risk mitigation for visitors and mission-essential/nonmission essential personnel on KSC's Federal property. The Air Force provides the Director with written notification of launch area risk estimates for Shuttle ascent. No equivalent collaboration exists between NASA and the Air Force for addressing Orbiter entry and landing risks. For past Orbiter entry operations, NASA has not implemented public risk acceptability standards or a process for managing risk to the public.

NASA does not currently have an Agency risk policy that specifically addresses range flight operations, such as launch and entry of space vehicles and operation of uncrewed aircraft. However, NASA has a more general risk management requirement, codified in NASA Policy Directive (NPD) 8700.1A. This NPD calls for NASA to implement structured risk management processes using qualitative and quantitative risk-assessment techniques to make optimal decisions regarding safety and the likelihood of mission success. The NPD also requires program managers to implement risk management policies, guidelines, and standards and establish safety requirements within their programs. These and other related policies are designed to protect the public as well as NASA personnel and property.

¹NASA typically uses the term "entry," which is synonymous with the term "re-entry" used in the *Columbia* Accident Investigation Board (CAIB) report.

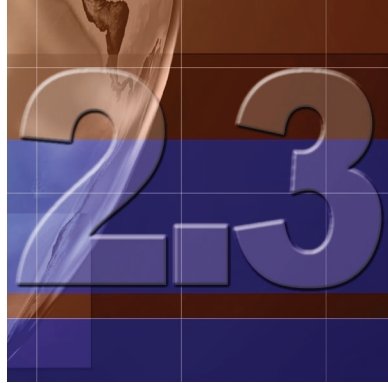
Individual NASA range safety organizations, such as those at Wallops Flight Facility (WFF) and Dryden Flight Research Center (DFRC), have established public and workforce risk management requirements and processes at the local level. These NASA organizations often work in collaboration with the Air Force and other government range safety organizations. They have extensive experience applying risk assessment to the operation of Expendable Launch Vehicles and uncrewed aircraft and are currently developing range safety approaches for the operation of future Reusable Launch Vehicles, which include launch and entry risk assessment.

NASA IMPLEMENTATION

Development of any Agency policy requires significant coordination with the NASA Centers and programs that will be responsible for its implementation. The NASA Headquarters Office of Safety and Mission Assurance (OSMA) has established a risk policy working group to perform the initial development and coordination on the risk acceptability policy for launch and entry of space vehicles and uncrewed aircraft. This working group hosted a range safety risk management workshop July 24 - 25, 2003, at NASA Headquarters. Working group members in attendance included NASA personnel from KSC, DFRC, WFF, Johnson Space Center (JSC), and Headquarters. Also in attendance were representatives from the CAIB.

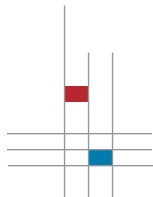
Thus far, the working group has received a comprehensive technical briefing on the CAIB-initiated entry risk study that was performed by ACTA Inc., and obtained perspective on the CAIB investigation and recommendations related to assessing public risk from a CAIB Staff Investigator. They have also obtained Agencywide perspective on application of risk assessment to range operations for all current and planned programs (e.g., Shuttle, Expendable Launch Vehicles, Reusable Launch Vehicles, Unmanned Aerial Vehicles, and high-altitude balloons). Building on this information, they have coordinated plans for addressing risk to the public for return to flight (RTF) and for development of NASA range safety risk policy and have begun to draft a proposed NASA risk policy.

The draft policy will be applicable to all range flight operations, including launch and entry of space vehicles and



CAIB Report, Volume II, Appendix D.a, “Supplement to the Report”

Volume II, Appendix D.a, also known as the “Deal Appendix,” augments the CAIB Report and its condensed list of recommendations. The Appendix outlines concerns raised by Brigadier General Duane Deal and others that, if addressed, might prevent a future accident. The fourteen recommendations contained in this Appendix expand and emphasize CAIB report discussions of Quality Assurance processes, Orbiter corrosion detection methods, Solid Rocket Booster External Tank Attach Ring factor-of-safety concerns, crew survivability, security concerns relating to Michoud Assembly Facility, and shipment of Reusable Solid Rocket Motor segments. NASA is addressing each of the recommendations offered in Appendix D.a. Many of the recommendations have been addressed in previous versions of the Space Shuttle RTF Implementation Plan and, therefore, our response to those recommendations refers to the location in the Plan where our previously provided response is found. Although the recommendations are not numbered in Appendix D.a, we have assigned a number to each of the fourteen recommendations for tracking purposes.



operation of uncrewed aircraft, and will include requirements for risk assessment, mitigation, and acceptance/disposition of residual risk to the public and operational personnel. It will incorporate performance standards that provide for safety while allowing appropriate flexibility needed to accomplish mission objectives and include acceptable risk criteria that are consistent with those used throughout the government, the commercial range community, and with other industries whose activities are potentially hazardous to the public.

Finally, the policy will provide a risk management process within which the required level of management approval increases as the level of assessed risk to public and the workforce increases and will be flexible enough to allow the fidelity of Program risk assessments to improve over time as knowledge of the vehicle's operational characteristics increases and models used to calculate risk are refined.

The policy document being developed will be a part of a NASA Procedural Requirements (NPR) 8715.XX, NASA Range Safety Program, which will describe NASA's range safety policy, roles and responsibilities, requirements, and procedures for protecting the safety and health of the public, the workforce, and property during range operations. Chapter 3 of this NPR will contain the NASA risk management policy for all range operations including launch and entry of space vehicles and operation of uncrewed vehicles.

SCHEDULE

Enter the resulting draft NPR into the January 2004 NODIS review cycle, which will lead to final signature by the end of April 2004.

Action	January NODIS Review Cycle
Begin SMA Discipline Review	10/30/03 (Complete)
SMA Review Comments Due	11/30/03 (Complete)
Disposition SMA Comments	11/30/03 – 12/22/03 (Complete)
Final Proofread, prepare NODIS Package, route for OSMA Management Signature, provide feedback to SMA Directors	12/22/03 – 1/6/04 (Complete)
Published Deadline for Submission to NODIS	1/16/04 (Complete)
NODIS Review Begins	1/27/04
NODIS Comments Due	2/26/04
Disposition Comments and Prepare Final Package	2/26/04 – 3/11/04
Signature (Purple) Package Due to JM	3/11/04
Signature Package Processing (Legal, Correspondence Control, Code A)	3/11/04 – 4/26/04
Anticipated Final Signature	4/26/04

NOTE: Gray-shaded boxes are hard deadlines

STATUS

The draft NPR, including the risk policy, is nearing completion. The NASA Safety and Mission Assurance (SMA) Directors were briefed on the draft NPR on October 15, 2003, with particular focus on the range safety risk policy. The SMA Directors and other members of the NASA SMA community completed a review of the draft NPR in November 2003. The resulting draft is now being readied for entry into the Agency's formal approval process using the NASA Online Directives Information System (NODIS).

FORWARD WORK

The draft risk policy requires that each program documents its safety risk management process in a written plan approved by the responsible NASA official(s). Prior to RTF, the Space Shuttle Program (SSP) will draft its plan and obtain the required Agency approvals. The SSP will also perform launch and entry risk assessments for the initial and subsequent planned Shuttle missions. Launch risk assessment will continue to be performed by the 45th Space Wing in coordination with the Shuttle program and KSC. SSP efforts to assess entry risk are addressed by Space Shuttle Program Action #2.

In accordance with the risk policy and the Space Shuttle safety risk management plan, the appropriate level of NASA management will review and address the assessed risk to the public and the workforce prior to RTF.



Columbia Accident Investigation Board

Observations 10.1-2 and 10.1-3

O10.1-2 NASA should develop and implement a plan to mitigate the risk that Shuttle flights pose to the general public.

O10.1-3 NASA should study the debris recovered from *Columbia* to facilitate realistic estimates of the risk to the public during Orbiter re-entry.

BACKGROUND

The *Columbia* accident raised important questions about public safety, since *Columbia*'s debris was scattered over a ground impact footprint approximately 200 miles long and 15 miles wide. Although there were no injuries to the public due to the falling debris, the accident demonstrates that Orbiter breakup during entry has the potential to cause injury or casualties among the general public

NASA IMPLEMENTATION

NASA is currently studying the relative risks to persons and property associated with entry to its three primary Shuttle landing sites. Included in these analyses are data gathered from the debris recovery and reconstruction effort, such as entry survivability of certain hardware, the debris ground impact patterns, and likely ballistics coefficients. Based on these data, NASA will develop plans and policies to mitigate risk posed to the public by Shuttle overflight during entry. The results of these analyses will also determine if some ground tracks must be removed from consideration as normal, preplanned, end-of-mission landing opportunities. For a complete discussion of this topic, see the related actions in Space Shuttle Program Action 2 (SSP-2), Public Risk of Overflight.

STATUS

The Space Shuttle Program issued a Program Requirements Review Board (PRCB) Directive to JSC/DA (Mission Operations Directorate) to develop and implement a plan to mitigate the risk to the general public.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Nov 03	Update to Return to Flight (RTF) Planning Team and SSP PRCB
SSP	Jan 04	Report to RTF Planning Team and SSP PRCB





Columbia Accident Investigation Board

Observation 10.2-1

Future crewed-vehicle requirements should incorporate the knowledge gained from the *Challenger* and *Columbia* accidents in assessing the feasibility of vehicles that could ensure crew survival even if the vehicle is destroyed.

NASA IMPLEMENTATION

A multidisciplinary team at the NASA Johnson Space Center, called the Crew Survival Working Group (CSWG), is developing a report incorporating lessons learned from both the *Challenger* and *Columbia* accidents. The CSWG has participation from the Flight Crew Operations, Engineering, and Space and Life Sciences Directorates. The CSWG report will provide recommendations for enhancing crew survivability for crewed vehicles.

In addition, NASA published a Human Rating Requirements and Guidelines for Space Flight Systems policy document, NPG 8705.2, in July 2003. This document includes a requirement for flight crew survivability achieved through a combination of abort and crew escape capabilities. The requirements in NPG 8705.2 evolved from NASA lessons learned from the Space Shuttle, Space Station and other human space flight programs, including the lessons from the *Challenger* and *Columbia* accidents.

STATUS

The CSWG is developing a report that will include the findings and recommendations from the *Challenger* and *Columbia* accidents.

NPG 8705.2 requires all new programs developing space flight systems that will carry humans to develop a program-specific human rating plan to address all of the crew survivability requirements in the NPG. The Orbital Space Plane (OSP) program developed an OSP Human Rating Plan early in the concept phase prior to the Systems Requirements Review. The Associate Administrator for Space Flight chartered a Human Rating Independent Review Team (HRIRT) to assess the OSP program requirements development, design, and operations in accordance with the NPG. After a thorough review of OSP requirements development, the OSP HRIRT recommended approval of the initial OSP Human Rating Plan on September 12, 2003. This plan was approved by the Office of Space Flight and released on September 19, 2003.

FORWARD WORK

The CSWG report will contain recommendations for improving crew survivability for crewed vehicles. These recommendations will be coordinated with the appropriate program offices.

The OSP program is progressing toward a Request for Proposal and Systems Design Review that will address detailed technical requirements to ensure crew survivability through abort and crew escape. The OSP HRIRT will continue to independently assess the OSP program's progress in meeting these requirements.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
CSWG	Nov 03	Draft report and recommendations complete
OSP	Nov 03	OSP Request for Proposal
CSWG	Jan 04	Recommendations coordinated with programs
OSP	Jan 04	OSP Systems Design Review





Columbia Accident Investigation Board

Observation 10.4-1

Perform an independently led, bottom-up review of the Kennedy Space Center Quality Planning Requirements Document to address the entire quality assurance program and its administration. This review should include development of a responsive system to add or delete government mandatory inspections.

BACKGROUND

The response to this observation is addressed in detail in Space Shuttle Program Action 1 (SSP-1), Quality Planning and Requirements Document (QPRD)/Government Mandated Inspection Points (GMIPs).

NASA IMPLEMENTATION

The Space Flight Leadership Council and the Associate Administrator for Safety and Mission Assurance, with concurrence from the Safety and Mission Assurance (SMA) Directors at Kennedy Space Center (KSC), Johnson Space Center (JSC), and Marshall Space Flight Center (MSFC), chartered an independent assessment of the Space Shuttle Program GMIPs for KSC Orbiter Processing and Michoud Assembly Facility (MAF) External Tank manufacturing. The Leadership Council also approved the establishment of an assessment team consisting of members from various NASA centers, the Federal Aviation Administration, the U.S. Army, and the U.S. Air Force. This Independent Assessment Team will assess the KSC QPRD and the MAF Mandatory Inspection Document criteria, their associated quality assurance processes, and the organizations that perform them. The team has already performed site visits, held discussions with Safety and Mission Assurance personnel, and conducted interim discussions with representatives at both KSC and MAF. The team is developing findings, recommendations, and observations. A draft report will be provided to the sponsoring organizations for review and comment. After resolving issues, a final report will be issued. Recommendations will become formal Space Shuttle Program actions. This report will be used as a basis for the Program to evaluate similar GMIP activity at other Space Shuttle manufacturing and processing locations.

In parallel with the Independent Assessment Team's (IAT) review, a new process to make changes to GMIP requirements has been developed, approved, and baselined at

KSC. This process ensures that anyone can submit a proposed GMIP change, and that the initiator who requests a change receives notification of the disposition of the request and the associated rationale. That effort was completed with the release of KSC procedural document P-1822. This process will use a database for tracking the change proposal, the review team's recommendations and the Change Board's decisions. The database automatically notifies the requester of the decision, and the process establishes a means to appeal decisions. Additional changes to the process will be based in part on the results of the IAT's review.

STATUS

The IAT determined that the NASA Quality Assurance programs in place today are relatively good based on the ground rules that were in effect when the programs were formulated; however, these rules have changes since the program's formulation. The IAT recommended that NASA reassess its quality assurance requirements based on the modified ground rules established as a result of the *Columbia* accident. The modified ground rules for the Space Shuttle include an acknowledgement that the Space Shuttle is an aging, relatively high risk development vehicle. As a result, the NASA Safety and Mission Assurance Quality Assurance Program must help to ensure both safe hardware and an effective contractor quality program.

The IAT's findings echo the Observations and Recommendations of the CAIB. Among the recommendations the team identified are

- Strengthen the Agency-level policy and guidance to specify the key components of a comprehensive Quality Assurance Program that includes, among other things, the appropriate application of GMIPs

- Establish a formal process for periodic review of QPRD and GMIP requirements at KSC, and the Mandatory Inspection Documents and GMIPs at MAF, against updates to risk management documentation (Hazard Analyses, Failure Modes and Effects Analyses/Critical Item List) and other system changes
- Continue to define and implement formal, flexible processes for changing the QPRD and adding, changing, or deleting GMIPs
- Document and implement a comprehensive Quality Assurance Program at KSC in support of the Space Shuttle Program activities
- Develop and implement a well defined, systematically deployed Quality Assurance Program at MAF

In response to the CAIB Report, Marshall Space Flight Center (MSFC) and KSC Shuttle Processing Safety and Mission Assurance initiated efforts to address the identified Quality Assurance Program shortfalls. The activities under way at KSC include

- A formal process was implemented to revise GMIPs
- A change review board comprised of the Shuttle Processing Chief Engineer, Safety and Mission Assurance, and, as applicable, contractor engineering representatives has been established to disposition proposed changes
- A new process is under development to document and to implement temporary GMIPs while permanent GMIP changes are pending, or as deemed necessary for one-time or infrequent activities
- A pilot project was initiated to trend GMIP accept/reject data to enhance first-time quality determination and identify paths for root cause correction
- Surveillance has been increased through additional random inspections for hardware and compliance audits for processes
- Enhanced Quality Inspector training, based on benchmarking similar processes, is under development

In response to the shortfalls identified at MAF, MSFC initiated the following:

- Applying CAIB observations and the IAT recommendations to all MSFC propulsion elements
- Formalizing and documenting processes that have been in place for Quality Assurance program planning and execution at each manufacturing location
- Increasing the number of inspection points for External Tank assembly
- Increasing the level and scope of vendor audits (process, system, and supplier audits)
- Improving training across the entire MSFC SMA community, with concentration on the staff stationed at manufacturer and vendor resident management offices

To further strengthen the overall Space Shuttle Quality Assurance Program, a new management position has been established and filled on the Shuttle SMA Manager's staff with a specific focus on Quality.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
NASA HQ	Oct 03 (Complete)	Report out from IAT
NASA HQ	Jan 04 (Complete)	Publish the IAT report



Columbia Accident Investigation Board

Observation 10.4-2

Kennedy Space Center's Quality Assurance programs should be consolidated under one Mission Assurance office, which reports to the Center Director.

BACKGROUND

As part of KSC 2000, separate safety and mission assurance (SMA) offices were formed in each appropriate operational directorate at Kennedy Space Center (KSC). This was done to provide direct SMA support to each of the directorates.

NASA IMPLEMENTATION

In close coordination with the effort led by the Associate Administrator for Safety and Mission Assurance (AA/SMA) in responding to CAIB Recommendation 7.5-2, KSC has established a center-level team to assess the KSC SMA organizational structure.

STATUS

A team is being formed from each KSC directorate with SMA organizations. KSC's Safety, Health and Independent

Assessment Directorate is working with the AA/SMA to determine the optimal organizational structure to support the Space Shuttle and other programs at KSC.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC Safety, Health and Assessment Directorate and AA/SMA	TBD	Recommendations to KSC Center Director





Columbia Accident Investigation Board

Observation 10.4-3

KSC quality assurance management must work with NASA and perhaps the Department of Defense to develop training programs for its personnel.

BACKGROUND

The *Columbia* Accident Investigation Board reported most of the training for quality engineers, process analysts, and quality assurance specialists was on-the-job training rather than formal training. In general, Kennedy Space Center (KSC) training is extensive for the specific hardware tasks (e.g., crimping, wire bonding, etc.), but includes approximately 160 hours of formal, on-the-job, and safety/area access training for each quality assurance specialist. However, there are deficiencies in basic quality assurance philosophy and skills.

NASA IMPLEMENTATION

NASA will benchmark quality assurance training programs as implemented by the Department of Defense (DoD) and Defense Contract Management Agency (DCMA). NASA's goal is to develop comparable training programs for the quality engineers, process analysts, and quality assurance specialists. The training requirements will be documented in our training records template.

STATUS

KSC has benchmarked with DoD and DCMA to understand their training requirements and to determine where we can directly use their training. A team consisting of engineers

and specialists from both the Shuttle and International Space Station Programs is meeting to develop and document a more robust training program.

FORWARD WORK

KSC will benchmark with DoD and the companies used to provide their quality assurance training. Later, KSC will document a comparable training program and update the training templates. Personnel will be given a reasonable timeframe in which to complete the training.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Complete	Benchmark DoD and DCMA training programs
KSC	Mar 04	Develop and document improved training requirements
KSC	Jun 04	Complete personnel training





Columbia Accident Investigation Board

Observation 10.4-4

Kennedy Space Center should examine which areas of International Organization for Standardization 9000/9001 truly apply to a 20-year-old research and development system like the Space Shuttle.

BACKGROUND

The *Columbia* Accident Investigation Board report highlighted Kennedy Space Center's (KSC's) reliance on the International Organization for Standardization (ISO) 9000/9001 certification. The report stated, "While ISO 9000/9001 expresses strong principles, they are more applicable to manufacturing and repetitive-procedure industries, such as running a major airline, than to a research-and-development, flight test environment like that of the Space Shuttle. Indeed, many perceive International Standardization as emphasizing process over product." ISO 9000/9001 is also currently a contract requirement for United Space Alliance (USA).

NASA IMPLEMENTATION

NASA has assembled a team of Agency and industry experts to examine the ISO 9000/9001 standard and its applicability to the Space Shuttle Program. Specifically, this examination will address the following: 1) ISO 9000/9001 applicability to USA KSC operations; 2) how NASA should use USA's ISO 9000/9001 applicable elements in evaluating USA performance; 3) how NASA currently uses USA's ISO certification in evaluating its performance; and, 4) how NASA will use the ISO certification in the future.

STATUS

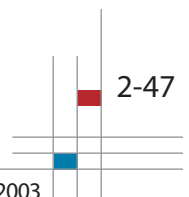
NASA has assembled the ISO 9000/9001 review team. The team has established a review methodology and has partially completed the first step, determining the applicability of the standard to USA KSC operations.

FORWARD WORK

- | The team is working to the schedule defined below which has changed since the last release of the Implementation Plan. After completion of all activities, the KSC surveillance plan will be updated to reflect the proper and implemented use of ISO 9000/9001 certification.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Nov 03	Identify applicability to USA KSC Operations
KSC	Jan 04	Proper usage of standard in evaluating contractor performance
KSC	Jan 04	Current usage of standard in evaluating contractor performance
KSC	Feb 04	Future usage of standard and changes to surveillance or evaluation of contractor
KSC	Feb 04	Presentation of Review







Columbia Accident Investigation Board

Observation 10.5-1

Quality and Engineering review of work documents for STS-114 should be accomplished using statistical sampling to ensure that a representative sample is evaluated and adequate feedback is communicated to resolve documentation problems.

BACKGROUND

The Kennedy Space Center (KSC) Processing Review Team (PRT) conducted a review of the ground processing activities and work documents from all systems for STS-107 and STS-109, and from some systems for Orbiter Major Modification. This review examined approximately 3.9 million work steps and identified 9672 processing and documentation discrepancies resulting in a work step accuracy rate of 99.75%. While this is comparable with our past performance in recent years, our goal is to further reduce our processing discrepancies; therefore, we initiated a review of STS-114 paper.

NASA IMPLEMENTATION

In complying with this observation, NASA has performed a review and systemic analysis of STS-114 work documents for the time period of Orbiter Processing Facility roll-in through system integration test of the flight elements in the Vehicle Assembly Building. Pareto analysis of the discrepancies revealed areas where root cause analysis is required.

STATUS

The STS-114 Problem Resolution Team systemic analysis revealed six Corrective Action recommendations consistent with the technical observations noted in the STS-107/109

review. Teams were formed to determine the root cause and long-term corrective actions. These recommendations were assigned Corrective Action Requests that will be used to track the implementation and effectiveness of the corrective actions. In addition to the remedial actions from the previous review, there were nine new system specific remedial recommendations. These remedial actions address other observations that are primarily documentation errors.

FORWARD WORK

The root cause analysis results and Corrective Actions will be presented to the Space Shuttle Program tentatively scheduled for November 2003. Quality and Engineering will continue to statistically sample and analyze work documents for all future flows.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Dec 03	Program Requirements Control Board





Columbia Accident Investigation Board

Observation 10.5-2

NASA should implement United Space Alliance's suggestions for process improvement, which recommend including a statistical sampling of all future paperwork to identify recurring problems and implement corrective actions.

BACKGROUND

The Kennedy Space Center (KSC) Processing Review Team (PRT) conducted a review of the ground processing activities and work documents from all systems for STS-107 and STS-109, and from some systems for the Orbiter Major Modification. This review examined approximately 3.9 million work steps and identified 9672 processing and documentation discrepancies resulting in a work step accuracy rate of 99.75%. These results were validated with the review of STS-114 work documents (ref. Observation 10.5-1). Pareto analysis of the discrepancies revealed areas where corrective action is required and where NASA Shuttle Processing surveillance needs augmentation.

NASA IMPLEMENTATION

NASA will refocus engineering and safety and mission assurance (SMA) surveillance efforts and enhance the communication of surveillance results between the two organizations. Engineering surveillance of similar tasks and the design process for government-supplied equipment and ground systems will be increased to allow NASA earlier visibility into the tasks. SMA surveillance will be expanded to include sampling of closed paper and hardware (ref. Observation 10.5-3). The initial focus for sampling closed paper will be to determine the effectiveness of corrective action taken by the contractor as a result of the Processing Review Team's work.

NASA will improve communication between engineering and SMA through the activation of a Web-based log and the use of a new Quality Planning and Requirements Document (QPRD) change process for government inspection requirements.

STATUS

Engineering and SMA organizations are evaluating and revising their surveillance plans. Required changes to the Ground Operations Operating Procedures are being identified. Development of the QPRD change process for government inspection requirements and the supporting database is nearing completion. The upgrade of Engineering's daily status log (ELOG) to a Web-based version for all Shuttle Processing activities is in test.

FORWARD WORK

NASA will implement periodic reviews of our surveillance plans and adjust the tasks as necessary to target problem areas identified by data trends and audits.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Oct 03	QPRD change process
KSC	Nov 03	Surveillance task identification
KSC	Nov 03	Surveillance plan documentation update
KSC	Nov 03	ELOG deployment





Columbia Accident Investigation Board

Observation 10.5-3

NASA needs an oversight process to statistically sample the work performed and documented by Alliance technicians to ensure process control, compliance, and consistency.

BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a statistically valid sampling program to evaluate contractor operations. Kennedy Space Center (KSC) currently samples contractor operations within the Space Shuttle Main Engine Processing Facility; however, the sample size is not statistically significant and does not represent all processing activities.

NASA IMPLEMENTATION

NASA will implement a sampling program and evaluate the resources required to collect sufficient samples to provide statistically significant data. The initial program will be very similar to the contractor-deployed program; however, NASA data will be maintained separately from the contractor data. NASA will develop and trend metrics to provide enhanced insight into contractor performance.

STATUS

KSC previously completed a pilot for a sampling program similar to that used by United Space Alliance. This sampling program has been implemented with two NASA process analysts.

FORWARD WORK

KSC will determine the resources required to provide a statistically significant sampling program. Metrics, including goals, will be developed and trended.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Nov 03	Provide resource estimate
KSC	Complete	Implement sampling program (not statistically valid until fully resourced)
KSC	Mar 04	Develop metrics





Columbia Accident Investigation Board

Observation 10.6-1

The Space Shuttle Program Office must make every effort to achieve greater stability, consistency, and predictability in Orbiter Major Modification planning, scheduling, and work standards (particularly in the number of modifications). Endless changes create unnecessary turmoil and can adversely impact quality and safety.

BACKGROUND

NASA agrees that greater stability in Orbiter Maintenance Down Period (OMDP) processes will reduce risk.^

NASA IMPLEMENTATION AND STATUS

The next OMDP, for OV-105, will begin in December 2003. In planning for this OMPD, NASA is emphasizing stability in the work plan to ensure that quality and safety are maintained at the highest possible levels.

FORWARD WORK

Before beginning OMDP work, the Space Shuttle Program (SSP) will define all required modifications to allow accurate planning.

NASA will continue to integrate lessons learned from each OMDP and will emphasize factors that could destabilize plans and schedules.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Oct 03	OV-105 OMDP Modification Site Flow Review





Columbia Accident Investigation Board

Observation 10.6-2

NASA and United Space Alliance managers must understand workforce and infrastructure requirements, match them against capabilities, and take actions to avoid exceeding thresholds.

BACKGROUND

The transfer of Orbiter maintenance down periods (OMDPs) from Palmdale to Kennedy Space Center placed additional demands on the existing infrastructure, Ground Support Equipment, and personnel. NASA made significant efforts to anticipate these demands, to transfer the needed equipment from Palmdale, and to hire additional personnel required to accomplish the OMDP related tasks independent of normal Orbiter flow processing. Because of the fluctuating demands on the Orbiters supporting the flight manifest, some workers with unique critical skills were frequently shared among the Orbiter in OMDP and the Orbiters in the flight line. Additional inspection and modification requirements, and unanticipated rework for structural corrosion and thermal protection systems, created demands on limited critical skill sets not previously anticipated.

NASA IMPLEMENTATION

NASA has learned from the just completed OV-103 OMDP and applied these lessons to the planning of the OV-105 OMDP. These lessons will provide NASA and United Space Alliance managers with an early opportunity to integrate infrastructure, equipment, and personnel from a more complete set of work tasks, unlike the piecemeal approach used on just completed OV-103 OMDP. The requirements for the second OV-105 OMDP have been approved, with the exception of two modifications. The Program Requirements Control Board approved 72 modifications at the Modification Site Requirements Review in early July 2003, and is currently scheduled to review the overall modification plan again in mid-October at the Modification Site Flow Review. The OV-105 OMDP is scheduled to begin in December 2003.

Many “out of family” discrepancies identified as the result of scheduled structural and wiring inspections require design center coordination and disposition. The incorporation of new Orbiter modifications also requires close coordination for design issue resolution. Timely design response can reduce the degree of re-scheduling

and critical skill rebalancing required. During the OV-103 OMDP, design center engineers were available on the floor in the Orbiter Processing Facility where the work was being accomplished to efficiently and effectively disposition discrepancies when identified. This approach seemed to reduce the need to reschedule work until a disposition was made, thus reducing the need for workload or resource rebalancing.

STATUS

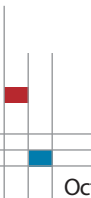
- Lesson Learned from the third OV-103 OMDP are being incorporated into the current OV-105 OMDP planning. More accurate estimates of structural inspection and wiring discrepancies are anticipated from the review of OV-103 discrepancy data.
- Additional personnel hiring focusing on critical skill sets is being coordinated with NASA Shuttle Processing Directorate and the NASA Orbiter Project Office.
- Additional emphasis on “on floor” design response helped to reduce rescheduling and resource rebalancing on OV-103’s third OMDP. This effort will be expanded for OV-105’s first OMDP.

FORWARD WORK

The Space Shuttle Program will follow the practice of approving most or all of the known modifications for incorporation at the beginning of an Orbiter Vehicle’s OMDP, typically at the Modification Site Requirements Review. Lessons learned will be captured for each ensuing OMDP and will be used to improve future OMDP processing.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Oct 03	Mod Site Flow Review
SSP	Dec 03	Complete OV-103 Lessons Learned





Columbia Accident Investigation Board

Observation 10.6-3

NASA should continue to work with the U.S. Air Force, particularly in areas of program management that deal with aging systems, service life extension, planning and scheduling, workforce management, training, and quality assurance.

BACKGROUND

In June 2003, NASA requested that the U.S. Air Force conduct an assessment of the Orbiter Maintenance Down Period/Orbiter Major Modification (OMDP/OMM) being performed at Kennedy Space Center. The U.S. Air Force team compared best practices, identified similarities and differences between NASA and the U.S. Air Force practices, identified potential deficiencies, and provided recommendations and areas for potential improvements. NASA is using this information to improve our practices and processes in evaluating the Orbiter fleet, and to formulate our approach for continued benchmarking.

NASA has also initiated a number of aging vehicle assessment activities as part of the integrated Space Shuttle Service Life Extension activities. Each of the Space Shuttle element organizations is pursuing appropriate vehicle assessments to ensure that the Shuttle Program operations remain safe and viable through 2020 and beyond.

NASA IMPLEMENTATION

NASA will continue to work with the U.S. Air Force in its development of aging vehicle assessment plans. Planned assessments for the Space Shuttle Orbiter, for example, include a mid-life certification assessment along with expanded fleet leader hardware programs and corrosion control programs.

In addition to working with the Air Force on these assessments, NASA is actively drawing upon other resources external to the Space Shuttle Program that have valuable experience in managing the operations of aging aircraft and defense systems. NASA is identifying contacts across government agencies and within the aerospace and defense industries to bring relevant expertise from outside the Shuttle program to assist the team. The Orbiter project has already augmented its mid-life certification assessment team with aging systems experts from Boeing Integrated Defense Systems.

In 1999, NASA began a partnership with the U.S. Air Force Research Laboratory, Materials and Manufacturing Directorate, at Wright-Patterson Air Force Base to characterize and investigate wire anomalies. The Joint NASA/FAA/DOD Conference on Aging Aircraft focused on studies and technology to identify and characterize these aging systems. NASA will continue this partnership with constant communication, research collaboration and technical interchange.

Following the June 2003 Air Force assessment of the OMDP/OMM being performed at Kennedy Space Center, a group of engineers went on a fact finding trip to Warner-Robins Air Force Base to learn more about Air Force maintenance on C-130s, C-141s, and C-5s. They met with Air Force personnel who had performed the previous assessment. All agreed that a joint working group, including United Space Alliance (USA), needed to be formed. The next targeted visit will most likely be to Tinker Air Force Base to review maintenance on KC-135 and possibly to Hill Air Force Base to review B-2 maintenance.

STATUS

NASA will continue to solicit participation of government and industry aging system experts from across the aerospace and defense sectors in the Space Shuttle aging vehicle assessment activities. NASA is particularly interested in benchmarking the aging system management practices of relevant programs within the U.S. Air Force and other agencies and will work to establish opportunities for meetings and ongoing interchange on this subject.

FORWARD WORK

NASA will continue to work with the U.S. Air Force to benefit from its knowledge of operating and maintaining long life aircraft systems. Collaboration, such as the recent benchmarking of best practices related to OMM/OMDP to Air Force B-2 fleet Program Depot-level Maintenance, demonstrated the benefits.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC/U.S. Air Force	TBD	Establish Joint U.S. Air Force/NASA Working Group
KSC	TBD	Benchmark additional U.S. Air Force Logistics Centers



Columbia Accident Investigation Board

Observation 10.6-4

The Space Shuttle Program Office must determine how it will effectively meet the challenges of inspecting and maintaining an aging Orbiter fleet before lengthening Orbiter Major Maintenance intervals.

BACKGROUND

An aging Orbiter fleet presents inspection and maintenance challenges that must be incorporated in the planning of the Orbiter Maintenance Down Periods (OMDPs).

NASA IMPLEMENTATION

Orbiter aging vehicle assessments, initiated as part of Shuttle Service Life Extension activity, will ensure that inspection requirements are evaluated to address aging vehicle concerns. An explicit review of all hardware inspection requirements will be conducted during the Orbiter mid-life certification assessment to determine if aging hardware or certification issues warrant the addition of new inspection requirements or modification to existing requirements. After completion of the mid-life certification assessment, inspection requirements will be evaluated through ongoing aging vehicle assessment activities, including the Orbiter fleet leader program and corrosion control program.

STATUS

NASA has initiated an assessment to ensure that Space Shuttle operations remain safe and viable throughout the Shuttle's service life.

FORWARD WORK

Orbiter mid-life certification assessments are currently underway for the highest criticality hardware components. Completion of certification verification for the remaining Orbiter hardware will be conducted in a prioritized manner through 2006. Planning for the expanded Orbiter fleet leader hardware assessment and corrosion control programs is underway with an anticipated start date in early 2004.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	2006	Orbiter mid-life certification assessment





Columbia Accident Investigation Board

Observations 10.7-1, 10.7-2, 10.7-3, and 10.7-4

O10.7-1 Additional and recurring evaluation of corrosion damage should include non-destructive analysis of the potential impacts on structural integrity.

O10.7-2 Long-term corrosion detection should be a funding priority.

O10.7-3 Develop non-destructive evaluation inspections to find hidden corrosion.

O10.7-4 Inspection requirements for corrosion due to environmental exposure should first establish corrosion rates for Orbiter-specific environments, materials, and structural configurations. Consider applying Air Force corrosion prevention programs to the Orbiter.

BACKGROUND

The Space Shuttle Program (SSP) has initiated an action to assess the *Columbia* Accident Investigation Board observations related to corrosion damage in the Shuttle Orbiters. This action has been assigned to the Orbiter Project Office.

NASA IMPLEMENTATION

TBS

STATUS

TBS

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	TBD	TBD





Columbia Accident Investigation Board

Observations 10.8-1, 10.8-2, 10.8-3, and 10.8-4

O10.8-1 Teflon (material) and Molybdenum Disulfide (lubricant) should not be used in the carrier panel bolt assembly.

O10.8-2 Galvanic coupling between aluminum and steel alloys must be mitigated.

O10.8-3 The use of Room Temperature Vulcanizing 560 and Koropon should be reviewed.

O10.8-4 Assuring the continued presence of compressive stresses in A-286 bolts should be part of their acceptance and qualification procedures.

BACKGROUND

The Space Shuttle Program (SSP) has initiated an action to assess the *Columbia* Accident Investigation Board observations related to the use of A-286 bolts in the Shuttle Orbiters. This action has been assigned to the Johnson Space Center Engineering Directorate.

NASA IMPLEMENTATION

TBS

STATUS

TBS

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	TBD	TBD

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP, KSC, USA	Oct 03	Present to SSP ICB
SSP, KSC, USA	Oct 03	Present to SSP Program Requirements Control Board
SSP, KSC, USA	Nov 03	Design Review
SSP, KSC, USA	Dec 03	Wire Design Engineering
HQ IA Team	Dec 03	Independent Assessment Final Report
HQ IA Team	Mar 04	Wire Installation Engineering



Columbia Accident Investigation Board

Observation 10.9-1

NASA should consider a redesign of the (Hold-Down Post Cable) system, such as adding a cross-strapping cable, or conduct advanced testing for intermittent failure.

BACKGROUND

Each of the two Solid Rocket Boosters (SRBs) is attached to the Mobile Launch Platform by four hold-down bolts that are each secured by a 5-inch-diameter restraint nut. The restraint nuts each contain two pyrotechnic initiators designed to split the nuts in half when the SRBs ignite, releasing the Space Shuttle stack to lift off the launch platform. There are 16 Pyrotechnics Initiator Controllers (PICs) for Hold-Down Post (HDP) Systems A and B and four PICs for the External Tank Vent Arm Systems (ETVAS) A and B. A postlaunch review of STS-112 indicated that the System A HDP and ETVAS PICs did not discharge. Although the root cause has not yet been isolated, the T-0 electrical connectors were identified as the primary contributing cause.

The STS-112 investigation resulted in the replacement of all T-0 ground cables after every flight, a redesign of the T-0 interface to the PIC rack cable, and replacement of all Orbiter T-0 connector savers. Also, the pyrotechnic connectors will be prescreened with pin-retention tests and the connector saver mate process will be verified using videoscopes. The *Columbia* Accident Investigation Board (CAIB) determined that the prelaunch testing procedures for this system may not be adequate to identify intermittent failure. Therefore, the CAIB suggested that NASA consider a redesign of the system or implement advanced testing for intermittent failures.

NASA IMPLEMENTATION

Five options for redesign of this system were presented to the Orbiter Project Configuration Control Board (OCCB) on August 20, 2003. The recommended redesign configuration provides redundancy directly at the T-0 umbilical, which was determined to be the primary contributing cause of the STS-112 anomaly. The selected option results in the least impact to hardware (fewer connectors, less

wiring, less weight added), can be implemented in a reasonably short time period, and requires only limited modifications to existing Ground Support Equipment. Orbiter and ground-side implementations are not affected as they interface at the same T-0 pins.

STATUS

A cross-strapping cable was not recommended as part of the redesign options because of concerns that it would introduce a single point failure that could inhibit both hold-down post pyrotechnic systems. The recommended redesign, plus the previously identified processing and verification modifications, are considered sufficient to mitigate the risks identified during the STS-112 anomaly investigation. Actions are in place to investigate additional methods to verify connector mating and system integrity. Several technical issues associated with the implementation of this redesign are continuing to be evaluated.

FORWARD WORK

Actions for further assessment of this redesign option were assigned by the Space Shuttle Program (SSP) Systems Engineering and Integration Manager with the recommended redesign option and associated action responses to be presented to the SSP Integration Control Board (ICB).

Additionally, a NASA Headquarters (HQ) sponsored Independent Assessment (IA) Team has been formed to review this anomaly and generically review the T-0 umbilical electrical/data interfaces. While this independent review is not considered a constraint to implementing the redesign, it provides an opportunity to ensure that the original investigation was thorough and to look for additional recommendations or improvements that might be implemented.





Columbia Accident Investigation Board

Observation 10.10-1

NASA should reinstate a safety factor of 1.4 for the Attachment Rings – which invalidates the use of ring serial numbers 16 and 15 in their present state – and replace all deficient material in the Attachment Rings.

BACKGROUND

The External Tank Attach (ETA) rings are located on the Solid Rocket Boosters (SRBs) on the forward end of the aft motor segment (figure 10.10-1-1). The rings provide the aft attach points for the SRBs to the External Tank (ET). Approximately two minutes after liftoff, the SRBs separate from the Shuttle vehicle.

In late 2002, Marshall Space Flight Center (MSFC) engineers were performing tensile tests on ETA ring web material prior to the launch of STS-107 and discovered the ETA ring material strengths were lower than the design requirement. The ring material was from a previously flown and subsequently scrapped ETA ring representative of current flight inventory material. A one-time waiver was granted for the STS-107 launch based on an evaluation of the structural strength factor of safety requirement for the ring of 1.4 and adequate fracture mechanics safe-life at launch. The most probable cause for the low strength material was an off-nominal heat treatment process. Following SRB retrieval, the STS-107 rings were inspected as a

normal part of postflight inspection, and no issues were identified with flight performance.

NASA IMPLEMENTATION

NASA will use a nonlinear analysis method to ensure the rings meet program strength requirements for a factor of safety of 1.4 or greater. The nonlinear analysis method is a well established technique employed throughout the aerospace industry that addresses the entire material stress-strain response and more accurately represents the material's ultimate strength capability by allowing load redistribution. Nonlinear analysis demonstrates that all ETA ring hardware meets program strength requirements.

NASA will update the strength and fracture analysis for the ETA rings. Fracture mechanics analysis will determine the minimum mission life for the rings and define the necessary inspection interval. NASA will use testing, inspection, and analyses of flight hardware to fully characterize the material for each of the ETA rings in the Shuttle Program inventory. This will provide added assurance that the flight hardware meets Shuttle Program requirements and continues to have an adequate margin for safety above the 1.4 factor of safety requirement.

STATUS

The SRB Project has developed and verified by test (figure O10.10-1-2) a nonlinear analysis approach.

Hardware materials characterization includes ring web thickness measurements and hardness testing (figure O10.10-1-3) of the splice plates and ring webs. Serial number 15 and 16 ETA rings have exhibited unacceptable material variability as noted by hardness measurements and thus are being set aside as the initial candidates for

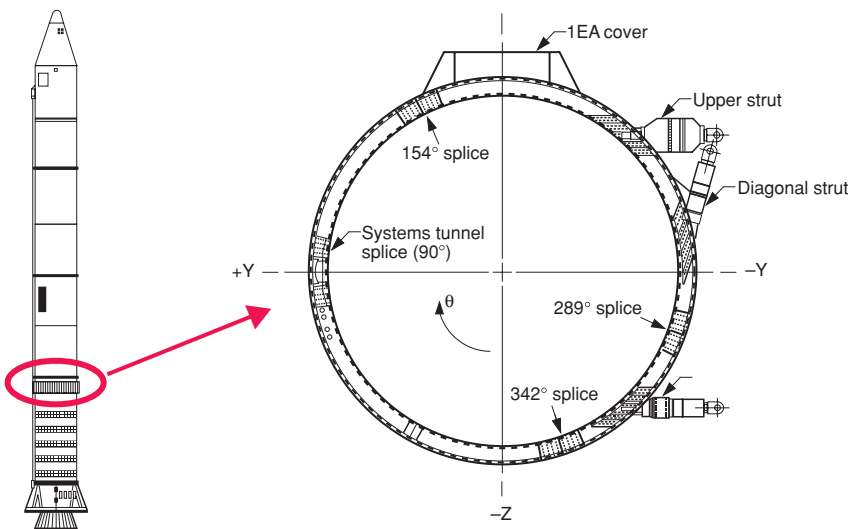
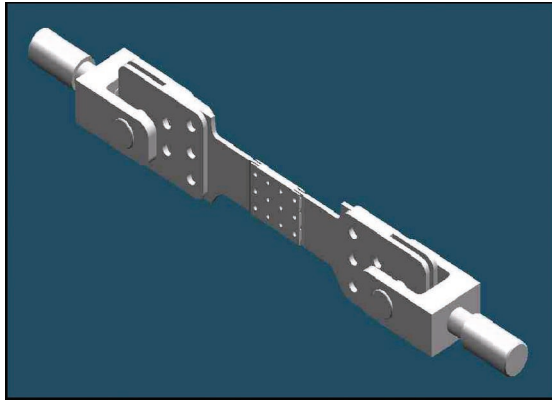
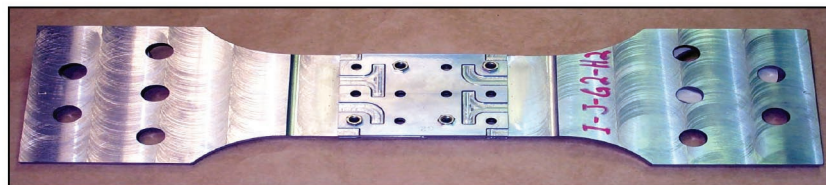


Figure O10.10-1-1. ETA ring location.



← **Test Fixture and Test Article configuration**

Test Article



| **Figure O10.10-1-2. Test articles.**

| upgrade/replacement. Any other rings that exhibit similarly unacceptable material or high variability in the hardness measurements will also be set aside for upgrade or replacement. Fracture Control Plan requirements compliance will be ensured by performing extensive nondestructive inspections (NDI) to rebaseline all areas of the ETA ring hardware.

| Hardware inspections for the first flight set of ETA rings are complete with no reportable indications noted and all areas of the rings meeting factor of safety requirements. Final safe

| life assessment is pending fracture property testing, which is scheduled for completion the end of January 2004. Processing of the second ETA ring flight set is under way.

FORWARD WORK

| Hardware inspections for each of the remaining ETA rings in the Space Shuttle Program inventory are continuing. A recommendation is being considered to replace the current ETA rings and impose the appropriate material property verification and NDI requirements. A decision package, including certification plans, is forthcoming.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SRB Project	Feb 04	First flight set ETA rings complete
SRB Project	Feb 04	New ring procurement package
SRB Project	Jan 06	Delivery of first new ETA ring



| **Figure O10.10-1-3. Harness testing.**



Columbia Accident Investigation Board

Observation 10.11-1

Assess NASA and contractor equipment to determine if an upgrade will provide the reliability and accuracy needed to maintain the Shuttle through 2020. Plan an aggressive certification program for replaced items so that new equipment can be put into operation as soon as possible.

BACKGROUND

The *Columbia* Accident Investigation Board (CAIB) review of Shuttle test equipment at NASA and contractor facilities revealed the use of antiquated and obsolete 1970s-era technology such as analog equipment. Current state-of-the-art technology is digital rather than analog. Digital equipment is less costly, easier to maintain, and more reliable and accurate than analog. The CAIB recommended that, with the Shuttle projected to fly through 2020, upgrading the test equipment to digital technology would avoid the high maintenance, lack of parts, and questionable accuracy of the equipment currently in use. Furthermore, although the new equipment would require certification for use, the benefit in accuracy, maintainability, and longevity would likely outweigh the drawbacks of certification costs.

NASA IMPLEMENTATION

In 2002, the Space Shuttle Program (SSP) Manager established a Program Logistics Office to provide stronger focus and leadership for long-term sustainability issues such as material, hardware and test equipment obsolescence. In 2002 and 2003, the Program Logistics Office performed comprehensive supportability reviews of all program elements and supporting contractors to identify near and long-term issues, with an emphasis on test equipment. The Program Logistics Office developed a health assessment metric to determine the relative health of the equipment and assist in prioritization of projects for funding. Additionally, the Program Logistics Office is refining and formalizing the health assessment process, now called the Shuttle Health Integrated Metric System (SHIMS), which will provide a formal, annual health assessment of all critical equipment, facilities and hardware required to support the SSP. This health assessment of all critical equipment will provide visibility into where equipment upgrades are required.

STATUS

In 2003, the logistics board approved \$32 million towards equipment modernizations or upgrades, such as the Space

Shuttle Main Engine (SSME) controller special test equipment (STE), the Orbiter inertial measurement unit, and the Star Tracker STE. Additionally, the Program Logistics Office identified and submitted through the Shuttle Service Life Extension Program (SLEP) an additional requirement for sustainability to support similar test equipment and obsolescence issues. Certification costs and schedules and the associated program risks are required elements of the total project package reviewed by the logistics board prior to authority to proceed.

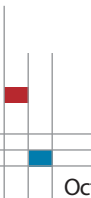
FORWARD WORK

The Program Logistics Office will assess all critical program equipment, through the use of the SHIMS health assessment tool and annual supportability reviews, and will determine where upgrades are needed to support the program through 2020 and beyond. Identified upgrades will be submitted through the SLEP process to ensure funding of specific projects.

SCHEDULE

This is an ongoing process. Near term (<5 year) equipment upgrade requirements will be defined by the Program and validated by the SLEP 2004 Sustainability Panel. Longer-term upgrade needs for support through 2020 and beyond will be identified through the annual SHIMS process. Approximately \$17 million in additional test equipment upgrades identified and approved through last year's SLEP summit for FY 2004 start will be implemented.

Responsibility	Due Date	Activity/Deliverable
SSP	Dec 03	Approve FY04 test equipment upgrades
SSP	Dec 03	Approve SHIMS process plan documentation
SLEP Sustainability Panel	Feb 04	Define FY05 test equipment upgrades





Columbia Accident Investigation Board

Observation 10.12-1

NASA should implement an agency-wide strategy for leadership and management training that provides a more consistent and integrated approach to career development. This strategy should identify the management and leadership skills, abilities, and experiences required for each level of advancement. NASA should continue to expand its leadership development partnerships with the Department of Defense and other external organizations

BACKGROUND

The NASA Training and Development Division offers a wide curriculum of leadership development programs to the NASA workforce. The content of internally sponsored programs are developed around the NASA leadership model, which delineates six leadership competencies at four different levels. Each level contains distinct core competencies along with a suggested curriculum. The four levels are executive leader, senior leader, manager/supervisor, and influence leader. NASA also develops leadership skills in the workforce by taking advantage of training and development opportunities at the Office of Personnel Management (OPM), Federal Executive Institute, Brookings Institute, and the Center for Creative Leadership, among many other resources. In addition, the Agency sponsors leadership development opportunities through academic fellowships in executive leadership and management, as well as through the NASA-wide Leadership Development Program.

Some NASA centers offer locally sponsored leadership development programs for their first level and/or mid-level managers and supervisors; these programs are unique to the Center, rather than being standardized across NASA. Neither the Agency as a whole nor most of the NASA centers have required, structured, basic supervisor/team lead training programs in place.

To enhance career development opportunities for the NASA workforce, the Agency recognizes that development assignments and career coaching should be a part of an employee's career development. The Agency has begun to address this issue by conducting a mobility study to assess job and development assignments experience across the Agency and by offering a formalized program to develop in-house coaches at each NASA center.

NASA IMPLEMENTATION

The NASA Office of Human Resources will establish an agency team to address the development and implementation of an Agencywide strategy for leadership and management development training. The team will be composed of NASA leaders, Agency and center training and development staff, line managers, and a member from the academic community. The Agency office will perform benchmarking of other government agencies, major corporations, and universities, relating to their leadership and management development programs. The office will also conduct fact finding through such organizations as the American Society of Training and Development and American Productivity and Quality Center.

STATUS

The NASA Training and Development Office is making contacts and working to get the agency team formed. The office is also starting benchmarking and data collection activities.

FORWARD WORK

NASA will continue to benchmark and gather data from OPM, the Department of Defense, corporations, and the academic community. NASA Headquarters will compile data received to date from the benchmarking and data collection activities work with center training officers to collect and assess all leadership and development opportunities offered at the centers and the training policies they have in place. Headquarters and centers will collaboratively develop recommendations and options for a more consistent and integrated approach to career development.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
HQ/Code FT (Agency Training Development Division)	Oct 03	Begin benchmarking Activities
HQ/Code FT	Oct 03	Begin the staff work to form the Agency team
HQ/Code FT	Jan 04	Bechmarking data to date compiled
Senior Leaders/ Code FT	Apr 04	Revalidation of NASA Leadership Model (as necessary)





Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section,

Recommendation D.a-1 Review Quality Planning Requirements

Document Process

Perform an independently led, bottom-up review of the Kennedy Space Center Quality Planning Requirements Document to address the entire quality assurance program and its administration. This review should include development of a responsive system to add or delete government mandatory inspections. Suggested Government Mandatory Inspection Point (GMIP) additions should be treated by higher review levels as justifying why they should not be added, versus making the lower levels justify why they should be added. Any GMIPs suggested for removal need concurrence of those in the chain of approval, including responsible engineers.

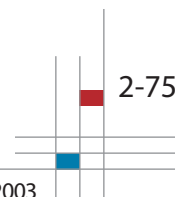
BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a responsive system for adding or deleting Government Mandatory Inspection Points (GMIPs), also noted in part of Observation O10.4-1 in section 2.2 of this Plan, and the need for a periodic review of the Quality Planning Requirements Document (QPRD). The Space Shuttle Program, Shuttle Processing Element located at the Kennedy Space Center is responsible for overseeing the QPRD process and implementation of associated GMIPs.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.1, Space Shuttle Program Action 1, and Section 2.2, Observation

10.4-1 of this Implementation Plan. Implementation of this recommendation has been in work since the issuance of the *Columbia* Accident Investigation Board Report, Volume I. NASA commissioned an assessment team, independent of the Space Shuttle Program, to review the effectiveness of the QPRD, its companion document at the Michoud Assembly Facility, referred to as the Mandatory Inspection Document, and the associated GMIPs. NASA continues work to improve this process through our defined implementation plan and will demonstrate our progress with this and future updates of our Plan.





Columbia Accident Investigation Board

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Recommendation D.a-2 Responsive System to Update Government Mandatory Inspection Points

Kennedy Space Center must develop and institutionalize a responsive bottom-up system to add to or subtract from Government Inspections in the future, starting with an annual Quality Planning Requirements Document review to ensure the program reflects the evolving nature of the Shuttle system and mission flow changes. At a minimum, this process should document and consider equally inputs from engineering, technicians, inspectors, analysts, contractors, and Problem Reporting and Corrective Action to adapt the following year's program.

BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a responsive system for updating Government Mandatory Inspection Points (GMIPs), including the need for a periodic review of the Quality Planning Requirements Document (QPRD). This issue is also noted in part of Observation O10.4-1 in Section 2.2 of this Implementation Plan. The Space Shuttle Program's Shuttle Processing Element, located at the Kennedy Space Center (KSC), is responsible for overseeing the QPRD process and implementation of associated GMIPs.

NASA IMPLEMENTATION

Shuttle Processing has assembled a team of inspectors, engineers, and managers, both NASA and contractor, to address the following items. First, Shuttle Processing is improving the change process for the QPRD. The changes will ensure anyone who requests a change receives a decision and the associated rationale to provide a feedback loop to the requestor. Furthermore, the change requests, disposition, and rationale will be tracked and maintained on line. The team is also developing a formal temporary GMIP process to accommodate one-time or infrequent GMIPs in a timely manner, while waiting for all the relevant parties to determine if the GMIP should become permanent. Finally, the team is providing a plan for

periodic review of the QPRD. As a part of this review, the team will survey the quality assurance specialists and systems engineers to identify GMIPs to be added or removed. Each candidate GMIP will be dispositioned through the improved GMIP change process.

STATUS

The team is reviewing the QPRD, has developed the QPRD change process, and is working on the temporary GMIP process. An initial survey of GMIPs has been conducted and a more thorough survey will follow.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC Shuttle Processing	Complete	Develop and implement GMIP change process
KSC Shuttle Processing	Jan 03	Develop and implement temporary GMIP process
KSC Shuttle Processing	Jun 04	Develop process for and review of QPRD



Columbia Accident Investigation Board

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Recommendation D.a-3 Statistically Driven Sampling of Contractor Operations

NASA Safety and Mission Assurance should establish a process inspection program to provide a valid evaluation of contractor daily operations, while in process, using statistically-driven sampling. Inspections should include all aspects of production, including training records, worker certification, etc., as well as Foreign Object Damage prevention. NASA should also add all process inspection findings to its tracking programs.

BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a statistically valid sampling program to evaluate contractor operations. Kennedy Space Center currently samples contractor operations within the Space Shuttle Main Engine Processing Facility; however, the sample size is not statistically significant and does not represent all processing activities.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.2, Observation 10.5-3 of this Implementation Plan. Implementation of this recommendation has been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. NASA continues to address this issue through our defined implementation plan and will demonstrate our progress in this and future updates of our Plan.



Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section,

Recommendation D.a-4 Forecasting and Filling Personnel Vacancies

The KSC quality program must emphasize forecasting and filling personnel vacancies with qualified candidates to help reduce overtime and allow inspectors to accomplish their position description requirements (i.e., more than the inspectors performing government inspections only, to include expanding into completing surveillance inspections.)

BACKGROUND

The *Columbia* Accident Investigation Board expressed concern regarding staffing levels of Quality Assurance Specialists (QAS) at Kennedy Space Center (KSC) and Michoud Assembly Facility (MAF). Specifically, they stated that staffing processes must be sufficient to select qualified candidates in a timely manner. Previously, KSC hired three QAS through a step program, none of whom had previous experience in quality assurance. The step program was a human resources sponsored effort to provide training and mobility opportunities to administrative staff. Of the three, only one remains a QAS. In addition to hiring qualified candidates, staffing levels should be sufficient to ensure the QAS function involves more than just inspection. Additional functions performed should include hardware surveillance, procedure evaluations, and assisting in audits.

NASA IMPLEMENTATION

NASA currently uses two techniques for selecting and developing qualified QAS. First, NASA can hire a QAS at the GS-7, GS-9, or GS-11 level if the candidate meets a predetermined list of requirements and experience. QAS candidates at all levels require additional training. Candidates selected at lower grades require additional classroom and on-the-job training before being certified as a QAS. NASA also uses a cooperative education program that brings in college students as part of their education process. This program is designed to develop QAS or quality control technicians for NASA and the contractor. The program is an extensive two-year

program, including classroom and on-the-job training. At the end of the cooperative education program, if the student does not demonstrate the required proficiency, NASA will not hire her or him.

Hiring practices have also improved. NASA can hire temporary or term employees. Although permanent hiring is preferred, this practice provides flexibility for short-term staffing issues. Examples include replacements for QAS military reservists who deploy to active duty and instances when permanent hiring authority is not immediately available.

Several QAS are deploying a hardware surveillance program. This program will define the areas in which hardware surveillance will be performed, the checklist of items to be assessed, the number of hardware inspections required, and the data to be collected.

STATUS

KSC has addressed the hiring issue. Training issues identified are addressed in Section 2.2, Observation O10.4-3. A team has been formed to develop, pilot, and deploy a hardware surveillance program.

FORWARD WORK

KSC will run a pilot hardware surveillance program, deploy it in the Orbiter Processing Facility (OPF), and then migrate it to the remaining facilities.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Complete	Develop and implement processes for timely hiring of qualified candidates
KSC	Dec 03	Develop and implement hardware surveillance program in the OPFs
KSC	Mar 04	Deploy hardware surveillance program to all QAS facilities
KSC	Mar 04	Develop reporting metric
KSC	Apr 04	Develop and implement procedure evaluation



Columbia Accident Investigation Board

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Recommendation D.a-5 Quality Assurance Specialist Job Qualifications

Job qualifications for new quality program hires must spell out criteria for applicants, and must be closely screened to ensure the selected applicants have backgrounds that ensure that NASA can conduct the most professional and thorough inspections possible.

BACKGROUND

The *Columbia* Accident Investigation Board expressed concern regarding staffing qualifications of Quality Assurance Specialists (QAS) at Kennedy Space Center (KSC). Previously, KSC hired three QAS through a step program, none of whom had previous experience in quality assurance. Of the three, only one remains as a QAS.

NASA IMPLEMENTATION

NASA currently uses two techniques for selecting and developing qualified QAS. First, NASA can hire a QAS at the GS-7, GS-9, or GS-11 level if the candidate meets a predetermined list of requirements and experience. QAS candidates at all levels require additional training. Candidates selected at lower grades require additional classroom and on-the-job training before being certified as a QAS. NASA also uses a cooperative education program that brings in college students as part of their education process. This program is designed to develop QAS or quality control technicians for NASA and the contractor. The program is an extensive two-year program, including classroom and on-the-job training. At the end of the cooperative education program, if the student does not demonstrate the required proficiency, NASA will not hire the individual.

NASA will benchmark assurance training programs that are implemented by the Department of Defense (DoD) and Defense Contract Management Agency (DCMA). NASA's present goal is to develop a comparable training program for the quality engineers, process analysts, and QAS. The training requirements will be documented in our formal training records template. Additional information on our training plan is found in Section 2.2, Observation O10.4-3.

STATUS

NASA has benchmarked with DoD and DCMA to understand their training requirements and to determine where we can directly use their training. A team consisting of engineers and QAS in both the Shuttle and International Space Station Programs has been formed to develop and document a more robust training program.

FORWARD WORK

KSC will document a comparable training program and update the training templates. Personnel not meeting the new training requirements will be given a reasonable timeframe to complete the training.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Complete	Develop and implement processes for hiring and developing qualified QAS
KSC	Nov 03	Benchmark DoD and DCMA training programs (from O10.4-3)
KSC	Jan 04	Develop and document improved training requirements (from O10.4-3)
KSC	Jun 04	Complete personnel training (from O10.4-3)



Columbia Accident Investigation Board

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Recommendation D.a-6 Review Mandatory Inspection Document Process

Marshall Space Flight Center should perform an independently-led bottom-up review of the Michoud Quality Planning Requirements Document to address the quality program and its administration. This review should include development of a responsive system to add or delete government mandatory inspections. Suggested Government Mandatory Inspection Point (GMIP) additions should be treated by higher review levels as justifying why they should not be added, versus making the lower levels justify why they should be added. Any GMIPs suggested for removal should need concurrence of those in the chain of approval, including responsible engineers.

BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a responsive system for adding or deleting Government Mandatory Inspection Points (GMIPs), including those at the Michoud Assembly Facility (MAF), also noted in part of Observation O10.4-1 in Section 2.2 of this Plan, and the need for a periodic review of the Quality Planning Requirements Document (QPRD). The Shuttle Propulsion Element at the Marshall Space Flight Center is responsible for overseeing the Mandatory Inspection Document process and implementation of associated GMIPs.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.1, Space Shuttle Program Action 1 and Section 2.2, Observation 10.4-1 of this Implementation Plan. Implementation of this recommendation has been in work since the issuance of the Columbia Accident Investigation Board Report, Volume I. NASA commissioned an assessment team, independent of the Space Shuttle Program to review the effectiveness of the QPRD and its companion document at the MAF, referred to as the Mandatory Inspection Document, and the associated GMIPs. NASA continues efforts to improve this process through our defined implementation plan and will demonstrate our progress with this and future updates of our Plan.



Columbia Accident Investigation Board

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Recommendation D.a-7 Responsive System to Update Government Mandatory Inspection Points at the Michoud Assembly Facility

Michoud should develop and institutionalize a responsive bottom-up system to add to or subtract from Government Inspections in the future, starting with an annual Quality Planning Requirements Document review to ensure the program reflects the evolving nature of the Shuttle system and mission flow changes. Defense Contract Management Agency manpower at Michoud should be refined as an outcome of the QPRD review.

BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a responsive system for updating Government Mandatory Inspection Points (GMIPs), including the need for a periodic review of the Quality Planning Requirements Document (QPRD). This issue is also noted in part of Observation O10.4-1 in Section 2.2 of this Implementation Plan. The Space Shuttle Program Shuttle Processing Element located at the Kennedy Space Center is responsible for overseeing the QPRD process and implementation of associated GMIPs.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.1, Space Shuttle Program Action 1 and Section 2.2, Observation 10.4-1 of this Implementation Plan. Implementation of this recommendation has been in work since the issuance of the *Columbia* Accident Investigation Board Report, Volume I. NASA commissioned an assessment team, independent of the Space Shuttle Program, to review the effectiveness of the QPRD, its companion at the Michoud Assembly Facility, referred to as the Mandatory Inspection Document, and the associated GMIPs. NASA continues efforts to improve this process through our defined implementation plan and will demonstrate our progress with this and future updates of our Plan.



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Recommendation D.a-8 Use of ISO 9000/9001

Kennedy Space Center should examine which areas of ISO 9000/9001 truly apply to a 20-year-old research and development system like the Space Shuttle.

BACKGROUND

The *Columbia* Accident Investigation Board report highlighted Kennedy Space Center's reliance on the International Organization for Standardization (ISO) 9000/9001 certification. The report stated, "While ISO 9000/9001 expresses strong principles, they are more applicable to manufacturing and repetitive-procedure industries, such as running a major airline, than to a research-and-development, flight test environment like that of the Space Shuttle. Indeed, many perceive International Standardization as emphasizing process over product." Currently, ISO 9000/9001 certification is a contract requirement for United Space Alliance.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.2, Observation 10.4-4, of this Implementation Plan. Implementation of this recommendation has been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. NASA continues efforts to improve this process through our defined implementation plan and will demonstrate our progress with this and future updates of our Plan.



Columbia Accident Investigation Board

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Recommendation D.a-9 Orbiter Corrosion

Develop non-destructive evaluation inspections to detect and, as necessary, correct hidden corrosion.

BACKGROUND

The Space Shuttle Program has initiated an action to assess the *Columbia* Accident Investigation Board observations related to corrosion damage in the Orbiters. This action has been assigned to the Orbiter Project Office.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.2, Observation 10.7-1 through 10.7-4 of this Implementation Plan. Implementation of this recommendation has been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. NASA continues efforts to improve this process through our defined implementation plan and will demonstrate our progress with this and future updates of our plan.



Columbia Accident Investigation Board

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Recommendation D.a-10 Hold-Down Post Cable Anomaly

NASA should evaluate a redesign of the Hold-Down Post Cable, such as adding a cross-strapping cable or utilizing a laser initiator, and consider advanced testing to prevent intermittent failure.

BACKGROUND

The Shuttle Hold-Down Post (HDP) pyrotechnic release system is designed to cleanly release the Space Shuttle Vehicle from the Mobile Launch Platform (MLP) HDPs after receiving a signal from the Orbiter General Purpose Computers and the Orbiter Master Event Controller at T-0. Release is normally accomplished by simultaneously firing two redundant pyrotechnic charges called NASA Standard Initiators (NSIs) on each of eight Solid Rocket Booster (SRB) HDP stud frangible nuts. Two independent ground-based Pyrotechnic Initiation Control (PIC) systems, A and B, are used to receive the command and to distribute the firing signals to each HDP. On STS-112, the system A Fire 1 command was not received by the ground-based PIC system; however, the redundant system B functioned properly and fired all system B NSIs, separated the frangible nuts, and enabled the release of the stud frangible nuts on all posts. As a result, the Shuttle safely separated from the MLP. NASA was unable to conclusively isolate the anomaly in any of the failed components. The most probable cause was determined to be an intermittent connection failure at the MLP-to-Orbiter interface at the Tail Service Mast (TSM) caused by the dynamic vibration environment after main engine start. Several contributing factors were identified, including ground-side connector corrosion at the TSM T-0 umbilical, weak connection spring force, potential non-locked Orbiter connector savers, lack of proper inspections, and a blind (nonvisually verified) mate between the ground cable and the Orbiter connector saver.

NASA IMPLEMENTATION

Since the NASA-initiated STS-112 investigation team concluded a TSM cable intermittent connection most likely caused the anomaly, Kennedy Space Center (KSC) has implemented a number of processing changes to greatly reduce the possibility of another intermittent condition at the TSM. The ground cables from the Orbiter interface to the TSM bulkhead plate are now replaced after each use; reuse after inspection was previously allowed. The ground connector springs that maintain the mating force against the Orbiter T-0 umbilical are all removed and tested to verify

the spring constants meet specification between each flight. Cables from the TSM bulkhead plate to PIC rack were previously inspected for damage, replaced as needed, and thoroughly tested. The Orbiter T-0 connector savers are inspected before each flight and are now secured with safety wire before the MLP cables are connected. New ground cables are thoroughly inspected before mate to the Orbiter. In addition, the connection process was enhanced to provide a bore scope optical verification of proper mate.

For STS-114 Return to Flight, the Space Shuttle Program is implementing several design changes and enhancements to further reduce the risk of a similar event. The Orbiter Project is adding redundant command paths for each HDP Arm, Fire 1, Fire 2, and return circuits from the Orbiter through separate connectors on the Orbiter/TSM umbilical. The Ground Support Equipment cables will be modified to extend the signals to the ground PIC rack solid-state switches. This modification adds copper path redundancy through the most dynamic and susceptible environment in the PIC system. Additionally, the KSC Shuttle Processing Project is redesigning and replacing all electrical cables from the Orbiter T-0 umbilical, through the TSMs, to their respective distribution points. The new cables will be factory constructed with a more robust insulation and be better suited for the environment in which they are used. This new cable design also eliminates the old style standard polyimide (“Kapton”) wire insulation that can be damaged by handling and degrades with age.

Space Shuttle Program technical experts have investigated laser-initiated ordnance devices and have concluded that there would be no functional improvement in the ground PIC system operation. Although laser-initiated ordnance has positive capabilities, no conclusive benefit for use on the Space Shuttle systems has been confirmed. Additionally, use of laser-initiated ordnance would have only changed the firing command path from the ground PIC rack to each of the HDP ordnance devices. This would not change or have any impact on master command path failures experienced during the STS-112 launch, since they would still be electrical copper paths.

In a separate action, the Shuttle Processing team is investigating the addition of a cross-strapped ordnance manifold at the HDPs so that either a system A command or a system B command will cause both NSIs in any individual HDP to fire. This new manifold will eliminate the failure scenario of a single capacitor discharge from the ground PIC rack out to a HDP causing only one NSI detonation at that HDP. With the cross-strapping modification, either redundant capacitor discharge will detonate both booster cartridges on each nut simultaneously. The NSI bridgewire circuits are electrically tested several times during the launch count-down activities to verify that the copper paths through the NSIs are intact. As an added benefit, the cross-strapping of the NSIs will eliminate the nonsimultaneous firing (skew time) of the NSIs as a factor in “stud hang-up.”

NASA has been engaged for more than three years with the joint Department of Defense/NASA/Federal Aviation Agency/industry aging aircraft wiring community to develop, test, and implement fault-detection methods and equipment to find emerging wire anomalies and intermittent failures before they prevent electrical function. Several tools have been developed and tested for that purpose but no tool is available with a conclusive ability to guarantee total wire function, especially under dynamic conditions that cannot be tested in place just before use.

STATUS

Proposed hardware modifications and development activity status include:

1. The TSM cable preliminary redesign is completed and has been designated a “return to flight” mandatory modification by the Shuttle Processing Project.
2. The Orbiter Project is implementing the T-0 redundancy modification in the Orbiter cable system and T-0 connectors. KSC will modify ground-side circuits accordingly.
3. The Space Shuttle Program is not currently considering laser pyrotechnic firing for the Shuttle Program but may readdress the issue in the future as the technology matures and the flight vehicle is upgraded.
4. NASA is currently supporting two separate strategies to determine wiring integrity. In addition, NASA is engaged with the Department of Defense and the Federal Aviation Agency to encourage further studies and projects.

FORWARD WORK

1. The evaluation team for laser initiation of pyrotechnics will continue to monitor hardware development for application to Shuttle hardware.
2. The NASA team will continue to engage in development of emerging wire fault detection and fault location tools with the government/industry wiring community. NASA will advocate funding for tool development and implement all new effective methods.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program	Dec 03	Approve new Operational Maintenance Requirements and Specification Documents requirement for specific ground cable inspections as a condition for mating
Orbiter Project	Dec 03	Provide redundant firing path in the Orbiter for HDP separation
Shuttle Integration	Feb 04	Implement cross-strapping for simultaneous NSI detonation
Space Shuttle Program	May 04	Report on new-technology wire fault-detection capability
Space Shuttle Program	May 04	New laser-firing study task
KSC	RTF	Modify, install, and certify the ground cabling to protect against damage and degradation and to implement a redundant ground electrical path to match orbiter commands



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Recommendation D.a-11 Solid Rocket Booster External Tank Attach Ring

NASA must reinstate a safety factor of 1.4 for the Attach Rings—which invalidates the use of ring serial numbers 15 and 16 in their present state—and replace all deficient material in the Attach Rings.

BACKGROUND

The *Columbia* Accident Investigation Board found that NASA often used analysis when testing would have been more appropriate to determine material properties. NASA's use of analysis to determine the adequacy of the tensile strength of the Solid Rocket Booster (SRB) to External Tank (ET) attachment rings was given as an example of a case where subsequent testing determined the factor of safety to be below the requirement threshold of 1.4.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.2, Observation 10.10-1, of this Implementation Plan. Implementation of this recommendation has been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. NASA continues to address this issue and will demonstrate our progress in updates of our Implementation Plan. SRB ET Attach Rings sets will be physically tested to verify compliance with the 1.4 factor-of-safety requirement before each flight until materials can be verified as compliant.



Columbia Accident Investigation Board

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Recommendation D.a-12 Crew Survivability

To enhance the likelihood of crew survivability, NASA must evaluate the feasibility of improvements to protect the crew cabin on existing Orbiters.

BACKGROUND

The *Columbia* Accident Investigation Board found that in both the *Challenger* and the *Columbia* accidents, the crew cabin initially survived the disintegration of the Orbiter intact. Evidence indicates that the *Challenger* crew cabin remained intact until it impacted the Atlantic Ocean and that the *Columbia* crew cabin maintained structural integrity until the entry heating environment began to disintegrate its aluminum skin, leading to its destruction.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.2, Observation 10.2-1, of this Implementation Plan. Implementation of this recommendation has been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. NASA continues efforts to improve this process through our defined implementation plan and will demonstrate our progress with this and future updates of our Plan. The Crew Survivability Working Group will consider options and make recommendations for protecting the crew cabin as it evaluates options to enhance crew survivability.



Columbia Accident Investigation Board

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Recommendation D.a-13 RSRM Segment Shipping Security

NASA and ATK Thiokol perform a thorough security assessment of the RSRM segment security, from manufacturing to delivery to Kennedy Space Center, identifying vulnerabilities and identifying remedies for such vulnerabilities.

BACKGROUND

During security program assessments at the ATK Thiokol Reusable Solid Rocket Motor (RSRM) Production Facility, the *Columbia* Accident Investigation Board raised concerns about several elements of the overall security program. Most notable of these concerns was protection of completed segments prior to rail shipment to the Kennedy Space Center (KSC).

NASA IMPLEMENTATION

NASA will conduct a full security program vulnerability assessment of the ATK Thiokol RSRM Production Facility with the goal of identifying and mitigating security vulnerabilities.

In support of the return to flight activity, NASA security, in conjunction with ATK Thiokol Security Program officials, will perform an assessment of the RSRM security program from RSRM manufacturing to delivery, inspection, and

storage at KSC. The assessment will include a review of the ATK Thiokol manufacturing plant to the railhead, and the participation in the rail shipment activities of RSRM segment(s) to or from KSC, regional and local threats, and Rotation, Processing, and Storage Facility security at KSC.

STATUS

An assessment team has been formed and has developed assessment criteria and methodologies.

SCHEDULE

The date for completion of the security assessment has been set for March 2004 so that the assessment period will coincide with the next RSRM delivery from ATK Thiokol to KSC. A report will be developed identifying security vulnerabilities, if any, and remedies for those vulnerabilities.



Columbia Accident Investigation Board

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Recommendation D.a-14 Michoud Assembly Facility Security

NASA and Lockheed-Martin complete an assessment of the Michoud Assembly Facility security, focusing on items to eliminate vulnerabilities in its current stance.

BACKGROUND

During security program assessments at the Michoud Assembly Facility (MAF), the *Columbia* Accident Investigation Board expressed concerns about several elements of the overall security program. Most notable of these concerns is the adequacy of particular security equipment and staffing.

NASA IMPLEMENTATION

NASA will conduct a full security program vulnerability assessment of the MAF and External Tank (ET) production activity with the goal of identifying and mitigating security vulnerabilities.

In support of return to flight, NASA Security, in conjunction with MAF Security Program officials, will assess the MAF and the ET production security programs from ET manufacturing to delivery, inspection, and storage at

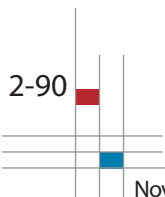
Kennedy Space Center (KSC). The assessment will include a review of MAF to the shipping port, shipping activities of the ET to and from KSC, regional and local threats, and Vehicle Assembly Building security at KSC.

STATUS

An assessment team has been formed and has developed assessment criteria and methodologies.

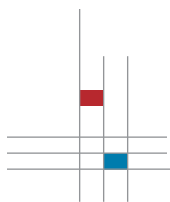
SCHEDULE

The completion date of the security assessment has been set for March 2004 so that the assessment period will be adequate to perform a thorough assessment in accordance with NASA's Mission Essential Infrastructure Protection Program. A report identifying security vulnerabilities, if any, and remedies to mitigate identified vulnerabilities will follow.





Appendix A: NASA's Return to Flight Process



BACKGROUND

The planning for return to flight (RTF) began even before the Agency received the first two *Columbia* Accident Investigation Board (CAIB) preliminary recommendations on April 16, 2003. Informally, activities started in mid-February as the Space Shuttle projects and elements began a systematic fault-tree analysis to determine possible RTF constraints. In a more formal sense, the RTF process had its beginnings in a March 2003 Office of Space Flight (OSF) memorandum.

Mr. William F. Readdy, the Associate Administrator for Space Flight, initiated the Space Shuttle Return to Flight planning process in a letter to Maj. Gen. Michael C. Kostelnik, the Deputy Associate Administrator for International Space Station and Space Shuttle Programs, on March 12, 2003. The letter gave Maj. Gen. Kostelnik the direction and authority “to begin focusing on those activities necessary to expeditiously return the Space Shuttle to flight.”

Maj. Gen. Kostelnik established a Return to Flight Planning Team (RTFPT) under the leadership of veteran astronaut Col. James Halsell. The RTF organization is depicted in figure A-1.

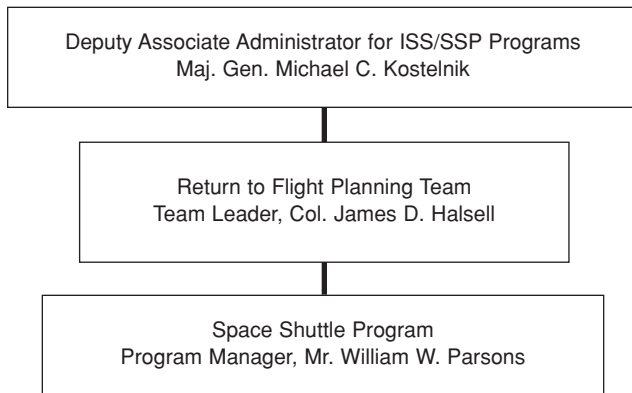


Figure A-1. RTFPT organization.

Space Shuttle Program (SSP) Role in Return to Flight

The SSP provided the analyses required to determine the NASA return to flight constraints (RTFCs). SSP project and element fault-tree analyses combined with technical working group documentation and analyses provided the database needed to create a list of potential RTFCs. The

SSP organized first as the Orbiter Vehicle Engineering Working Group (OVEWG) to develop fault tree analyses, and later as the Orbiter Return to Flight Working Group to recommend implementation options for RTFCs. The OVEWG structure and its subgroups are listed in figure A-2.

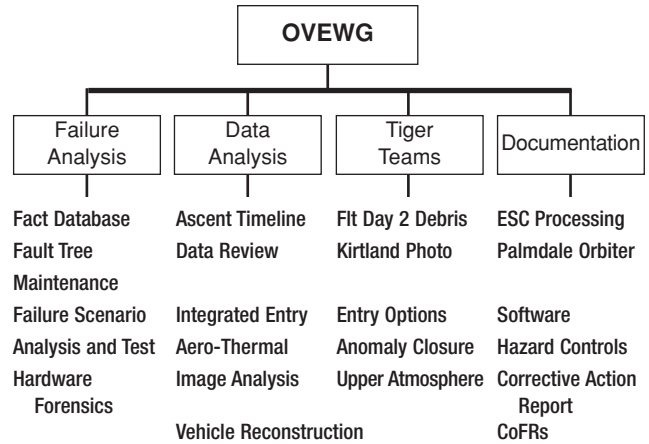


Figure A-2. OVEWG organization.

Once analyses were complete, the working groups briefed the CAIB on their findings and solicited the Space Shuttle Program Requirements Control Board’s (SSPRCB’s) approval of identified corrective actions. Each SSP project and element formed similar organizations to accomplish thorough fault-tree analysis and closure.

Return to Flight Planning Team

The RTFPT was formed to address those actions needed to comply with formal CAIB recommendations, and to determine the fastest path for a safe RTF. The 25- to 30-member team was assembled with representatives from NASA Headquarters and the OSF Field Centers, crossing the Space Shuttle Operations, Flight Crew Operations, and Safety and Mission Assurance disciplines.

Starting in early April, the RTFPT held weekly teleconferences to discuss core team processes and product delivery schedules. Weekly status reports, describing the progress of RTF constraints, were generated for Maj. Gen. Kostelnik and Dr. Michael Greenfield, one of the Space Flight Leadership Council (SFLC) cochair. These reports were also posted on a secure Web site for the RTFPT membership and other senior NASA officials to review. The RTFPT often previewed

RTF briefing packages being prepared for SSPRCBs. The leader of the RTFPT, Col. Halsell, became a voting member of the SSPRCB for all RTF issues. The RTFPT also arranged for all recommended SSPRCB RTF issues to be scheduled for SFLC review and approval. These RTFPT tasks were primarily assessment, status, and scheduling activities. The team's most significant contribution has been preparing and maintaining this Implementation Plan, a living document chronicling NASA's RTF.

Space Flight Leadership Council

Cochaired by the Associate Administrator for Space Flight and the Associate Deputy Administrator for Technical Programs, the purpose of the SFLC (figure A-3) was to receive and disposition the joint RTFPT/SSPRCB recommendations on RTF issues. The SFLC is the only group charged with approving RTF items and directing the implementation of specific corrective actions. The SFLC could also direct independent analysis on technical issues related to RTF issues or schedule (e.g., the category of wiring inspection on Orbiter Vehicle (OV)-103/Discovery, even though it will not be the RTF vehicle). The membership of the SFLC includes the OSF Center Directors (Johnson Space Center, Kennedy Space Center (KSC), Marshall Space Flight Center, and Stennis Space Center) and the Associate Administrator for Safety and Mission Assurance. SFLC meetings are scheduled as needed.

Return to Flight Task Group (RTFTG)

Known informally as the Stafford-Covey Task Group, the RTFTG was established by the NASA Administrator to perform an independent assessment of NASA's actions to implement the CAIB recommendations. The RTFTG was chartered from the existing Stafford International Space Station Operations Readiness

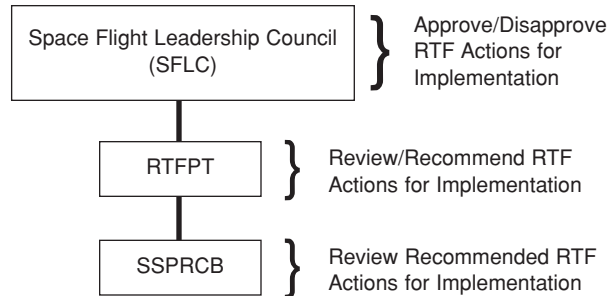


Figure A-3. Space Flight Leadership Council organization for return to flight issue review.

Task Force (Stafford Task Force), a Task Force under the auspices of the NASA Advisory Council. The RTFTG is comprised of standing members of the Stafford Task Force, other members selected by the cochair, and a nonvoting ex-officio member (the Associate Administrator for Safety and Mission Assurance). The RTFTG is organized into three panels: technical, operations, and management. The team held its first meeting, primarily for administrative and orientation purposes, in early August at KSC.

Operational Readiness Review

Prior to RTF, the SFLC will convene a meeting to disposition NASA's internal handling of all RTF constraints. The exact date and process for this meeting have yet to be decided. Additionally, it has not been determined how the RTFTG will participate in this process.



Return to Flight Milestones

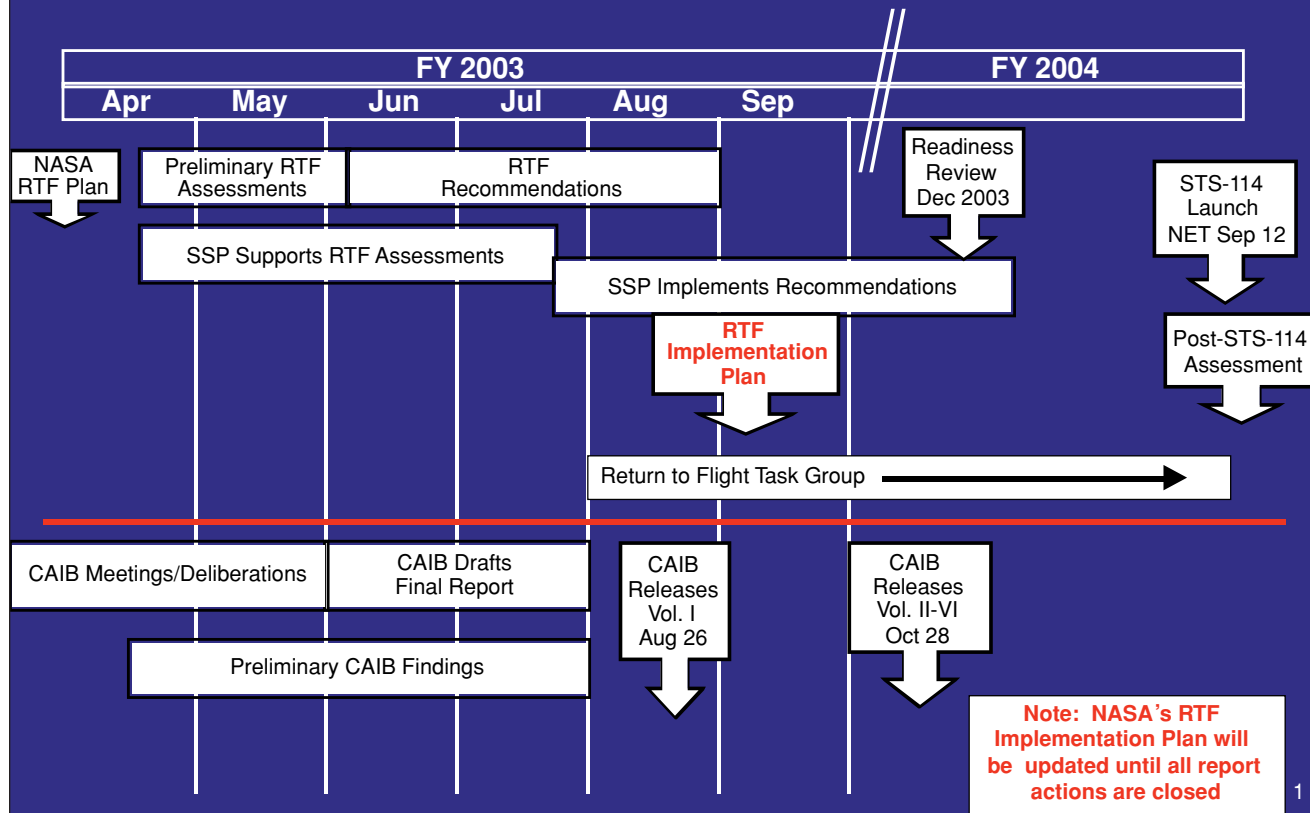
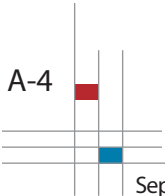


Figure A-4. RTF and RTFTG schedules overlaid with the schedule for release of the CAIB final report.

A-4

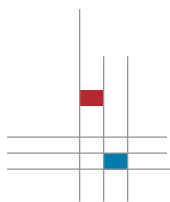


September 8, 2003



Appendix B: Return to Flight Task Group





INTRODUCTION

The Return to Flight Task Group, cochaired by Thomas P. Stafford and Richard O. Covey, was formed to address the Shuttle Program's return to flight effort. The Task Group is chartered to perform an independent assessment of NASA's actions to implement the *Columbia* Accident Investigation Board (CAIB), as they relate to the safety and operational readiness of STS-114.

The Stafford/Covey Task Group will report on the progress of NASA's response to the CAIB report and may also make other observations on safety or operational readiness that it believes appropriate.

The Task Group will formally and publicly report its results to NASA on a continuing basis, and we will fold their recommendations into our formal planning for return to flight. The paragraphs below describe the charter and membership for the Task Group.

RETURN TO FLIGHT TASK GROUP CHARTER ESTABLISHMENT AND AUTHORITY

The NASA Administrator, having determined that it is in the public interest in connection with performance of the Agency duties under the law, and with the concurrence of the General Services Administration, establishes the NASA Return to Flight Task Group ("Task Group"), pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§1 et seq.

PURPOSE AND DUTIES

1. The Task Group will perform an independent assessment of NASA's actions to implement the CAIB recommendations as they relate to the safety and operational readiness of STS-114. As necessary to their activities, the Task Group will consult with former members of the CAIB.
2. While the Task Group will not attempt to assess the adequacy of the CAIB recommendations, it will report on the progress of NASA's response to meet their intent.
3. The Task Group may make other observations on safety or operational readiness as it believes appropriate.
4. The Task Group will draw on the expertise of its members and other sources to provide its assessment to the Administrator. The Task Group will hold meetings and make site visits as necessary to accomplish its

fact finding. The Task Group will be provided information on activities of both the Agency and its contractors as needed to perform its advisory functions.

5. The Task Group will function solely as an advisory body and will comply fully with the provisions of the Federal Advisory Committee Act.

ORGANIZATION

The Task Group is authorized to establish panels in areas related to its work. The panels will report their findings and recommendations to the Task Group.

MEMBERSHIP

1. In order to reflect a balance of views, the Task Group will consist of non-NASA employees and one NASA nonvoting, ex-officio member, the Deputy Associate Administrator for Safety and Mission Assurance. In addition, there may be associate members selected for Task Group panels. The Task Group may also request appointment of consultants to support specific tasks. Members of the Task Group and panels will be chosen from among industry, academia, and Government personnel with recognized knowledge and expertise in fields relevant to safety and space flight.
2. The Task Group members and Cochairs will be appointed by the Administrator. At the request of the Task Group, associate members and consultants will be appointed by the Associate Deputy Administrator (Technical Programs).

ADMINISTRATIVE PROVISIONS

1. The Task Group will formally report its results to NASA on a continuing basis at appropriate intervals, and will provide a final written report.
2. The Task Group will meet as often as required to complete its duties and will conduct at least two public meetings. Meetings will be open to the public, except when the General Counsel and the Agency Committee Management Officer determine that the meeting or a portion of it will be closed pursuant to the Government in the Sunshine Act or that the meeting is not covered by the Federal Advisory Committee Act. Panel meetings will be held as required.
3. The Executive Secretary will be appointed by the Administrator and will serve as the Designated Federal Officer.

4. The Office of Space Flight will provide technical and staff support through the Task Force on International Space Station Operational Readiness. The Office of Space Flight will provide operating funds for the Task Group and panels. The estimated operating costs total approximately \$2M, including 17.5 work-years for staff support.

5. Members of the Task Group are entitled to be compensated for their services at the rate equivalent to a GS 15, step 10. Members of the Task Group will also be allowed per diem and travel expenses as authorized by 5 U.S.C. § 5701 et seq.

DURATION

The Task Group will terminate two years from the date of this charter, unless terminated earlier or renewed by the NASA Administrator.

STAFFORD-COVEY TASK GROUP MEMBERS

Col. James C. Adamson, U.S. Army (Ret.): *CEO, Monarch Precision, LLC, consulting firm*

Col. Adamson, a former astronaut, has an extensive background in aerodynamics as well as business management. He received his Bachelor of Science degree in Engineering from the U.S. Military Academy at West Point and his Master's degree in Aerospace Engineering from Princeton University. He returned to West Point as an Assistant Professor of Aerodynamics until he was selected to attend the Navy Test Pilot School at Patuxent River, Md. in 1979. In 1981 he became Aerodynamics Officer for the Space Shuttle Operational Flight Test Program at the Johnson Space Center's Mission Control Center. Col. Adamson became an astronaut in 1984 and flew two missions, the first aboard *Columbia* (STS-28) and the second aboard *Atlantis* (STS-43).

After retiring from NASA in 1992, he created his own consulting firm, Monarch Precision, and was then recruited by Lockheed as President/Chief Executive Officer (CEO) of Lockheed Engineering and Sciences Company. In 1995 he helped create United Space Alliance and became their first Chief Operating Officer, where he remained until 1999. In late 1999, Col. Adamson was again recruited to serve as President/CEO of Allied Signal Technical Services Corporation, which later became Honeywell Technology Solutions, Inc. Retiring from Honeywell in 2001, Col. Adamson resumed part-time consulting with his own company, Monarch Precision, LLC. In addition to corporate board positions, he has

served as a member of the NASA Advisory Council Task Force on Shuttle-Mir Rendezvous and Docking Missions and is currently a member of the NASA Advisory Council Task Force on International Space Station Operational Readiness.

Maj. Gen. Bill Anders, U.S. Air Force Reserve, (Ret.):

After graduation in 1955 as an electrical engineer from the United States Naval Academy, Maj. Gen. Anders earned his pilot's wings in 1956. He received a graduate degree in nuclear engineering from the U.S. Air Force (USAF) Institute of Technology while concurrently graduating with honors in aeronautical engineering from Ohio State University. In 1963 he was selected for the astronaut corps. He was the Lunar Module Pilot of Apollo 8 and backup Command Module Pilot for Apollo 11. Among other successful public and private endeavors, Maj. Gen. Anders has served as a Presidential appointee to the Aeronautics & Space Council, the Atomic Energy Commission, and the Nuclear Regulatory Commission (where he was the first chairman), and as U.S. Ambassador to Norway.

Subsequent to his public service, he joined the General Dynamics Corporation as Chairman and CEO (1990–1993), and was awarded the National Security Industrial Association's "CEO of the Year" award.

During his distinguished career, Maj. Gen. Anders was the co-holder of several world flight records and has received numerous awards including the USAF, NASA, and Atomic Energy Commission's Distinguished Service Medals. He is a member of the National Academy of Engineering, the Society of Experimental Test Pilots, and the Experimental Aircraft Association. He is the founder and President of the Heritage Flight Museum.

Dr. Walter Broadnax:

Dr. Broadnax is President of Clark Atlanta University in Atlanta, Ga. Just before coming to Clark, Broadnax was Dean of the School of Public Affairs at American University in Washington. Previously, he was Professor of Public Policy and Management in the School of Public Affairs at the University of Maryland, College Park, Md., where he also directed the Bureau of Governmental Research. Before joining the University of Maryland faculty, Dr. Broadnax served as Deputy Secretary and Chief Operating Officer of the U.S. Department of Health and Human Services; President, Center for Governmental Research, Inc., in Rochester, N.Y.; President, New York State Civil



Service Commission; Lecturer and Director, Innovations in State and Local Government Programs in the Kennedy School of Government at Harvard University; Senior Staff Member, The Brookings Institution; Principal Deputy Assistant Secretary for Planning and Evaluation, U.S. Department of Health, Education and Welfare; Director, Children, Youth and Adult Services, State of Kansas; and Professor, The Federal Executive Institute, Charlottesville, Va.

He is one of America's leading scholar-practitioners in the field of public policy and management. He has published widely in the field and served in leadership positions in various professional associations: American Political Science Association, American Public Personnel Association, Association of Public Policy and Management, National Association of Schools of Public Affairs and Administration, National Association of State Personnel Executives, and American Society for Public Administration.

Broadnax received his Ph.D. from the Maxwell School at Syracuse University, his B.A. from Washburn University, and his M.P.A. from the University of Kansas. He is a Fellow of the National Academy of Public Administration and a former trustee of the Academy's Board. In March, he was installed as President of the American Society for Public Administration for 2003–2004. He is a member of the Syracuse University Board of Trustees, Harvard University's Taubman Center Advisory Board, and United States Comptroller General Advisory Board. He has also served on several corporate and nonprofit boards of directors including the CNA Corporation, Keycorp Bank, Medecision Inc., Rochester General Hospital, Rochester United Way, and the Ford Foundation/Harvard University Innovations in State and Local Government Program, the Maxwell School Advisory Board, and the National Blue Ribbon Commission on Youth Safety and Juvenile Justice Reform in the District of *Columbia*.

Rear Adm. Walter H. Cantrell, USN (Ret.):

Rear Adm. Cantrell has a long history of successfully solving high-profile, technical issues. He is frequently asked to conduct reviews of complex, politically sensitive programs and to make recommendations for corrective actions.

He graduated from the U.S. Naval Academy in 1958 with a Bachelor of Science degree in Naval Science. He received Master's degrees in Naval Architecture and Marine and Naval Engineering, and a NavEng (Professional Degree) from the Massachusetts Institute of Technology in 1965.

He is a graduate of the Senior Officials in National Security Program, JFK School of Government at Harvard. After an extensive and distinguished naval career, he retired in 1995.

He then joined Global Associates Limited as Executive Director for Technology and Systems. From 1996 to 1997, he was President of the Signal Processing Systems Division. Most recently, from 1997 to 2001, he was Program Director, Land Level Transfer Facility, Bath Iron Works, and was responsible for the design and construction of a \$260M state-of-the-art shipbuilding facility. Rear Adm. Cantrell currently serves on NASA's Aerospace Safety Advisory Panel.

Dr. Kathryn Clark:

Dr. Clark is the Vice President for Education at TIVY, Inc., an exciting game that combines strategy and mathematics in a manner that makes learning fun. Organized competitions for the game have provided a strong motivation for students to improve their skills, resulting in increased standardized math scores. Baseball TIVY has competitions at professional baseball games, with competitors and their parents receiving free tickets to the game. Space TIVY has a National Tournament on Space Day at the National Air and Space Museum the first Thursday in May each year.

Dr. Clark is also consultant in the fields of space, oceans, and education. She consults for the Jean-Michel Cousteau Society, the National Marine Sanctuaries, and the Sea World–Hubbs Institute to enhance the study of oceans and marine wildlife and use the data for education and awareness of the environment of the seas.

She recently completed a job for the Michigan Virtual High School to aid in the development of the Math, Science, and Technology Academy. She worked on the vision and mission of the Academy as well as the development of partners as they increase the scope and reach of the program to a national and international scale. She recently resigned from her job as NASA's Chief Scientist for the Human Exploration and Development of Space Enterprise (HEDS), a position she accepted in August 2000 after completing a 2-year term as NASA's Chief Scientist for the International Space Station Program. On leave from the University of Michigan Medical School, she worked in the Chief Scientist position with scientists from all other areas of NASA to communicate research needs and look for possible collaboration among

the science programs at NASA. She also assisted with education and outreach activities related to any human space flight endeavors, including the International Space Station, the Shuttle, any expendable launch vehicles intended to further human endeavors in space, and future missions to the Moon and Mars. Her particular interest is in "Human Factors:" all the elements necessary for the health, safety, and efficiency of crews involved in long-duration space flight. These include training, interfacing with machines and robotics, biological countermeasures for the undesirable physical changes associated with space flight, and the psychological issues that may occur in response to the closed, dangerous environments while traveling in space or living on other planets.

She received both her Master's and Doctoral degrees from the University of Michigan and then joined the faculty in the Department of Cell and Developmental Biology in 1993. She also served as the Deputy Director of the NASA Commercial Space Center, the Center for Microgravity Automation Technology (CMAT) from 1996 to 1998. CMAT provides imaging technology for use on the International Space Station. The primary commercial focus of that Center is on using high-fidelity imaging technology for science and education.

Dr. Clark's scientific interests are focused on neuromuscular development and adaptation to altered environments. Her experiments are performed at the tissue level and include immunocytochemistry and in situ hybridization of skeletal muscle and spinal cord grown both in vivo and in vitro. Her experience with NASA began with a neuromuscular development study (NIH.R1) that flew on STS-66 in November 1994. These experiments were repeated and augmented (NIH.R2) on STS-70 in July 1995. She was also involved in the Neurolab project flown on STS-90 in May 1998 and the ladybug experiment that flew on STS-93 with Commander Eileen Collins.

Dr. Clark is the Chair of the Academic Affairs Committee of Board of Control of Michigan Tech University, the Chair of the Board of Visitors of Western Reserve Academy, and serves on the boards of The Space Day Foundation and Orion's Quest, both education oriented not-for-profit organizations.

She is a past member of the Board of Directors of Women in Aerospace, is an airplane pilot and a member of the 99's (the International Society of Women Pilots), and is an avid cyclist, swimmer, and cross-country skier. She owns a jazz club in Ann Arbor, Michigan. She is married

to Dr. Robert Ike, a rheumatologist at the University of Michigan Medical School.

Mr. Benjamin A. Cosgrove:

Consultant

Mr. Cosgrove has a long and distinguished career as an engineer and manager associated with most of Boeing jet aircraft programs. His extensive background in aerospace stress and structures includes having served as a stress engineer or structural unit chief on the B-47, B-52, KC-135, 707, 727, 737, and 747 jetliners. He was Chief Engineer of the 767.

He was honored by Aviation Week and Space Technology for his role in converting the Boeing 767 transport design from a three-man to a two-man cockpit configuration and received the Ed Wells Technical Management Award for addressing aging aircraft issues. He received the National Aeronautics Association's prestigious Wright Brothers Memorial Trophy in 1991 for his lifetime contributions to commercial aviation safety and for technical achievement. He is a member of the National Academy of Engineering and a fellow of both the AIAA and England's Royal Aeronautical Society. Having retired from his position as Senior Vice President of the Boeing Commercial Airplane Group in 1993 after 44 years of service, he is now a consultant. He holds a Bachelor of Science degree in Aeronautical Engineering and received an honorary Doctorate of Engineering degree from the University of Notre Dame in 1993. Mr. Cosgrove is a member of the NASA Advisory Committee's Task Force on International Space Station Operational Readiness.

Col. Richard O. Covey, U.S. Air Force (Ret.):

Cochair, Return to Flight Task Group

Vice President, Support Operations, Boeing Homeland Security and Services

Col. Covey, a veteran of four Space Shuttle flights, has over 35 years of aerospace experience in both the private and public sectors. He piloted STS-26, the first flight after the *Challenger* accident, and was commander of STS-61, the acclaimed *Endeavour*/Hubble Space Telescope first service and repair mission.

Covey is a highly decorated combat pilot and Outstanding Graduate of the Air Force Test Pilot School, holds a Bachelor of Science degree in Engineering Sciences from the U.S. Air Force Academy, and has a Master of Science degree in Aeronautics and Astronautics from Purdue University.

He served as the U.S. Air Force Joint Test Force Director for F-15 electronic warfare systems developmental and production verification testing. During his distinguished 16-year career at NASA, he held key management positions in the Astronaut Office and Flight Crew Operations Directorate at Johnson Space Center (JSC). Covey left NASA and retired from the Air Force in 1994.

In his position at Boeing, his organization provides system engineering, facility/system maintenance and operations, and spacecraft operations and launch support to commercial, Department of Defense, and other U.S. Government space and communication programs throughout the world. Prior to his current position, Covey was Vice President of Boeing's Houston Operations.

He has been the recipient of numerous awards such as two Department of Defense Distinguished Service Medals, the Department of Defense Superior Service Medal, the Legion of Merit, five Air Force Distinguished Flying Crosses, 16 Air Medals, the Air Force Meritorious Service Medal, the Air Force Commendation Medal, the National Intelligence Medal of Achievement, the NASA Distinguished Service Medal, the NASA Outstanding Leadership Medal, the NASA Exceptional Service Medal, and the Goddard and Collier Trophies for his role on STS-61.

Dan L. Crippen, Ph.D.:

Former Director of the Congressional Budget Office

Dr. Crippen has a strong reputation for objective and insightful analysis. He served, until January 3, 2003, as the fifth Director of the Congressional Budget Office. His public service positions also include Chief Counsel and Economic Policy Adviser to the Senate Majority Leader (1981–1985); Deputy Assistant to the President for Domestic Policy (1987–1988); and Domestic Policy Advisor and Assistant to the President for Domestic Policy (1988–1989), where he advised the President on all issues relating to domestic policy, including the preparation and presentation of the Federal budget. He has provided service to several national commissions, including membership on the National Commission on Financial Institution Reform, Recovery, and Enforcement.

Dr. Crippen has substantial experience in the private sector as well. Before joining the Congressional Budget Office, he was a principal with Washington Counsel, a law and consulting firm. He has also served as Executive Director of the Merrill Lynch International Advisory Council and as a founding partner and Senior Vice President of The Duberstein Group.

He received a Bachelor of Arts degree from the University of South Dakota in 1974, a Master of Arts from Ohio State University in 1976, and a Doctor of Philosophy degree in Public Finance from Ohio State in 1981.

Mr. Joseph W. Cuzzupoli:

Vice President and K-1 Program Manager, Kistler Aerospace Corporation

Mr. Cuzzupoli brings to the Task Group more than 40 years of aerospace engineering and managerial experience. He began his career with General Dynamics as Launch Director (1959–1962), and then became Manager of Manufacturing/Engineering and Director of Test Operations for Rockwell International (1962–1966). Cuzzupoli directed all functions in the building and testing of Apollo 6, Apollo 8, Apollo 9, and Apollo 12 spacecraft as Rockwell's Assistant Program Manager for the Apollo Program; he later was Vice President of Operations. In 1978, he became the Vice President and Program Manager for the Space Shuttle Orbiter Project and was responsible for 5000 employees in the development of the Shuttle.

He left Rockwell in 1980 and consulted on various aerospace projects for NASA centers until 1991, when he joined American Pacific Corporation as Senior Vice President. In his current position at Kistler Aerospace (Vice President and Program Manager, 1996–present), he has primary responsibility for design and production of the K-1 reusable launch vehicle.

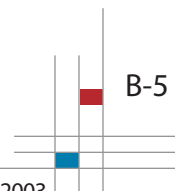
He holds a Bachelor of Science degree in Mechanical Engineering from the Maine Maritime Academy, a Bachelor of Science degree in Electrical Engineering from the University of Connecticut, and a Certificate of Management/Business Administration from the University of Southern California.

He was a member of the NASA Advisory Council's Task Force on Shuttle-Mir Rendezvous and Docking Missions and is a current member of the NASA Advisory Council's Task Force on International Space Station Operational Readiness.

Charles C. Daniel, Ph.D.:

Engineering Consultant

Dr. Daniel has over 35 years experience as an engineer and manager in the fields of space flight vehicle design, analysis, integration, and testing; and he has been involved in aerospace programs from Saturn V to the International Space Station. In 1968, he began his career at Marshall



Space Flight Center (MSFC), where he supported Saturn Instrument Unit operations for Apollo 11, 12, and 13. In 1971, he performed avionics integration work for the Skylab Program and spent the next decade developing avionics for the Solid Rocket Boosters (SRBs). He was SRB flight operations lead in that activity.

Dr. Daniel worked as part of the original Space Station Skunk Works for definition of the initial U.S. space station concept and developed the master engineering schedule for the station.

Following the *Challenger* accident, he led the evaluation of all hazards analyses associated with Shuttle and coordinated acceptance analyses associated with the modifications to the Solid Rocket Motors (SRMs) and SRBs. During Space Station Freedom development, he was the avionics lead and served as MSFC lead for Level II assembly and configuration development. He was part of the initial group to define the concept for Russian participation in the Space Station Restructure activity and later returned to MSFC as Chief Engineer for Space Station.

He holds a Doctorate degree in Engineering and has completed postgraduate work at the University of California, Berkeley, and MIT. He was a member of the NASA Advisory Council Task Force on Shuttle-Mir Rendezvous and Docking Operations and is a member of the NASA Advisory Council Task Force, ISS Operational Readiness.

Richard Danzig, J.D., Ph.D.:

A Director of National Semiconductor Corporation, Human Genome Sciences, and Saffron Hill Ventures

Dr. Danzig, former Under Secretary of the Navy (1993–1997) and Secretary of the Navy (1998–2001), has vast and varied expertise in law, business, military, and Government operations as well as national service. He is currently a Director of the National Semiconductor Corporation and a Director of Human Genome Sciences. He also serves as a consultant to the Department of Defense (DOD) and other Federal agencies regarding response to terrorism, and is Chairman of the Board of the Center for Strategic and Budgetary Assessment.

Dr. Danzig holds a Doctor of Jurisprudence degree from Yale Law School and Bachelor and Doctor of Philosophy degrees from Oxford University, where he was a Rhodes Scholar. He served as a law clerk for U.S. Supreme Court Justice Byron White. In the 1970s, he was an Associate Professor of Law at Stanford University, a Prize Fellow

at Harvard, and a Rockefeller Foundation Fellow. He later served as a Deputy Assistant Secretary of Defense in the Office of the Secretary of Defense and then as the Principal Deputy Assistant Secretary of Defense for Manpower, Reserve Affairs, and Logistics. Between 1981 and 1993, he was a partner in the law firm of Latham and Watkins, co-authored a book on national service, and taught a law class at Georgetown University Law School. He has written a book, *Joseph's Way*, on innovation in large organizations, which will be published in 2004.

During his distinguished public career at DOD, Dr. Danzig received the Defense Distinguished Public Service Award (the highest Department of Defense civilian award) three times. He is a member of the NASA Advisory Council.

Amy K. Donahue, Ph.D.:

Assistant Professor of Public Administration at the University of Connecticut Institute of Public Affairs.

Dr. Donahue teaches graduate courses in public organizations and management, policy analysis, intergovernmental relations, and research methods. Her research focuses on the productivity of emergency services organizations and on the nature of citizen demand for public safety services. She is author of published work about the design, management, and finance of fire departments and other public agencies. Dr. Donahue serves as a consultant for local governments seeking to improve the structure and management of their fire and emergency services.

Under the Intergovernmental Personnel Act, Dr. Donahue serves as Senior Advisor to the NASA Administrator for Homeland Security. She functions as NASA's liaison with the Department of Homeland Security and the Homeland Security Council. She also works within NASA to discern opportunities to contribute to homeland security efforts Government-wide, including evaluating existing projects and identifying new opportunities for interagency collaboration targeted at homeland security. She recently spent three months in the field in Texas managing the *Columbia* recovery operation.

Previously, Dr. Donahue was a senior research associate at the Alan K. Campbell Public Affairs Institute at Syracuse University. She conducted research and analysis in support of the Government Performance Project, a five-year initiative funded by the Pew Charitable Trusts to evaluate comprehensively performance of Federal, state, and local government management systems. She developed conceptual models and evaluation criteria, designed

written survey instruments for administration to governments and agencies, and conducted data analysis.

Dr. Donahue has 20 years of field experience and training in an array of emergency services-related fields, including managing a 911 communications center and working as a firefighter and emergency medical technician in Fairbanks, Ala., and upstate New York.

As an officer in the U.S. Army Medical Service Corps, she spent four years on active duty in the 6th Infantry Division, where her positions included Main Support Battalion Training and Operations Officer, Officer-in-Charge of the division's Forward Surgical Team, and Chief of Mobilization, Education, Training and Security at Bassett Army Hospital.

She holds a doctor of Philosophy degree in Public Administration and a Master of Public Administration from the Maxwell School of Citizenship and Public Affairs at Syracuse University, and a Bachelor of Arts in Geological and Geophysical Sciences from Princeton University.

She has been honored with the National Association of Schools of Public Affairs and Administration Dissertation Award, the Syracuse University Doctoral Prize, the Jon Ben Snow Graduate Fellowship in Nonprofit Management at Syracuse University, the Arthur F. Buddington Award for Excellence in the Earth Sciences at Princeton University, and several military awards, including the Meritorious Service Medal, three Army Commendation Medals, the Expert Field Medical Badge, Air Assault Badge, and Basic Military Parachutist Badge.

Gen. Ron Fogleman, U.S. Air Force (Ret.):
President and Chief Operating Officer of Durango Aerospace Incorporated

Gen. Fogleman has vast experience in air and space operations, expertise in long-range programming and strategic planning, and extensive training in fighter and mobility aircraft. He served in the Air Force for 34 years, culminating in his appointment as Chief of Staff, until his retirement in 1997. Fogleman has served as a military advisor to the Secretary of Defense, the National Security Council, and the President of the United States.

Among other advisory boards, he is a member of the National Defense Policy Board, the NASA Advisory Council, the Jet Propulsion Laboratory Advisory Board, the Council on Foreign Relations, and the congressionally

directed Commission to Assess United States National Security Space Management and Organization. He is chairing a National Research Council Committee on Aeronautics Research and Technology for Vision 2050: An Integrated Transportation System.

Gen. Fogleman received a Master's Degree in Military History from the U.S. Air Force Academy, a Master's Degree in Political Science from Duke University, and graduated from the U.S. Army War College. He has been awarded several military decorations including Defense Distinguished Service Medal with two oak leaf clusters, the Air Force Distinguished Service Medal with oak leaf cluster, both the Army and Navy Distinguished Service Medals, Silver Star, Purple Heart, Meritorious Service Medal, and two Distinguished Flying Crosses.

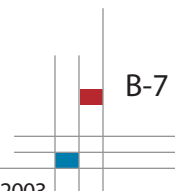
Ms. Christine H. Fox :
Vice President and Director, Operations Evaluation Group, Center for Naval Analyses

Christine H. Fox is Vice President and Director of the Operations Evaluation Group at the Center for Naval Analyses, a federally funded research and development center based in Alexandria, VA. In this role she is responsible for approximately 40 field representatives and 45 Washington-based analysts whose analytical focus is on helping operational commanders execute their missions.

Ms. Fox has spent her career as an analyst, assisting complex organizations like the U.S. Navy assess challenges and define practical solutions. She joined the Center for Naval Analysis in 1981 where she has served in a variety of analyst, leadership, and management positions.

Her assignments at the Center include serving as Team Leader, Operational Policy Team; Director, Anti-air Warfare Department; Program Director, Fleet Tactics and Capabilities; Team Leader of Third Fleet Tactical Analysis Team; Field Representative to Tactical Training Group – Pacific; Project Director, Electronic Warfare Project; Field Representative to Fighter Airborne Early Warning Wing– U.S. Pacific Fleet; and Analyst, Air Warfare Division, Operations Evaluation Group.

Before joining the Center, Ms. Fox served as a member of the Computer Group at the Institute for Defense Analysis in Alexandria, where she participated in planning and analyses of evaluations of tactical air survivability during close air support, and effectiveness of electronic warfare during close air support.



Ms. Fox received a bachelor of science degree in mathematics and a master of science degree in applied mathematics from George Mason University.

Col. Gary S. Geyer, U.S. Air Force (Ret.):
Consultant

Col. Geyer has 35 years of experience in space engineering and program management, primarily in senior positions in the Government and industry that emphasize management and system engineering. He has been responsible for all aspects of systems' success, including schedule, cost, and technical performance.

He served for 26 years with the National Reconnaissance Office (NRO) and was the NRO System Program Office Director for two major programs, which encompassed the design, manufacture, test, launch, and operation of several of our nation's most important reconnaissance satellites. Col. Geyer received the NRO Pioneer Award 2000 for his contributions as one of 46 pioneers of the NRO responsible for our nation's information superiority that significantly contributed to the end of the Cold War.

Following his career at the NRO, Col. Geyer was Vice President for a major classified program at Lockheed Martin and responsible for all aspects of program and mission success. His other assignments have included Chief Engineer for another nationally vital classified program and Deputy for Analysis for the Titan IV Program. Col. Geyer is teaching a Space Design course and a System Engineering/Program Management course at New Mexico State University in Las Cruces, N.M. He has a Bachelor of Science degree in Electrical Engineering from Ohio State University, and a Master's in Electrical Engineering and Aeronautical Engineering from the University of Southern California.

Col. Susan J. Helms, U.S. Air Force
Chief, Space Control Division, Requirements Directorate, Air Force Space Command

After a 12-year NASA career that included 211 days in space, Col. Helms returned to the U.S. Air Force in July 2002 to take a position at Headquarters, U.S. Air Force Space Command. She is currently the Division Chief of the Space Control Division of the Requirements Directorate of Air Force Space Command in Colorado Springs, Colorado. Selected by NASA in January 1990, Helms became an astronaut in July 1991. She flew on

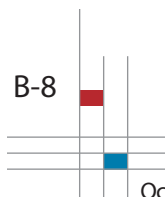
STS-54 (1993), STS-64 (1994), STS-78 (1996), and STS-101 (2000) and served aboard the International Space Station as a member of the Expedition-2 crew (2001). A veteran of five space flights, Col. Helms has logged 5,064 hours in space, including a world record EVA of 8 hours and 56 minutes.

Col. Helms graduated from the U.S. Air Force Academy in 1980. She received her commission and was assigned to Eglin Air Force Base, Florida, as an F-16 weapons separation engineer with the Air Force Armament Laboratory. In 1982, she became the lead engineer for F-15 weapons separation. In 1984, she was selected to attend graduate school. She received her degree from Stanford University in 1985 and was assigned as an assistant professor of aeronautics at the U.S. Air Force Academy. In 1987, she attended the Air Force Test Pilot School at Edwards Air Force Base, California. After completing one year of training as a flight test engineer, Col. Helms was assigned as a USAF Exchange Officer to the Aerospace Engineering Test Establishment, Canadian Forces Base, Cold Lake, Alberta, Canada, where she worked as a flight test engineer and project officer on the CF-18 aircraft. She was managing the development of a CF-18 Flight Control System Simulation for the Canadian Forces when selected for the astronaut program. As a flight test engineer, Col. Helms has flown in 30 different types of U.S. and Canadian military aircraft.

Col. Helms is the recipient of the Distinguished Superior Service Medal, the Defense Meritorious Service Medal, the Air Force Meritorious Service Medal, the Air Force Commendation Medal, the NASA Distinguished Service Medal, NASA Space Flight Medals, and the NASA Outstanding Leadership Medal. Named the Air Force Armament Laboratory Junior Engineer of the Year in 1983 and a Distinguished Graduate of the USAF Test Pilot School, she was the recipient of the R.L. Jones Award for Outstanding Flight Test Engineer, Class 88A. In 1990, she received the Aerospace Engineering Test Establishment Commanding Officer's Commendation, a special award unique to the Canadian Forces.

Mr. Richard Kohrs:
Chief Engineer, Kistler Aerospace Corporation

Richard Kohrs has over 40 years of experience in aerospace systems engineering, stress analysis, and integration. He has held senior management positions in major NASA programs from Apollo to the Space Station.



As a member of the Apollo Spacecraft Program's Systems Engineering and Integration Office, he developed the Spacecraft Operations Data Book system that documented systems and subsystem performance and was the control database for developing flight rules, crew procedures, and overall performance of the Apollo spacecraft.

After Apollo, he became Manager of System Integration for the Space Shuttle Program; Deputy Manager, Space Shuttle Program; and then Deputy Director of the Space Shuttle Program at JSC. As Deputy Director, he was responsible for the daily engineering, processing, and operations activities of the Shuttle Program, and he developed an extensive background in Shuttle systems integration. In 1989, he became the Director of Space Station Freedom, with overall responsibility for its development and operation.

After years of public service, he left NASA to become the Director of the ANSER Center for International Aerospace Cooperation (1994–1997). Mr. Kohrs joined Kistler Aerospace in 1997 as Chief Engineer. His primary responsibilities include vehicle integration, design specifications, design data books, interface control, vehicle weight, performance, and engineering review board matters. He received a Bachelor of Science degree from Washington University, St. Louis, in 1956.

Susan Morrissey Livingstone:

Susan Livingstone has served her nation for more than 30 years in both Government and civic roles. From July 2001–February 2003, she served as Under Secretary of the Navy. As “COO” to the Secretary of the Navy, she had a broad executive management portfolio (e.g., programming, planning, budgeting, business processes, organizational alignment), but also focused on Naval space, information technology, and intelligence/compartimented programs; integration of Navy-Marine Corps capabilities; audit, Inspector General and criminal investigative programs; and civilian personnel programs.

Ms. Livingstone is a policy and management consultant and also serves as a member of the National Security Studies Board of Advisors (Maxwell School, Syracuse University), is a board member of the Procurement Round Table, and was appointed to NASA's Return to Flight Task Group for safe return of Shuttle flight operations.

Prior to serving as Under Secretary of the Navy, she was CEO of the Association of the United States Army and deputy chairman of its Council of Trustees. She also served as a vice president and board member of the Procurement Round Table, and as a consultant and panel chairman to the Defense Science Board (on “logistics transformation”).

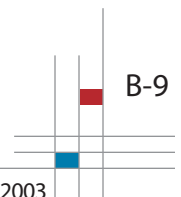
From 1993 to 1998, Ms. Livingstone served the American Red Cross Headquarters as Vice President of Health and Safety Services, Acting Senior Vice President for Chapter Services, and a consultant for Armed Forces Emergency Services.

As Assistant Secretary of the Army for Installations, Logistics and Environment from 1989 to 1993, she was responsible for a wide range of programs including military construction, installation management, Army logistics programs, base realignment and closures, energy and environmental issues, domestic disaster relief, and restoration of public infrastructure to the people of Kuwait following operation Desert Storm. She also was decision and acquisition management authority for the DOD chemical warfare materiel destruction program.

From 1981 to 1989, Ms. Livingstone served at the Veterans Administration (VA) in a number of positions including Associate Deputy Administrator for Logistics and Associate Deputy Administrator for Management. She served as the VA's Senior Acquisition Official and also directed and managed the Nation's largest medical construction program. Prior to her Executive Branch service, she worked for more than nine years in the Legislative branch on the personal staffs of both a Senator and two congressmen.

Ms. Livingstone graduated from the College of William and Mary in 1968 with an a Bachelor of Arts degree and completed a Master of Arts in political science at the University of Montana in 1972. She also spent two years in postgraduate studies at Tufts University and the Fletcher School of Law and Diplomacy.

Livingstone has received numerous awards for her community and national service, including the highest civilian awards from the NRO, VA, and the Departments of the Army and Navy. She is also a recipient of the Secretary of Defense Award for Outstanding Public Service.



Mr. James D. Lloyd:

Deputy Associate Administrator for Safety and Mission Assurance, NASA

Ex-Officio Member

Mr. Lloyd has extensive experience in safety engineering and risk management, and has supported a number of Blue Ribbon panels relating to mishaps and safety problems throughout his career. He began his career after an intern training period as a system safety engineer with the U.S. Army Aviation Systems Command in St. Louis.

He transferred to its parent headquarters, the Army Materiel Command (AMC) in 1973 and, after serving several safety engineering roles, was appointed as the Chief of the Program Evaluation Division in the Command's Safety Office, where he assured the adequacy of safety programs for AMC organizations.

In 1979, he continued his career as a civilian engineer with the AMC Field Safety Activity in Charlestown, IN, where he directed worldwide safety engineering, evaluation, and training support. In 1987, a year after the Shuttle Challenger disaster, Mr. Lloyd transferred from the U.S. Army to NASA to help the Agency rebuild its safety mission assurance program. He was instrumental in fulfilling several of the recommendations issued by the Rogers' Commission, which investigated the *Challenger* mishap. After the Shuttle returned to flight with the mission of STS-26, Mr. Lloyd moved to the Space Station Freedom Program Office in Reston, Va., where he served in various roles culminating in being appointed as the Program's Product Assurance Manager.

In 1993, he became Director, Safety and Risk Management Division in the Office of Safety and Mission Assurance, serving as NASA's "Safety Director" and was appointed to his present position in early 2003. He serves also as an ex-officio member of the NASA Advisory Council Task Force on ISS Operational Readiness. Lloyd holds a Bachelor of Science degree in Mechanical Engineering, with honors, from Union College, Schenectady, N.Y., and a Master of Engineering degree in Industrial Engineering from Texas A&M University, College Station.

Lt. Gen. Forrest S. McCartney, U.S. Air Force (Ret.):
Vice Chairman of the Aerospace Safety Advisory Panel

During Lt. Gen. McCartney's distinguished Air Force career, he held the position of program director for several major satellite programs, was Commander of the Ballistic

Missile Organization (responsible for Minuteman and Peacekeeper development), Commander of Air Force Space Division, and Vice Commander, Air Force Space Command.

His military decorations and awards include the Distinguished Service Medal, Legion of Merit with one oak leaf cluster, Meritorious Service Medal, and Air Force Commendation Medal with three oak leaf clusters. He was recipient of the General Thomas D. White Space Trophy in 1984 and the 1987 Military Astronautical Trophy.

Following the *Challenger* accident, in late 1986 Lt. Gen. McCartney was assigned by the Air Force to NASA and served as the Director of Kennedy Space Center until 1992. He received numerous awards, including NASA's Distinguished Service Medal and Presidential Rank Award, the National Space Club Goddard Memorial Trophy, and AIAA Von Braun Award for Excellence in Space Program Management.

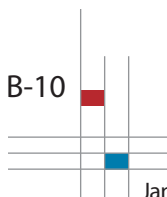
After 40 years of military and civil service, he became a consultant to industry, specializing in the evaluation of hardware failure/flight readiness. In 1994, he joined Lockheed Martin as the Astronautics Vice President for Launch Operations. He retired from Lockheed Martin in 2001 and is currently the Vice Chairman of the NASA Aerospace Safety Advisory Panel.

Lt. Gen. McCartney has a Bachelor's degree in Electrical Engineering from Auburn University, a Master's degree in Nuclear Engineering from the Air Force Institute of Technology, and an honorary doctorate from the Florida Institute of Technology.

Rosemary O'Leary J.D., Ph.D.:

Dr. Rosemary O'Leary is professor of public administration and political science, and coordinator of the Ph.D. program in Public Administration at the Maxwell School of Citizenship and Public Affairs at Syracuse University. An elected member of the U.S. National Academy of Public Administration, she was recently a senior Fulbright scholar in Malaysia. Previously Dr. O'Leary was Professor of Public and Environmental Affairs at Indiana University and cofounder and codirector of the Indiana Conflict Resolution Institute. She has served as the Director of Policy and Planning for a state environmental agency and has worked as an environmental attorney.

Dr. O'Leary teaches graduate courses in Public Organizations and Management, concentrating on organization change, organization culture, and the management of scientific and technical organizations.



| She was a consultant to the U.S. Department of the
| Interior, the U.S. Environmental Protection Agency, the
| Indiana Department of Environmental Management, the
| International City/County Management Association, the
| National Science Foundation, and the National Academy
| of Sciences.

| Dr. O'Leary is the author or editor of five books and more
| than 75 articles on public management. She has won
| seven national research awards, including Best Book in
| Public and Nonprofit Management for 2000 (given by the
| Academy of Management), Best Book in Environmental
| Management and Policy for 1999 (given by the American
| Society for Public Administration), and the Mosher
| Award, which she won twice, for best article by an acade-
| mician published in Public Administration Review.

| Dr. O'Leary was recently awarded the Syracuse
| University Chancellor's Citation for Exceptional
| Academic Achievement, the highest research award at the
| university. She has won eight teaching awards as well,
| including the national Excellence in Teaching Award
| given by the National Association of Schools of Public
| Affairs and Administration, and she was the recipient of
| the Distinguished Service Award given by the American
| Society for Public Administration's Section on
| Environment and Natural Resources Administration.
| O'Leary has served as national chair of the Public
| Administration Section of the American Political Science
| Association, and as the national chair of the Section on
| Environment and Natural Resources Administration of the
| American Society for Public Administration.

Dr. Decatur B. Rogers, P.E.,
*Dean Tennessee State University College
of Engineering, Technology and Computer Science*

Since 1988, Dr. Rogers has served as the Dean, College
of Engineering, Technology and Computer Science, and
Professor of Mechanical Engineering at Tennessee State
University in Nashville. Rogers served in professorship
and dean positions at Florida State University, Tallahassee;
Prairie View A&M University, Prairie View, Texas; and
Federal City College, Washington, D.C.

Dr. Rogers holds a Ph.D. in Mechanical Engineering from
Vanderbilt University; Masters' degrees in Engineering
Management and Mechanical Engineering from Vanderbilt
University; and a Bachelor's in Mechanical Engineering
from Tennessee State University.

Mr. Sy Rubenstein:
Aerospace Consultant

Mr. Rubenstein was a major contributor to the design,
development, and operation of the Space Shuttle and has
been involved in commercial and Government projects
for more than 35 years. As an employee of Rockwell
International, the prime contractor for the Shuttle, he was
the Director of System Engineering, Chief Engineer,
Program Manager, and Division President during 20 years
of space programs.

He has received the NASA Public Service Medal, the
NASA Medal for Exceptional Engineering, and the AIAA
Space Systems Award for his contributions to human
spacecraft development. Mr. Rubenstein, a leader, innovator,
and problem solver, is a fellow of the AIAA and the AAS.

Mr. Robert Sieck:
Aerospace Consultant

Mr. Sieck, the former Director of Shuttle Processing at the
Kennedy Space Center (KSC), has an extensive back-
ground in Shuttle systems, testing, launch, landing, and
processing. He joined NASA in 1964 as a Gemini
Spacecraft Systems engineer and then served as an Apollo
Spacecraft test team project engineer. He later became the
Shuttle Orbiter test team project engineer, and in 1976
was named the Engineering Manager for the Shuttle
Approach and Landing Tests at Dryden Flight Research
Facility in California. He was the Chief Shuttle Project
Engineer for STS-1 through STS-7, and became the first
KSC Shuttle Flow Director in 1983. He was appointed
Director, Launch and Landing Operations, in 1984, where
he served as Shuttle Launch Director for 11 missions.

He served as Deputy Director of Shuttle Operations from
1992 until January 1995 and was responsible for assisting
with the management and technical direction of the
Shuttle Program at KSC. He also retained his position as
Shuttle Launch Director, a responsibility he had held from
February 1984 through August 1985, and then from
December 1986 to January 1995. He was Launch Director
for STS-26R and all subsequent Shuttle missions through
STS-63. Mr. Sieck served as Launch Director for 52
Space Shuttle launches.

He earned his Bachelor of Science degree in Electrical
Engineering at the University of Virginia in 1960 and

obtained additional postgraduate credits in mathematics, physics, meteorology, and management at both Texas A&M and the Florida Institute of Technology. He has received numerous NASA and industry commendations, including the NASA Exceptional Service Medal and the NASA Distinguished Service Medal. Mr. Sieck joined the Aerospace Safety Advisory Panel as a consultant in March 1999.

**Lt. Gen. Thomas Stafford, U.S. Air Force (Ret.):
*Cochair, Return to Flight Task Group***

President, Stafford, Burke and Hecker Inc., technical consulting

Lt. Gen. Stafford, an honors graduate of the U.S. Naval Academy, joined the space program in 1962 and flew four missions during the Gemini and Apollo programs. He piloted Gemini 6 and Gemini 9, and traveled to the Moon as Commander of Apollo 10. He was assigned as head of the astronaut group in June 1969, responsible for the selection of flight crews for projects Apollo and Skylab.

In 1971, Lt. Gen. Stafford was assigned as Deputy Director of Flight Crew Operations at the NASA Manned Spacecraft Center. His last mission, the Apollo-Soyuz Test Project in 1975, achieved the first rendezvous between American and Soviet spacecrafts.

He left NASA in 1975 to head the Air Force Test Flight Center at Edwards Air Force Base and, in 1978, assumed duties as Deputy Chief of Staff, Research Development and Acquisition, U.S. Air Force Headquarters in Washington. He retired from government service in 1979 and became an aerospace consultant.

Lt. Gen. Stafford has served as Defense Advisor to former President Ronald Reagan; and headed The Synthesis Group, which was tasked with plotting the U.S. return to the Moon and eventual journey to Mars.

Throughout his careers in the Air Force and NASA space program, he has received many awards and medals including the Congressional Space Medal of Honor in 1993. He served on the National Research Council's Aeronautics and Space Engineering Board, the Committee on NASA Scientific and Technological Program Reviews, and the Space Policy Advisory Council.

He was Chairman of the NASA Advisory Council Task Force on Shuttle-Mir Rendezvous and Docking Missions.

He is currently the Chairman of the NASA Advisory Council Task Force on International Space Station Operational Readiness.

Mr. Tom Tate:

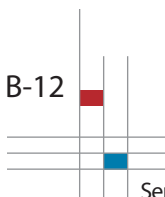
Mr. Tate was vice president of legislative affairs for the Aerospace Industries Association (AIA), the trade association representing the nation's manufacturers of commercial, military, and business aircraft, helicopters, aircraft engines, missiles, spacecraft, and related components and equipment. Joining AIA in 1988, Tate directs the activities of the association's Office of Legislative Affairs, which monitors policy issues affecting the industry and prepares testimony that communicates the industry's viewpoint to Congress.

Before joining AIA, Tate served on the staff of the House of Representative's Committee on Science and Technology for 14 years. Joining the staff in 1973 as a technical consultant and counsel to the House Subcommittee on Space Science and Applications, he was appointed deputy staff director of the House Subcommittee on Energy Research and Development in 1976. In 1978, Tate returned to the space subcommittee as chief counsel; and in 1981, he became special assistant to the chairman of the committee until joining AIA.

Mr. Tate worked for the Space Division of Rockwell International in Downey, Calif., from 1962 to 1973 in various engineering and marketing capacities and was director of space operations when he departed the company in 1973. He worked on numerous programs, including the Gemini Paraglider, Apollo, Apollo/Soyuz, and Shuttle Programs.

Mr. Tate worked for RCA's Missile and Surface Radar Division in Moorestown, N.J. from 1958 to 1962 in the project office of the Ballistic Missile Early Warning System (BMEWS) being built for the USAF. From 1957 to 1958, Tate served in the Army as an artillery and guided missile officer at Fort Bliss, Texas.

He received a Bachelor's degree in marketing from the University of Scranton in 1956 and a law degree from Western State University College of Law in Fullerton, Calif., in 1970. In his final year of law school, his fellow students awarded him the Gold Book Award as the most outstanding student. In 1991, he received the Frank J. O'Hara award for distinguished alumni in science and technology from the University of Scranton.



Mr. Tate is a member of numerous aerospace and defense associations including the AIAA, the National Space Club, and the National Space Institute, where he serves as an advisor. He also served as a permanent civilian member of the NASA Senior Executive Service Salary and Performance Review Board.

Dr. Kathryn C. Thornton:
Faculty, University of Virginia

After eleven years with NASA, Dr. Thornton left NASA on August 1, 1996, to join the faculty of the University of Virginia. Selected by NASA in May 1984, Dr. Thornton became an astronaut in July 1985. Her technical assignments have included conducting flight software verification in the Shuttle Avionics Integration Laboratory (SAIL), serving as a team member of the Vehicle Integration Test Team (VITT) at KSC, and serving as a spacecraft communicator (CAPCOM). A veteran of three space flights, Dr. Thornton flew on STS-33 in 1989, STS-49 in 1992, and STS-61 in 1993. She has logged over 975 hours in space, including more than 21 hours of extravehicular activity (EVA).

After earning her Ph.D. at the University of Virginia in 1979, Dr. Thornton was awarded a NATO Postdoctoral Fellowship to continue her research at the Max Planck Institute for Nuclear Physics in Heidelberg, West Germany. In 1980, she returned to Charlottesville, Virginia, where she was employed as a physicist at the U. S. Army Foreign Science and Technology Center.

Mr. William Wegner:
Consultant

Mr. Wegner graduated from the U.S. Naval Academy in 1948. He subsequently received Masters' degrees in Naval Architecture and Marine Engineering from Webb Institute in New York. In 1956 he was selected by Adm. Hyman Rickover to join the Navy's nuclear program and was sent to the Massachusetts Institute of Technology, where he received his Master's degree in Nuclear Engineering. After serving in a number of field positions, including that of Nuclear Power Superintendent at the Puget Sound Naval Shipyard, he returned to Washington. He served as deputy director to Adm. Rickover in the Naval Nuclear Program for 16 years and was awarded the DOD Distinguished Service Award and the Atomic Energy Commission's distinguished service award.

In 1979, he retired from Government service, and formed Basic Energy Technology Associates with three fellow

naval retirees. During its 10 successful years of operation, it provided technical services to over 25 nuclear utilities and other nuclear-related activities. Wegner has served on a number of panels including the National Academy of Sciences that studied the safety of Department of Energy nuclear reactors. From 1989 to 1992, he provided technical assistance to the Secretary of Energy on nuclear-related matters. He has provided technical services to over 50 nuclear facilities. Mr. Wegner served as a Director of the Board of Directors of Detroit Edison from 1990 until retiring in 1999.

Lt. Col. David Lengyel:
Executive Secretary, Return to Flight Task Group

Since February 2003, Lt. Col. Lengyel has served on the administrative staff of the *Columbia* Accident Investigation Board (CAIB). Prior to this, he was Executive Director of the Aerospace Safety Advisory Panel for almost two years.

From 1999 through 2000, he served a tour of duty as the Manager of the Moscow Technical Liaison Office (MTLO) for the International Space Station (ISS) Program in Russia. The MTLO interfaces with Russian contractors and space agency personnel to monitor and track the progress of Russian segment elements and Soyuz/Progress vehicles, as well as to provide technical liaison between U.S. and Russian engineering/mission integration personnel.

Lt. Col. Lengyel joined NASA in October 1993 as the third Executive Officer to Administrator Daniel S. Goldin. He served in several program operations and payloads capacities within the ISS and Shuttle-Mir Programs at JSC from 1994 to 1998. He led an analytical assessment of Shuttle-Mir lessons learned for application to the ISS.

Prior to joining NASA, he was a senior aircrew-training instructor for McDonnell-Douglas in St. Louis. He conducted pilot training for the FA-18 Hornet and F-15 Eagle for both foreign and domestic customers.

He is a Lieutenant Colonel in the Marine Corps Reserves and has accumulated over 2000 hours flight time in the F-4S Phantom II, OV-10 Bronco, and FA-18 Hornet.

Lt. Col. Lengyel holds a Bachelor of Science degree from the U.S. Naval Academy, a Master of Business Administration from the University of Missouri, and a Master of Arts in International Affairs from Washington University in St. Louis.

