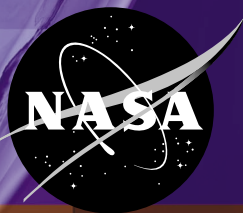


September 8, 2003

NASA's Implementation Plan for 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*



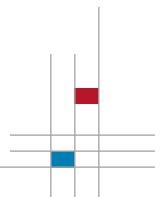


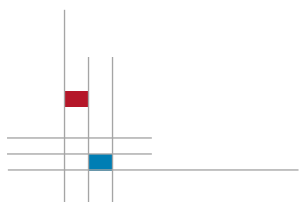
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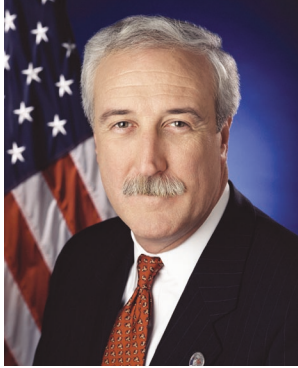
September 8, 2003

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





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.

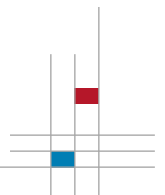
In order to achieve the first objective, I assigned a group of distinguished, uniquely qualified individuals led by Admiral Harold W. Gehman, Jr. (USN-Ret.) to form the *Columbia* Accident Investigation Board (CAIB) and determine the cause of this tragic event. The CAIB thoroughly and intensely examined 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.

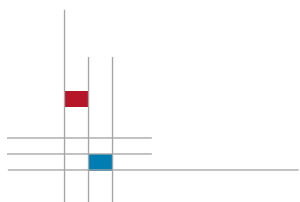
Now we embark on the second objective—to fix the problems identified by the CAIB. In this, our Return to Flight Implementation Plan, we embrace the CAIB report and its recommendations as our roadmap to do so. But we will not stop there. We have also undertaken to raise the bar above the CAIB recommendations. 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

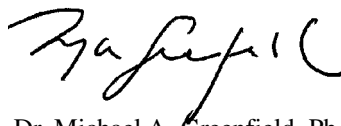
The *Columbia* Accident Investigation Board (CAIB) Report has provided NASA with a roadmap “to resume our journey into space.” The recommendations “reflect the Board’s strong support for return to flight at the earliest date consistent with the overriding objective of safety.” NASA fully accepts the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

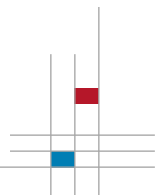
Smarter, stronger, safer!

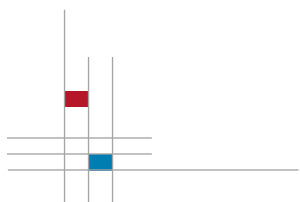


Dr. Michael A. Greenfield, Ph.D.
Associate Deputy Administrator
for Technical Programs



William F. Readdy
Associate Administrator
for Space Flight







Contents

Summary	ix
Overview	ix
Response Summaries	xv
CAIB Recommendations Implementation Schedule ...	xxv
Part 1 – NASA’s Response to the <i>Columbia</i> Accident Investigation Board’s Recommendations	
3.2-1 External Tank Thermal Protection System Modifications	1-1
3.3-2 Orbiter Hardening	1-11
3.3-1 Reinforced Carbon-Carbon Nondestructive Inspection	1-15
6.4-1 Thermal Protection System On-Orbit Inspect and Repair	1-19
3.3-3 Entry with Minor Damage	1-25
3.3-4 Reinforced Carbon-Carbon Database	1-27
3.3-5 Minimizing Zinc Primer Leaching	1-29
3.8-1 Reinforced Carbon-Carbon Spares	1-31
3.8-2 Modeling Reviews	1-33
3.4-1 Ground-Based Imagery	1-35
3.4-2 Downlink Post-Separation	1-39
3.4-3 On-Vehicle Ascent Imagery	1-41
6.3-2 National Imagery and Mapping Agency Memorandum of Agreement	1-45
3.6-1 Update Modular Auxiliary Data System	1-47
3.6-2 Modular Auxiliary Data System Redesign	1-49



Contents

4.2-2 Enhance Wiring Inspection Capability	1-51
4.2-1 Solid Rocket Booster Bolt Catcher	1-53
4.2-3 Closeout Inspection	1-57
4.2-4 Micrometeoroid and Orbital Debris Risk	1-59
4.2-5 Foreign Object Debris Processes	1-61
6.2-1 Scheduling	1-63
6.3-1 Mission Management Team Improvements	1-65
7.5-1 Independent Technical Engineering Authority	1-67
7.5-2 Safety and Mission Assurance Organization	1-67
7.5-3 Reorganize Space Shuttle Integration Office	1-69
9.1-1 Detailed Plan for Organizational Changes	1-67
9.2-1 Mid-Life Recertification	1-73
10.3-1 Digitize Closeout Photographs	1-75
10.3-2 Engineering Drawing Update	1-77

Part 2 – Raising the Bar – Other Corrective Actions

SSP-1 Quality Planning and Requirements Document/Government Mandated Inspection Point	2-1
SSP-2 Public Risk of Overflight	2-3
SSP-3 Contingency Shuttle Crew Support	2-5
SSP-4 Acceptable Risks	2-7
SSP-5 Critical Debris Sources	2-9
SSP-6 Waivers, Deviations, and Exceptions	2-11
SSP-7 NASA Accident Investigation Team Working Group Findings	2-13
SSP-8 Certification of Flight Readiness Improvements	2-15
SSP-9 Failure Mode and Effects Analyses/ Critical Items Lists	2-17
SSP-10 Contingency Action Plans	2-19

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

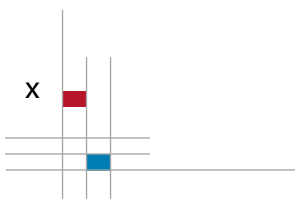
- Increased the responsibility and authority of the Space Shuttle Systems Integration Office in order ensure effective coordination among the diverse Space Shuttle elements. Staffing for the Office will also be expanded.
- Established a Deputy Space Shuttle Program Manager to provide technical and operational 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.

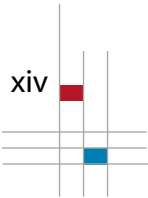
Conclusion

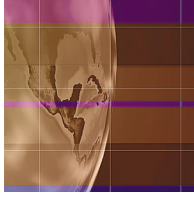
The American people have stood with NASA during this time of loss. From all across the country, volunteers from all walks of life joined our efforts to recover *Columbia*. These individuals gave their time and energy to search an area the size of Rhode Island on foot and from the air. The people of Texas 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)* – Potential solutions are a bellows boot, drip lip and drain, or a purge ring.
- *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.

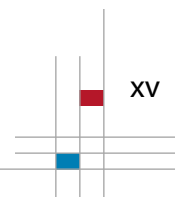
- *Foam Verification Reassessment* – NASA is reassessing the Thermal Protection System verification rationale and data for all processes for applying foam to the External Tank. NASA will ensure that at least two employees attend all final closeouts and critical hand-spraying procedures to ensure proper 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 ranging from near-term with low technical risk to very long-term with high technical risk. Eight near-term options were selected for further study. NASA is developing detailed feasibility assessments for each of these options.

NASA is also currently conducting foam impact tests on reinforced carbon-carbon (RCC) and tile to determine their ability to withstand impacts and to build computer models that will accurately predict impact damage.

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. In the near term, we will remove selected components and return them to the vendor for comprehensive nondestructive inspection (NDI). For the long-term, the Space Shuttle Program is reviewing inspection criteria and 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. This multi-center 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 is currently 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.

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 spares for flight use. We will also determine whether additional spare panels should be procured to support the long-term needs of the Program.

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 cameras in various locations on the Space Shuttle to supplement ground-based imagery until SRB separation and provide the primary views through ET separation. For STS-114, a camera with downlink capability is being added to the ET to view the bipod area and some of the Orbiter wing leading edge and lower tile acreage. On STS-115 and STS-116, we will add cameras that allow us to view the majority of the underside of the Orbiter, which includes critical landing gear door and umbilical door areas.

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 continuing to work toward the goal of developing nondestructive, highly effective wiring integrity verification.

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]

Processes and procedures are under evaluation to assure at least two people will attend all final closeouts and intertank area hand-spraying procedures to ensure proper processing.

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.

Micrometeoroid and orbital debris (MMOD) is recognized as a continuing concern. To comply with the recommendation to operate the Shuttle to the same degree of safety for MMOD as calculated for the International Space Station (ISS), NASA will evaluate Shuttle vehicle design upgrades to decrease vulnerability to MMOD and operational changes (for example, modify Shuttle orientation after docking to the ISS).

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

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 will be improved; NASA will provide foreign object debris prevention surveillance throughout the entire processing timeline; and foreign object debris training will be provided annually.



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.

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.

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, 7.5-3, 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.

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.

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.

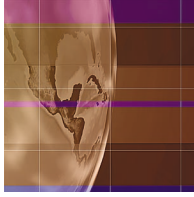
NASA will identify and acquire images of critical areas and details for capture in the digital image database. The images will be stored in a database from which they can be retrieved by cross-referencing to top-level drawings or vehicle zone locators. To improve the quality of broad-area closeout imaging, 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 accelerate the development of options for consideration by the Space Shuttle Program 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. The Digital Shuttle Project (DSP) has the potential to

- Convert vehicle engineering drawings into geometric solid models.
- Facilitate incorporation of engineering changes.
- Scan hardware to capture as-built configurations and create high-accuracy engineering models.
- Put an infrastructure and process in place to maintain and share the models.



Response Summaries

Part 2 – Raising the Bar – Other Corrective Actions

NASA has embraced the 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 has chartered a group of experts, including representatives from NASA, industry, the Department of Defense, and the Federal Aviation Administration to evaluate the effectiveness of the Space Shuttle Program’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.

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 over-flight 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 approximately 180 days.

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 Space Shuttle Program 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 Space Shuttle Program 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 Space Shuttle Program (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.

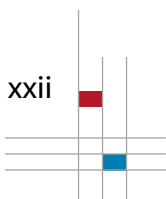
The certification of flight readiness (CoFR) is the process by which NASA ensures compliance with Program requirements and judges launch readiness. The CoFR process includes multiple reviews at progressively higher management levels, culminating with the Flight Readiness Review. Each organization that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



CAIB Observations

This section provides a list of the Observations that are found in Chapter 10, Volume I, of the CAIB Report. Subsequent versions of *NASA's Implementation Plan for Return to Flight and Beyond* will address CAIB observations and other suggestions as they are identified, evaluated and as individual implementation plans are developed.

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.

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 part, in 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.

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.

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 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 GMIP's 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 GMIP's are effectively assuring safe flight operations.

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

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

Test Equipment Upgrades

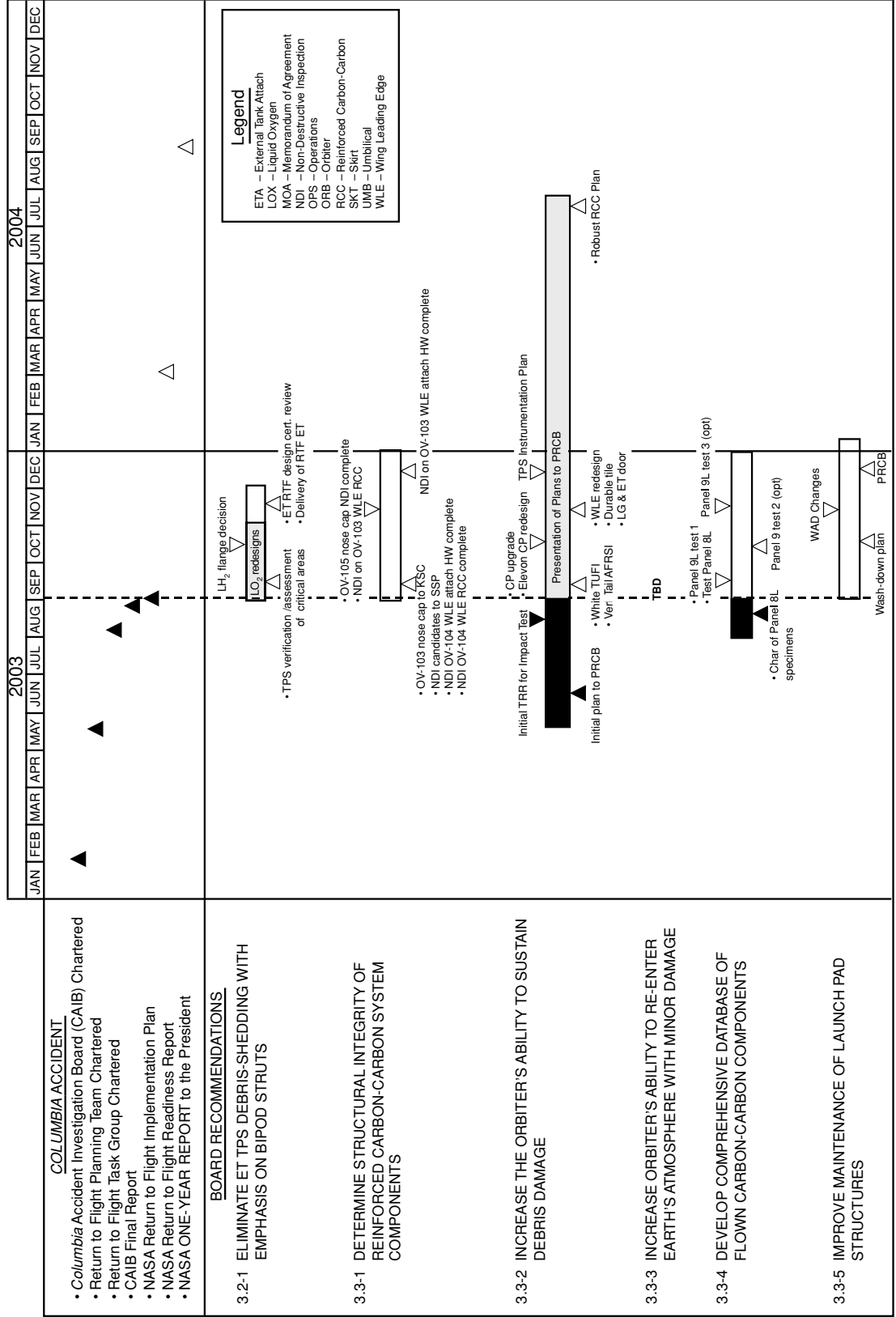
O10.11-1 Assess NASA and contractor equipment to determine if an upgrade will provide the reliability and accuracy needed to maintain the Shuttle through

2020. Plan an aggressive certification program for replaced items so that new equipment can be put into operation as soon as possible.

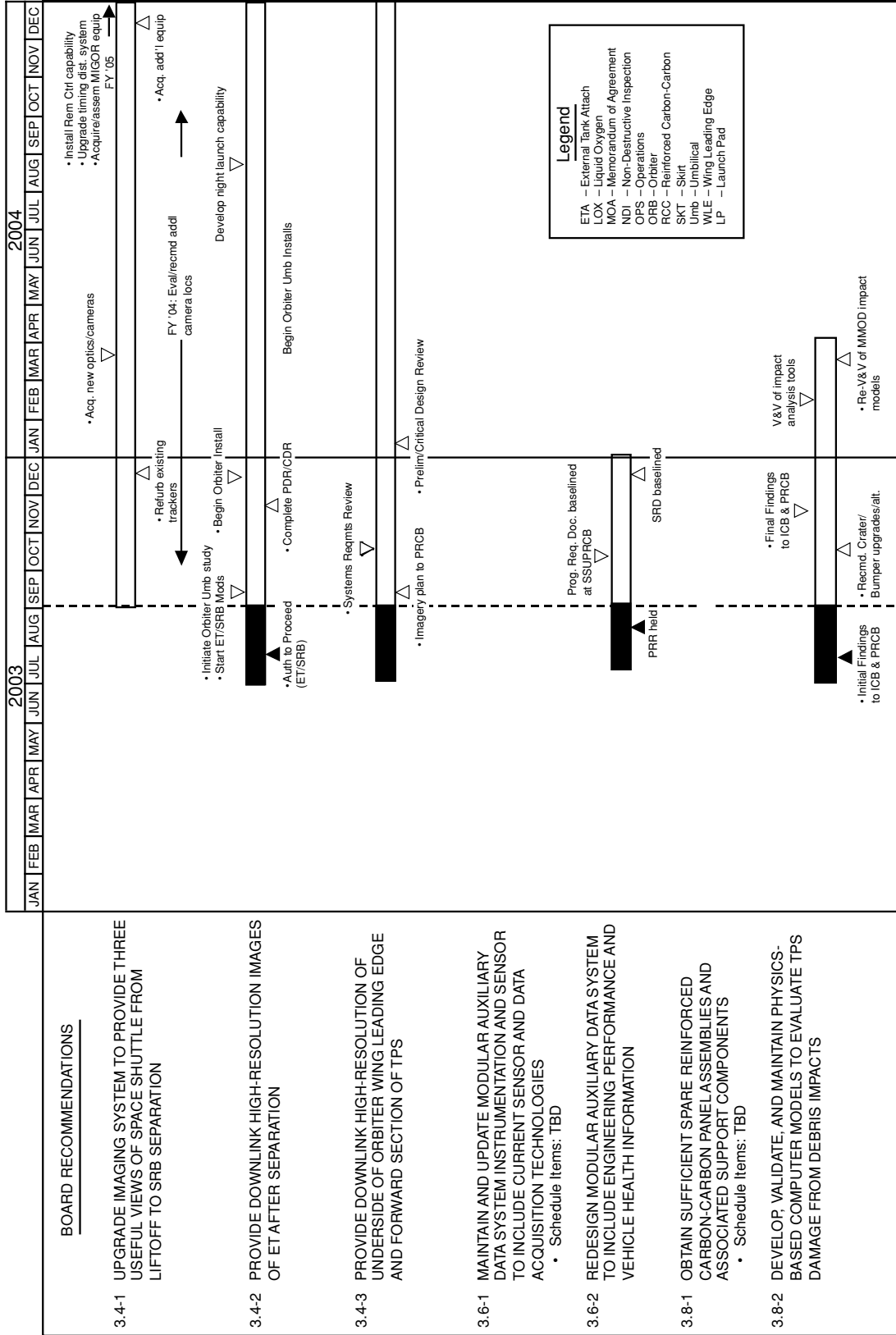
Leadership/Managerial Training

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.

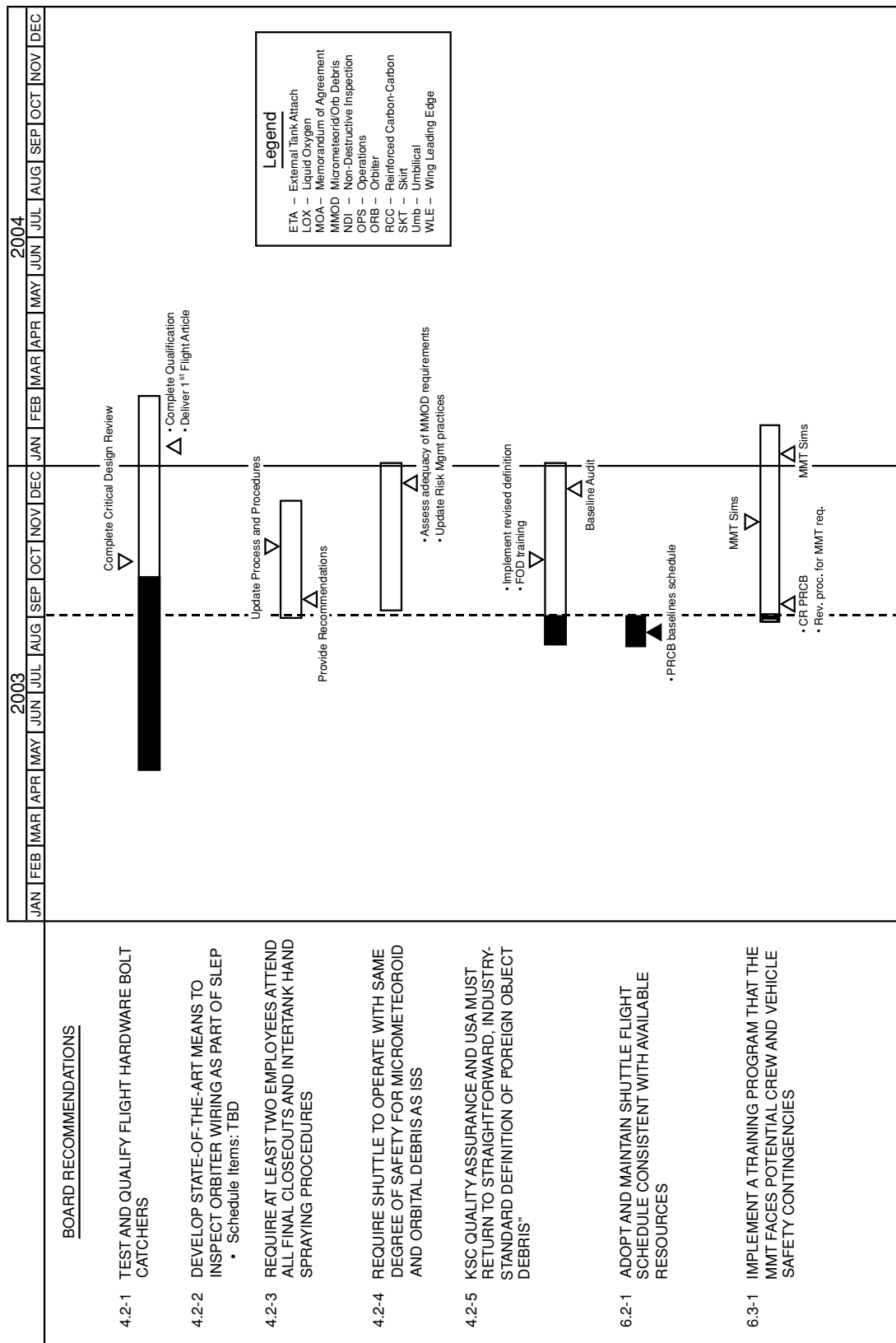
CAIB Recommendations Implementation Schedule



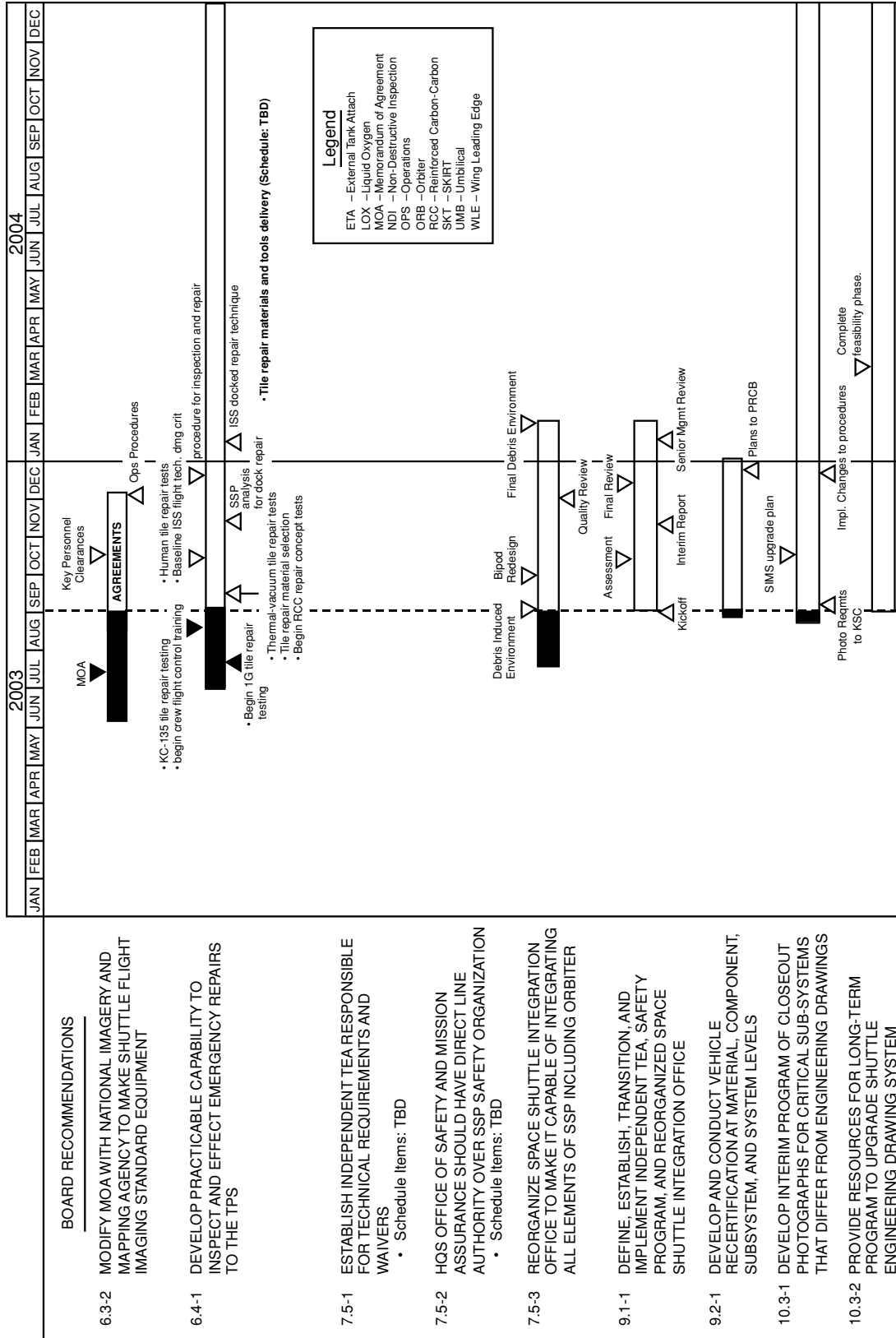
CAIB Recommendations Implementation Schedule



CAIB Recommendations Implementation Schedule



CAIB Recommendations Implementation Schedule



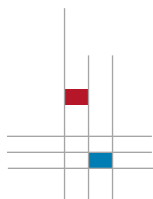
BOARD RECOMMENDATIONS

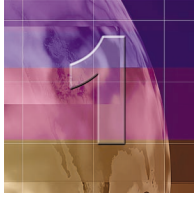
- 6.3-2 MODIFY MOA WITH NATIONAL IMAGERY AND MAPPING AGENCY TO MAKE SHUTTLE FLIGHT IMAGING STANDARD EQUIPMENT
- 6.4-1 DEVELOP PRACTICABLE CAPABILITY TO INSPECT AND EFFECT EMERGENCY REPAIRS TO THE TPS
- 7.5-1 ESTABLISH INDEPENDENT TEA RESPONSIBLE FOR TECHNICAL REQUIREMENTS AND WAIVERS
 - Schedule Items: TBD
- 7.5-2 HQS OFFICE OF SAFETY AND MISSION ASSURANCE SHOULD HAVE DIRECT LINE AUTHORITY OVER SSP SAFETY ORGANIZATION
 - Schedule Items: TBD
- 7.5-3 REORGANIZE SPACE SHUTTLE INTEGRATION OFFICE TO MAKE IT CAPABLE OF INTEGRATING ALL ELEMENTS OF SSP INCLUDING ORBITER
- 9.1-1 DEFINE, ESTABLISH, TRANSITION, AND IMPLEMENT INDEPENDENT TEA, SAFETY PROGRAM, AND REORGANIZED SPACE SHUTTLE INTEGRATION OFFICE
- 9.2-1 DEVELOP AND CONDUCT VEHICLE RECERTIFICATION AT MATERIAL, COMPONENT, SUBSYSTEM, AND SYSTEM LEVELS
- 10.3-1 DEVELOP INTERIM PROGRAM OF CLOSEOUT PHOTOGRAPHS FOR CRITICAL SUB-SYSTEMS THAT DIFFER FROM ENGINEERING DRAWINGS
- 10.3-2 PROVIDE RESOURCES FOR LONG-TERM PROGRAM TO UPGRADE SHUTTLE ENGINEERING DRAWING SYSTEM



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.

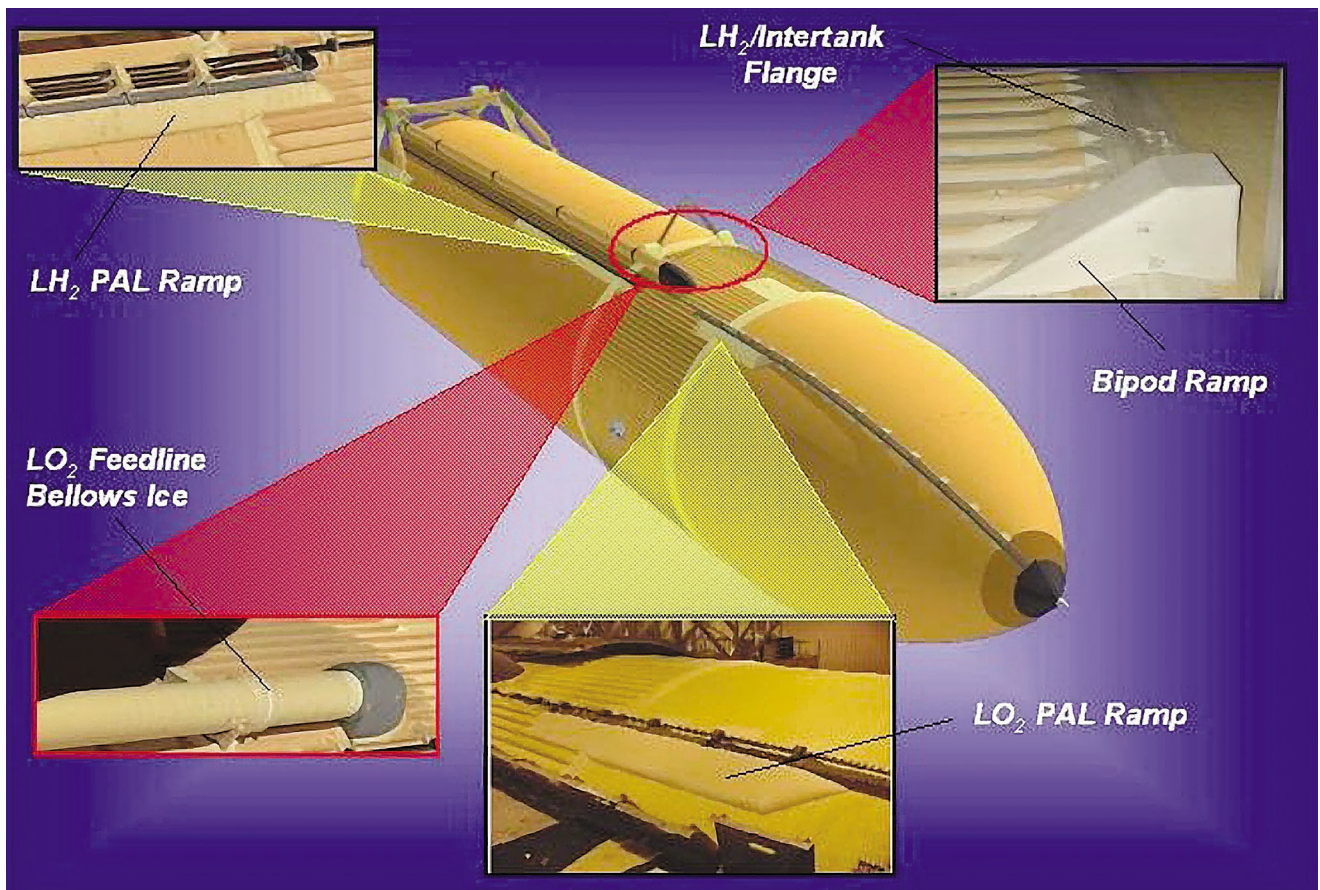


Figure 3.2-1-1. Primary potential ET debris sources being evaluated.



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

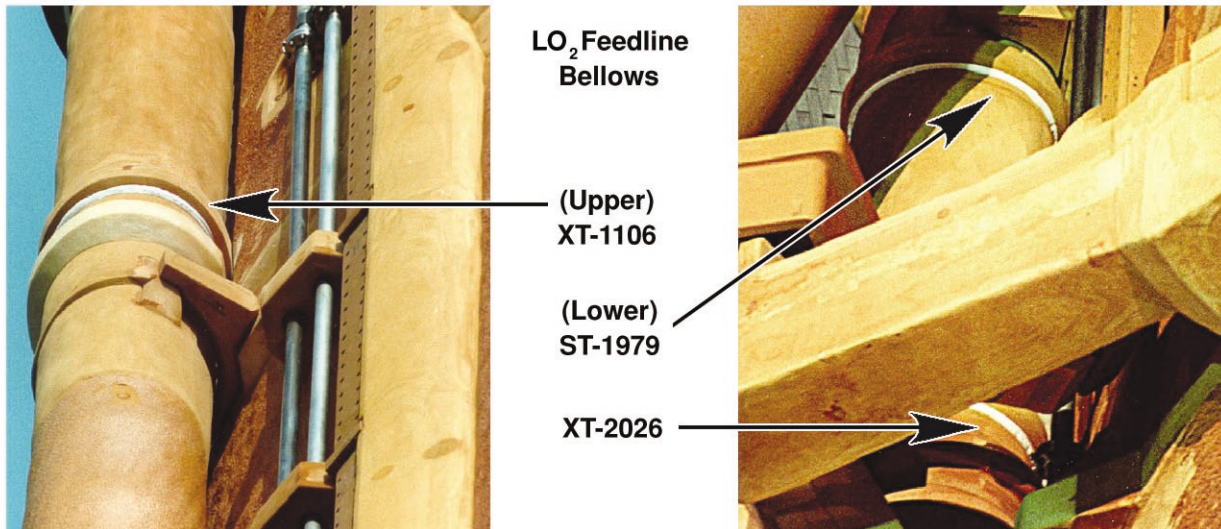
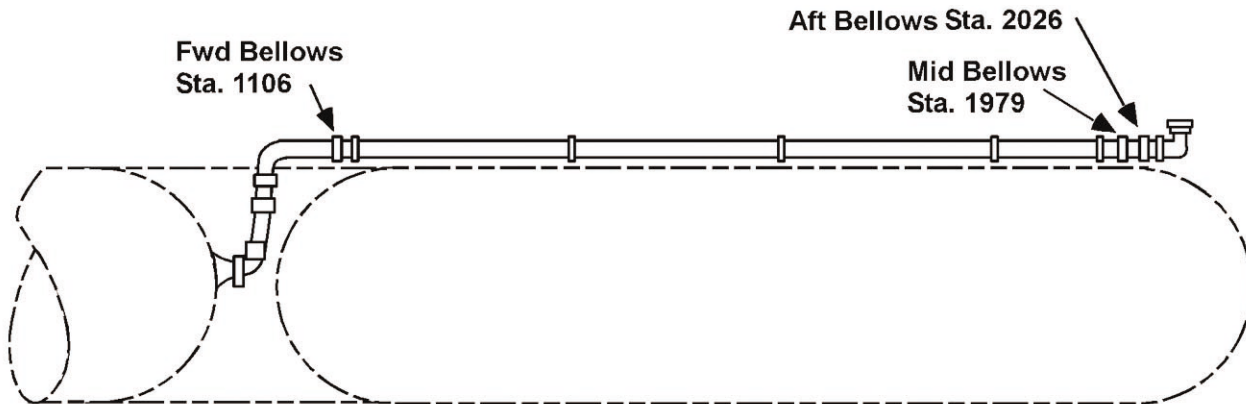


Figure 3.2-1-3. LO₂ feedline bellows.

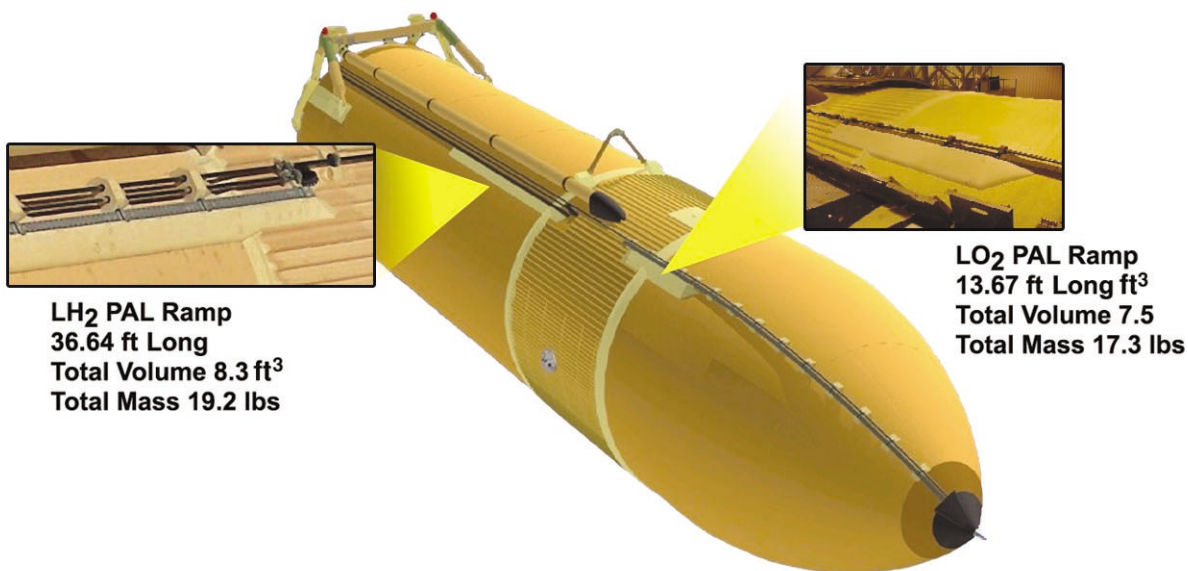


Figure 3.2-1-4. PAL ramp locations.

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 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 to 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 has documented a history of foam loss events from this area. The divots from the LH₂/intertank flange area are small (typically less than 0.100 lb.), and the debris emanates from within the critical debris zone.

NASA IMPLEMENTATION

As part of our efforts to eliminate debris loss, NASA will evaluate the potential for debris loss in all areas of the ET TPS. This task includes assessing the existing verification data and establishing requirements for additional data (test, dissections, plug pulls, etc.). Primary TPS areas where foam has been lost during ascent include the bipod ramp and the LH₂ intertank flange closeout. Additional areas of potential foam loss that need to be assessed are the LO₂ and LH₂ ET PAL ramps, other ET TPS areas

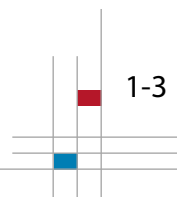
where debris loss has not historically been seen, and ice debris from the LO₂ bellows (figure 3.2-1-1).

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. Research is being conducted at Marshall Space Flight Center, Arnold Engineering and Development Center, Eglin Air Force Base, and elsewhere.

NASA will also pursue the development of TPS non-destructive investigation (NDI) techniques.

Focus areas for RTF were established with inputs from the ET Project, the ET Working Group, and a Lockheed Martin Ascent Debris Minimization Independent Review Team. NASA has established RTF plans that include activities in six areas:

- Forward bipod ramp
- LO₂ feedline bellows
- PAL ramps
- LH₂/intertank flange closeout
- Foam verification reassessment
- NDI of foam



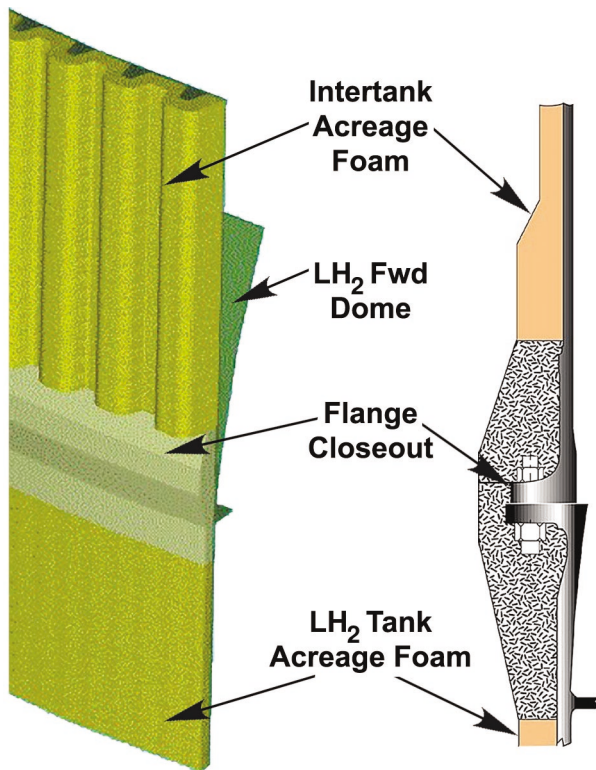


Figure 3.2-1-5. ET LH₂ flange area.

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 to prevent ice formation as a debris hazard.

LO₂ Feedline Bellows Implementation Approach

NASA will select one concept for RTF retrofit for preliminary design review (PDR)/critical design review (CDR) approval. The verification approach, which is dependent on the design solution (figure 3.2-1-7), will include a combination of analysis and testing. Design concepts under consideration for ET retrofit include a flexible bellows boot, heated gaseous nitrogen (GN₂) or gaseous helium purge, and incorporation of a hydrophobic coating material with a condensate drain.

PAL Ramps Implementation Approach

There has been only one observed PAL ramp foam loss event in the flight history (STS-4). The cause of this event was determined to be associated with a repair operation, which has been precluded by limiting repairs allowed on all PAL ramps. However, NASA is also assessing ET PAL ramp configurations to reduce or eliminate them as potential sources of TPS debris.

A dual approach is being taken in this area to increase confidence in the existing design, and develop design concepts to eliminate or reduce the size of the PAL ramps. The primary path for initial ET RTF is to gain confidence in the existing PAL ramp design. 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). The secondary path for RTF is to 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).

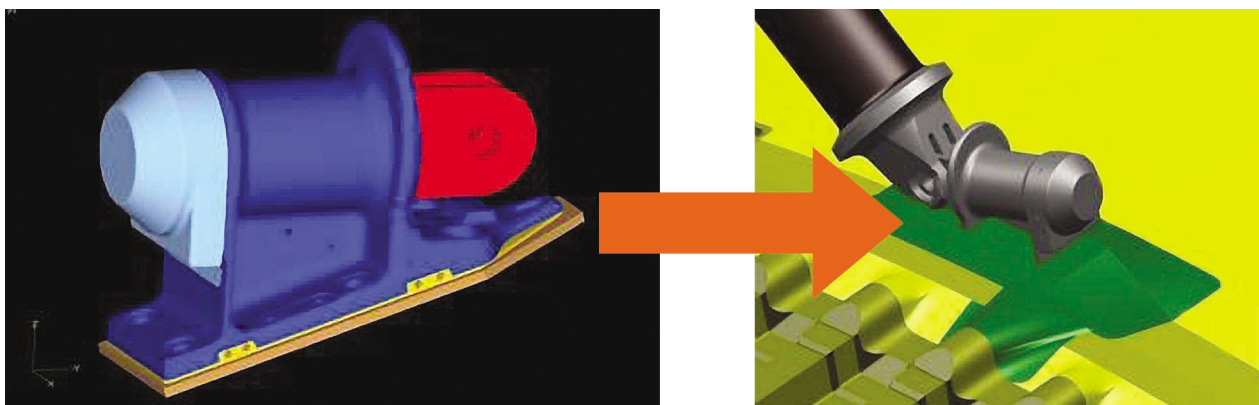
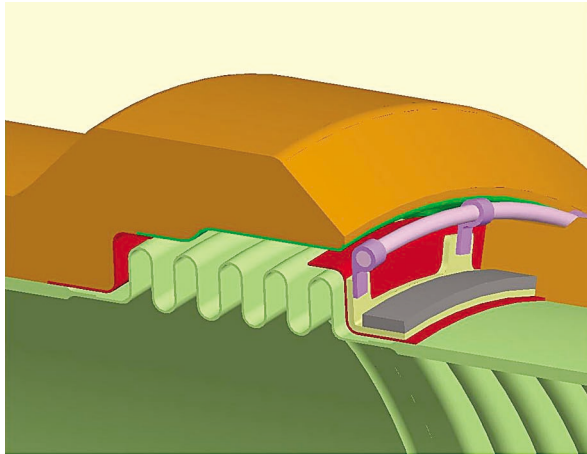


Figure 3.2-1-6. ET forward bipod redesign.



Heated GN₂ Purge

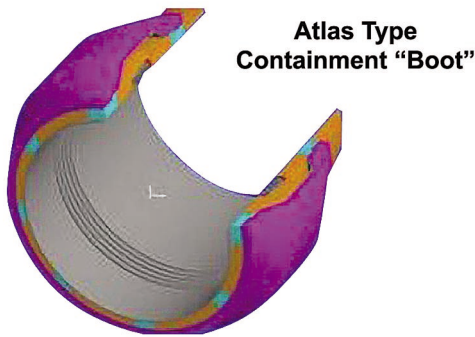
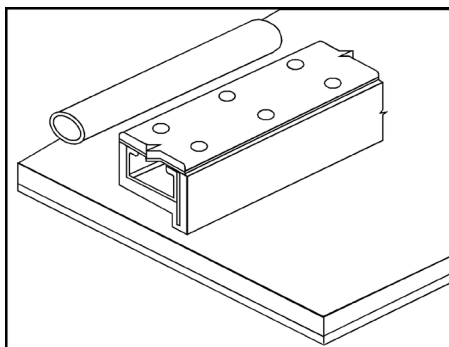


Figure 3.2-1-7. LO₂ feedline bellows design concept examples.



Leading Edge Fence LO₂ Tray Concept

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

LH₂/Intertank Flange Closeout Implementation Approach

NASA's approach is to first conduct tests to determine the cause of foam liberation from the LH₂/intertank flange area. Several design concepts are being evaluated for possible implementation once the cause is identified, ranging from active purge of the intertank crevice to enhanced foam application procedures that will ensure the LH₂/intertank flange closeouts will not generate critical debris in flight.

TPS (Foam) Verification Reassessment Implementation Approach

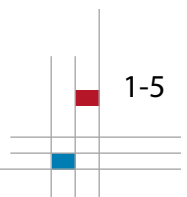
Our immediate focus is on critical manual TPS applications, such as the PAL ramps, identified during the STS-107 investigation. Manually applied TPS is more likely to have imperfections that might result in debonded foam. As a result, it requires a higher level of scrutiny. The verification assessment approach is divided into two basic tasks: (1) create a prioritized list of debris-critical TPS applications, and (2) assess existing verification data and establish requirements for data to provide added confidence (tests, dissections, etc.) (figure 3.2-1-9). Included with this assessment is 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.

NDI of Foam Implementation Approach

NASA is pursuing the development of TPS NDI techniques to improve our confidence in our foam application processes. If successful, advanced NDI could provide us with an additional level of process verification. Developing techniques for manually sprayed closeout applications is our initial focus.

The approach for this task is to survey state-of-the-art technologies, evaluate their capabilities, down-select, and qualify a system that will detect critical flaws in ET insulation systems. As an initial screening, test articles with known defects (e.g., voids, 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



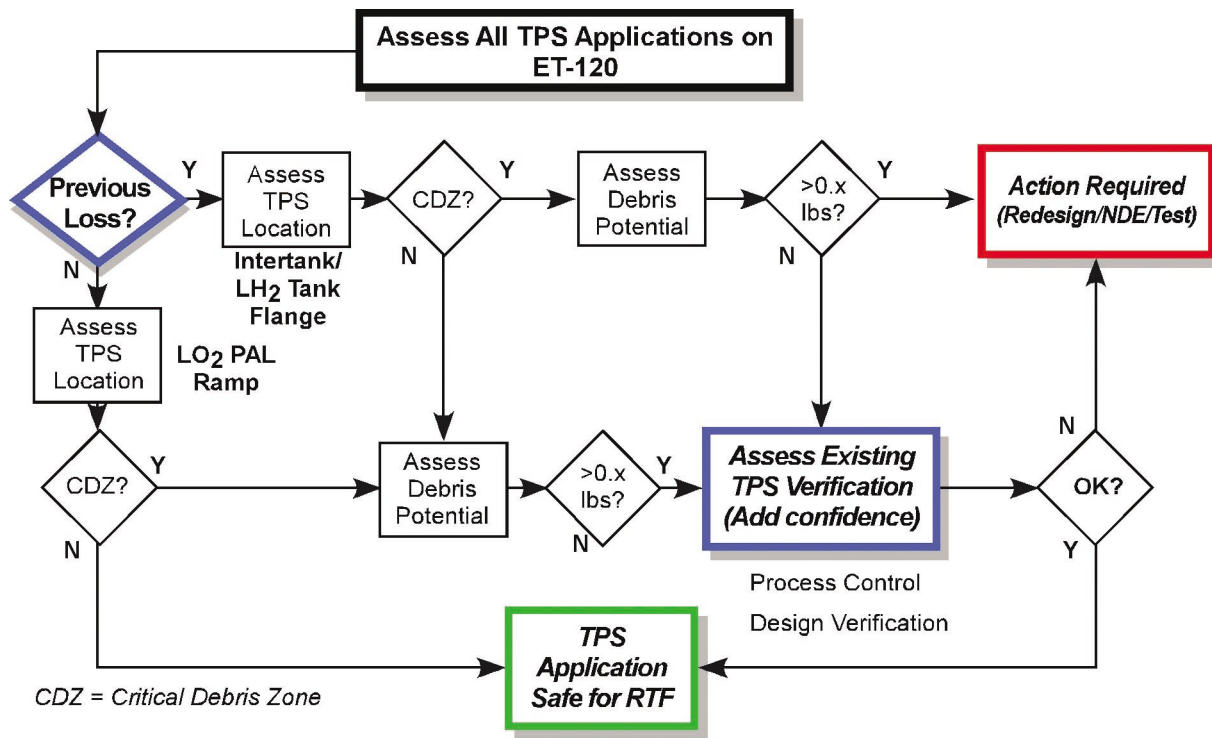


Figure 3.2-1-9. TPS verification reassessment logic.

comprehensive probability of detection (POD) and qualification testing for those applicable NDI methods.

NASA has an aggressive, focused plan to pursue technologies in this area for application on the ET.

STATUS

NASA has completed an 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 PDR and is planning a CDR in September or October 2003. Verification testing will consist of

- 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.

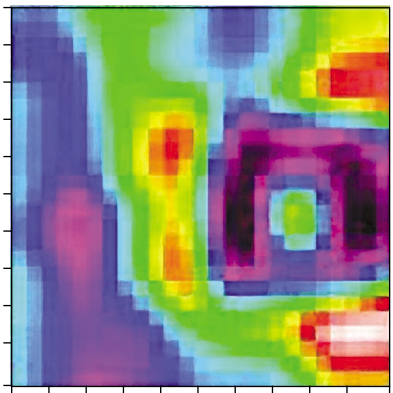
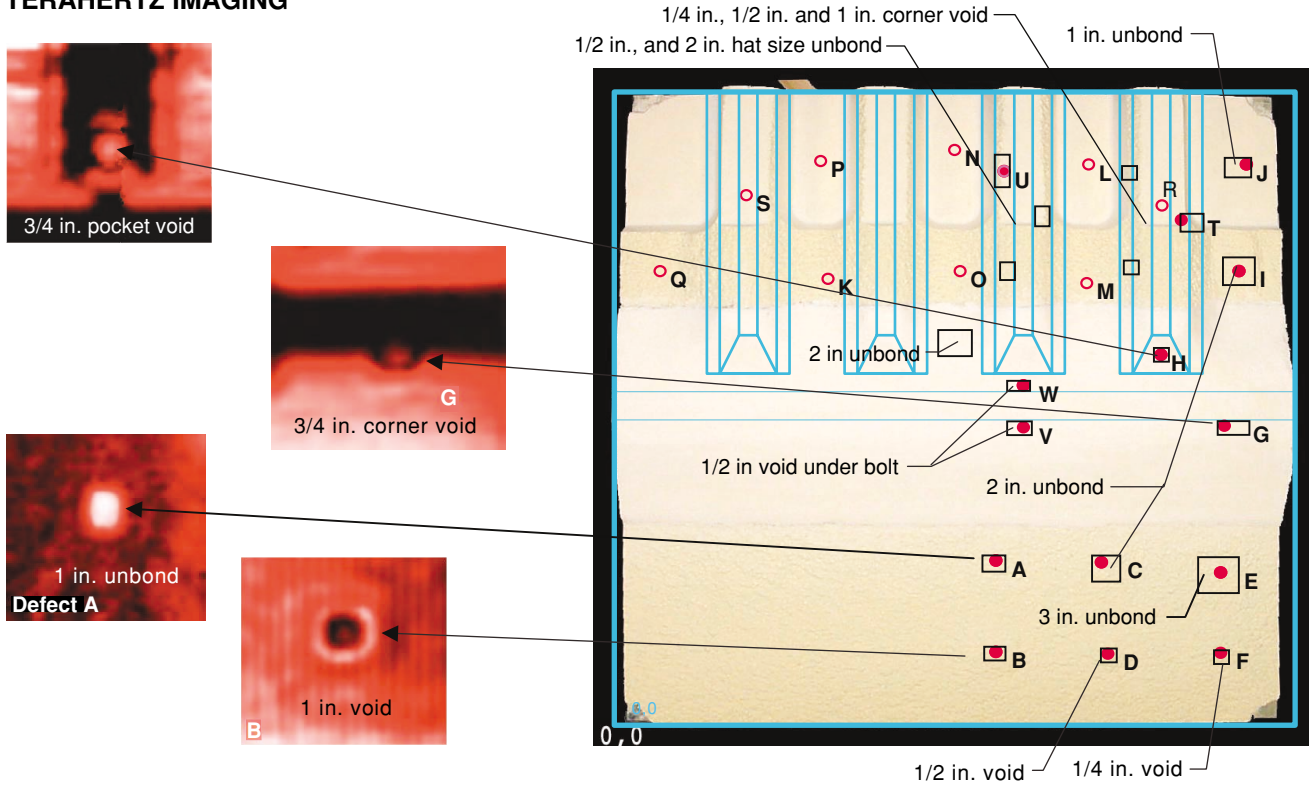
LO₂ Feedline Bellows Status

NASA has initiated redesign activities to eliminate the potential for ice debris from the LO₂ feedline bellows. To date, design options have been developed for all bellows locations. The assessment (analyzing transport mechanisms and debris impact) of the lower bellows is in progress to determine the criticality of these locations. Concepts are being developed to either prevent ice formation on the bellows or to contain ice debris during ascent. NASA is also investigating longer-term design solutions with the supplier of the feedline bellows assembly.

PAL Ramps Status

Concept design activities are in work. The plan is to conduct subscale wind tunnel testing of the candidates and down-select for full-scale testing. Because the PAL ramps (figure 3.2-1-11) have an excellent flight history, the baseline approach 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. A backup plan is in place to evaluate redesign solutions that include eliminating the PAL ramps, implementing smaller

TERAHERTZ IMAGING



**1 in. SOFI to AL delaminations
imaged with
Backscatter Radiography**

Figure 3.2-1-10. Terahertz images.

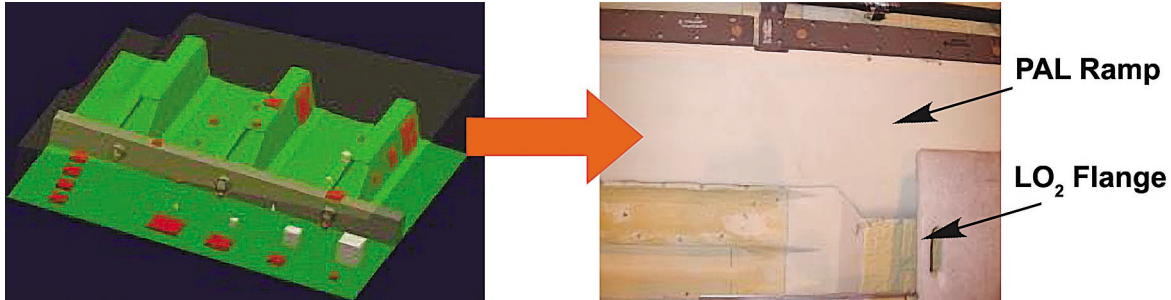


Figure 3.2-1-11. PAL ramp/flange test panel.

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.

LH₂/Intertank Flange Closeout Status

As part of the ET RTF activities, NASA is evaluating the LH₂/intertank closeout design to minimize potential debris from that area. 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, and developing enhanced foam application procedures).

TPS (Foam) Verification Reassessment Status

NASA has created a prioritized list of debris-critical TPS applications. The ET TPS applications were prioritized for assessment using discrete criteria (flight history, debris potential, and material) and scoring for each major assessment area.

NDI of Foam Status

NASA has initiated activities to develop NDI techniques for use on ET TPS. Currently being evaluated are the following prototype systems under development by industry and academia:

- 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 have been selected for further probability of detection testing based on the results of the initial proof-of-concept tests.

Potential Long-Term Activities

In addition to the ET RTF activities, NASA is also evaluating potential long-term changes in the ET design that will continue our aggressive program to eliminate debris shedding at the source. Options being considered include automating the critical manual spray processes; developing a smooth LO₂ tank and intertank; and developing a containment system (tunnel) for the LO₂ feedline, pressline, and cable trays. Other activities include developing additional NDI and TPS analysis capabilities, and reassessing TPS environments and requirements. These options will be considered as part of the Shuttle Service Life Extension activities.

FORWARD WORK

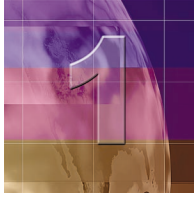
- Determine critical debris characteristics that could cause catastrophic damage to the Orbiter. Use these results to evaluate LO₂ feedline bellows, LH₂ intertank flange foam closeout, and LH₂/LO₂ PAL ramp redesign options.
- Complete CDR of bipod fitting redesign and conduct verification testing.
- Select and implement a single 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	Sep/Oct 03	Implementation of bipod and LO ₂ bellows redesigns
SSP	Sep 03	TPS verification reassessment of critical areas (PAL ramp and LH ₂ flange)
SSP	Oct 03	LH ₂ flange process enhancement definition and redesign decision
SSP	Nov 03	ET RTF design certification review
SSP	Nov 03	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 has been assigned that 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 a forward-looking assessment plan.

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 (a 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.

A TPS enhancement Orbiter hardening technical interchange meeting in May 2003 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 (TUF) Tiles**—Lessen impact damage susceptibility of certain upper surface tiles by replacing existing tile with white TUF tile.

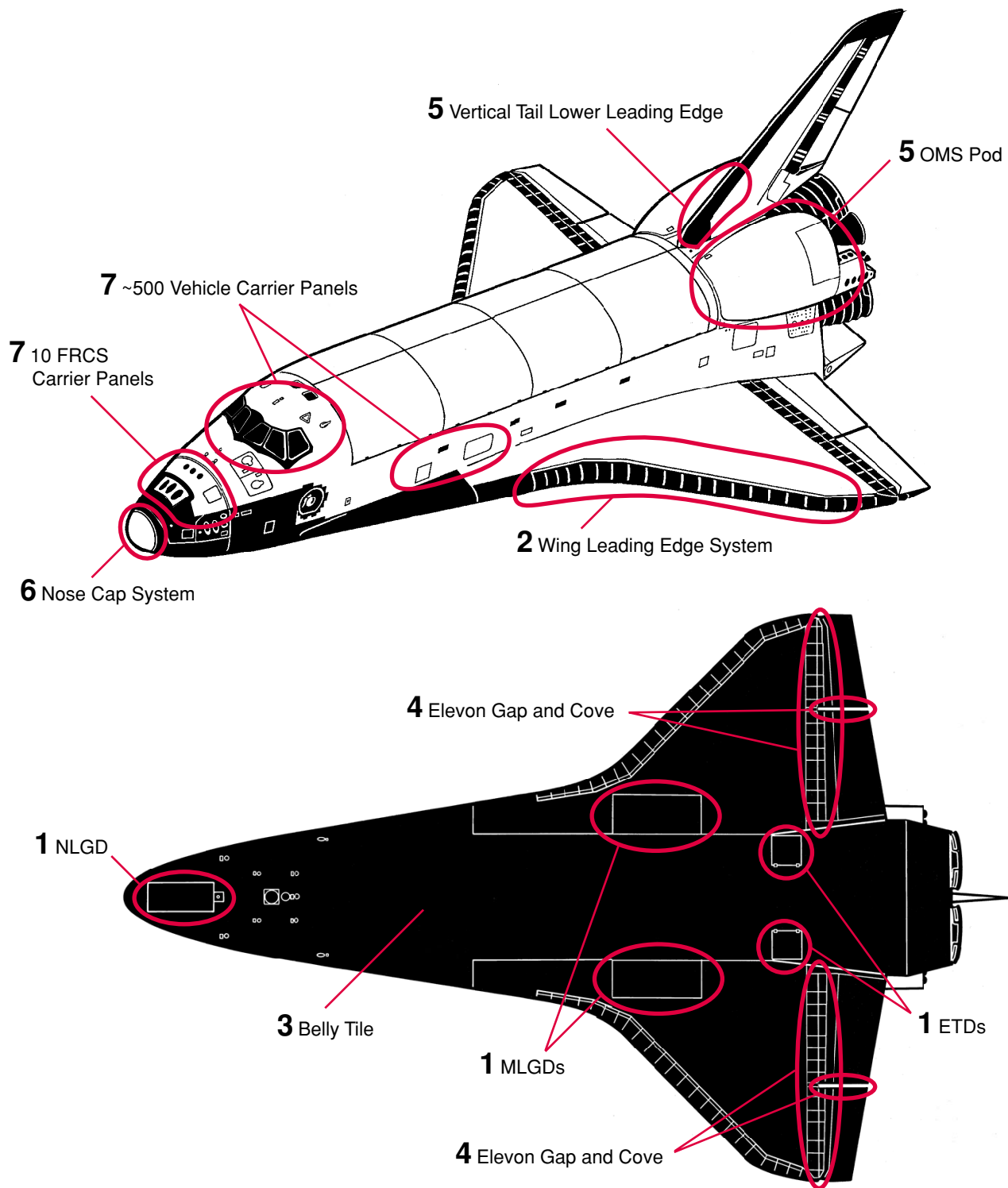


Figure 3.3-2-1. Seven critical TPS families targeted for enhancement.

- 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.
- Robust Reinforced Carbon-Carbon (RCC) Replacement Study—Apply new technologies to develop a more debris-tolerant material for the nose cone, 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. Available debris sources from all Space Shuttle elements including the ET, the Solid Rocket Boosters, and the Orbiter are in the process of being identified. The SSP Systems 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

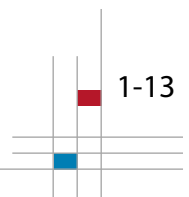
For each of the eight redesign options listed above, NASA is developing detailed feasibility assessments that will include cost and schedule for either full implementation or for the next proposed phase of the project. Debris sources are being identified, and test plans are being generated for the TPS impact tests.

FORWARD WORK

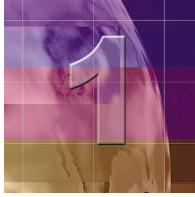
We will continue to implement the plan according to the schedule below. Decision packages for each redesign option will be brought to the PRCB for disposition.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 03	Initial plan reported to PRCB
SSP	Aug 03	Initial Test Readiness Review held for Impact Tests
SSP	Sep 03	White TUFU Options Implementation Plan to PRCB
SSP	Sep 03	Vertical Tail AFRSI High-Emittance Coating Options Implementation Plan to PRCB
SSP	Oct 03	Carrier Panel Upgrade Options Implementation Plan to PRCB
SSP	Oct 03	Elevon Leading Edge Carrier Panel Installation Redesign Options Implementation Plan to PRCB
SSP	Nov 03	WLE Redesign Options Implementation Plan to PRCB
SSP	Nov 03	Durable Tile Options Implementation Plan to PRCB
SSP	Nov 03	Landing Gear and ET Door Redesign Options Implementation Plan to PRCB
SSP	Dec 03	TPS Instrumentation Options Implementation Plan to PRCB
SSP	Jul 04	Robust RCC Development Plan to PRCB







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 have been 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 monitored through visual and tactile inspections and, for high-temperature components, periodic refurbishment of the outer coating.

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 under inspection from the vehicle. While eddy current is useful for assessing the health of the RCC outer coating and determining the extent of 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 collateral damage risk. Only the vendor is fully equipped and certified to perform RCC X-ray and ultrasound, even with hardware removed from the Orbiter.

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 June 2003 included NDI experts from across the country. This meeting highlighted five techniques with potential for near-term operational deployment: flash thermography, ultrasound (air- and liquid-coupled), advanced eddy current, shearography, and radiography. Of these, flash thermography and ultrasound show the greatest

promise for on-vehicle NDI. Finally, commercially available equipment must be assessed and standards developed for use against flight hardware. We have already begun testing these techniques. Shuttle Orbiter RCC components are pictured in figure 3.3-1-1. NASA is committed to clearing this hardware by certified inspection techniques prior to return to flight (RTF). The near-term plan calls for removing selected 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 August 2003, and specific options will be chosen for implementation in September 2003.

RCC structural integrity and mass loss estimates will be assured by removing and performing NDI on selected RCC components. WLE panels and seals will be removed from Orbiter Vehicle (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.

The OV-103 nose cap will be vendor-inspected, along with the nose cap and chin panel from OV-105 and a chin

panel previously flown on OV-104. The OV-104 nose cap and chin panel will be subjected to in-place, eddy current inspections. If structural integrity and mass loss estimates can be validated through vendor NDI of the removed RCC components and in-place inspection of the OV-104 components, the OV-104 nose cap and chin panel will remain on the vehicle and no additional NDI of this hardware will be necessary. Otherwise, the OV-104 nose cap and/or chin panel will be removed and returned to the vendor for NDI.

STATUS

OV-104: All WLE RCC panel assemblies have been removed from the vehicle and shipped to the vendor. After vendor inspection, left-hand (LH) panel 8 (8L) was shipped to Southwest Research Institute in San Antonio, Texas, for use in foam impact tests. It will be replaced with the 8L panel assembly removed from OV-103. Inspection of LH panels is complete, and tubular voids detected in seven of the LH panels have been accepted as appropriate by the Material Review Board. Eddy current inspections of the nose cap and chin panel are also complete; and the results compare favorably to data collected when the components were manufactured, indicating mass loss and coating degradation are within acceptable limits. Flash thermography is being performed and will be completed before panels are reinstalled on the Orbiter.

OV-103: As part of the OV-103 Orbiter major modification (OMM) effort, WLE panels were removed from the vehicle and inspected by visual and tactile means. These will be shipped to the vendor for NDI once OV-104 inspections are complete. X-ray inspection of the RCC nose cap, 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, surfaced nothing that might question the structural integrity of the nose cap on OV-104.

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

RCC Attach Hardware: The RCC Problem Resolution Team has presented 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. Vendor NDI will clear the WLE hardware for flight.

NASA is committed to efforts to develop advanced on-vehicle NDI techniques. Five candidates with good potential for near-term deployment have been identified and are being pursued. Of these, flash thermography and ultrasound are most promising; and thermographic inspections are being performed on flight hardware to collect data to be used to validate this technique. Once a suitable 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.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Sep 03	OV-103 nose cap return to Kennedy Space Center
SSP	Sep 03	Report viable on-vehicle NDI candidates to the SSP
SSP	Sep 03	Completion of NDI on OV-104 WLE attach hardware
SSP	Sep 03	OV-104 WLE RCC NDI complete
SSP	Nov 03	OV-105 nose cap NDI complete
SSP	Nov 03	OV-103 WLE RCC NDI complete
SSP	Dec 03	Completion of NDI on OV-103 WLE attach hardware
SSP	Nov 03	OV-103 WLE RCC NDI complete

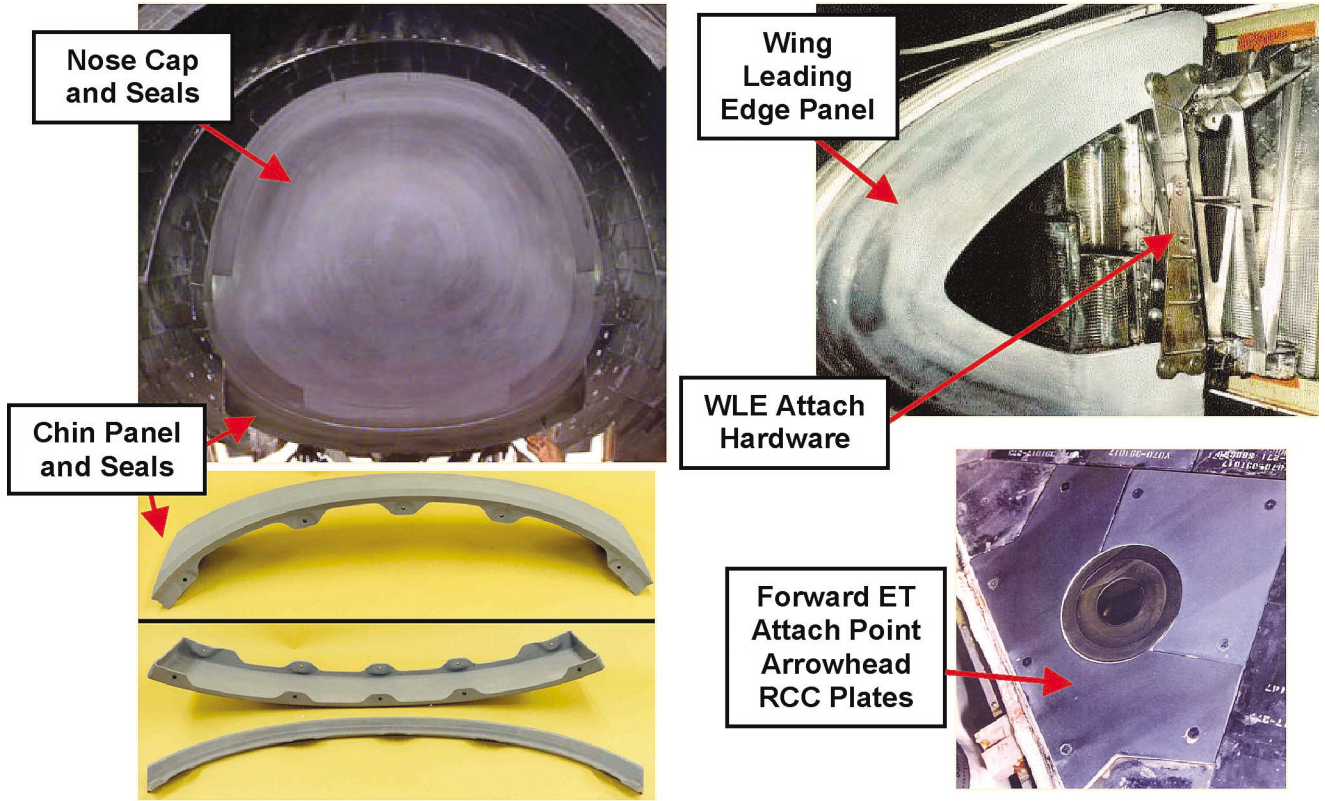
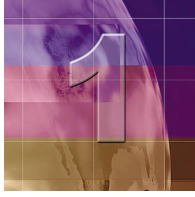


Figure 3.3-1-1. Shuttle Orbiter RCC components.





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, and the ability of the ISS to provide Contingency Shuttle Crew Support to a Shuttle crew until repair or rescue can be affected is being assessed. 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 autonomous (non-ISS) inspection and repair capability is in place in time to support the next Hubble Space Telescope servicing mission.

Damage Inspection Criteria

We have 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 is capable of resolving critical damage in the majority of TPS zones, with some gaps in coverage on the leading edges. We are now developing the capability to resolve critical TPS damage in all areas. Current capabilities do not measure damage depth. EVA can be used in the short term to measure depth in tile damage locations that exceed the surface dimension thresholds. The 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 desired resolutions. Return to flight (RTF) and long-term solutions are in work.

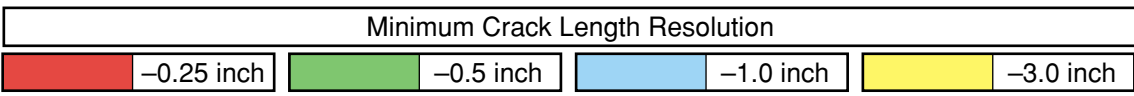
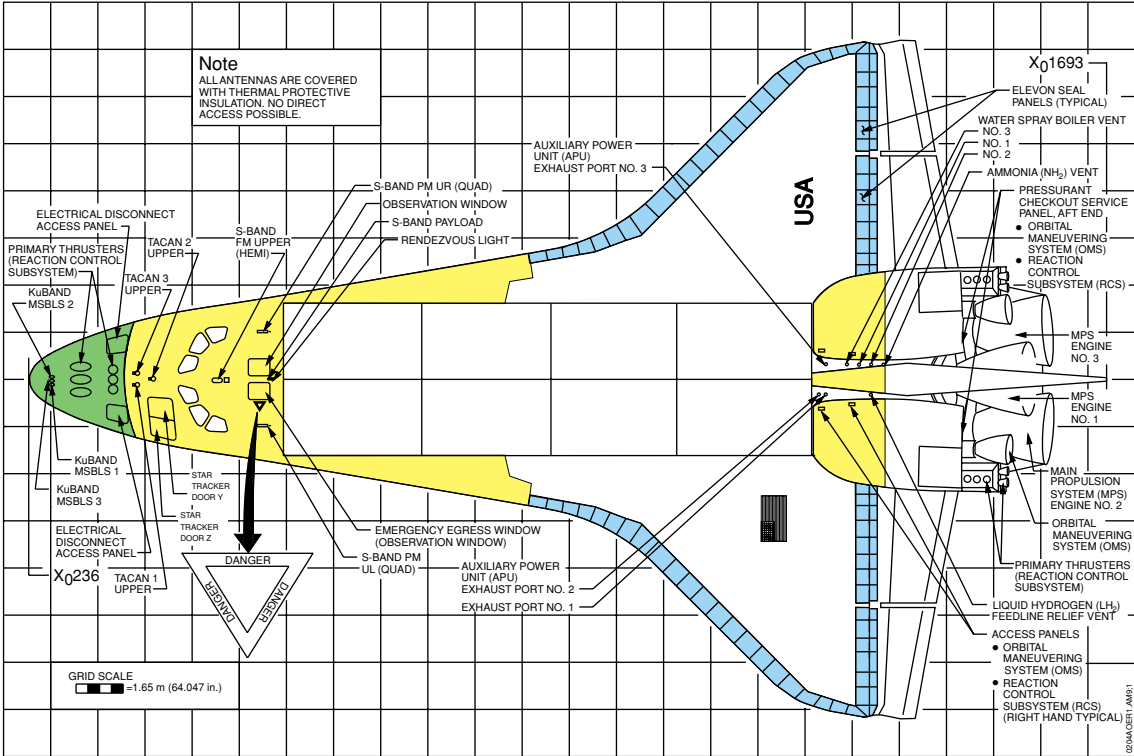
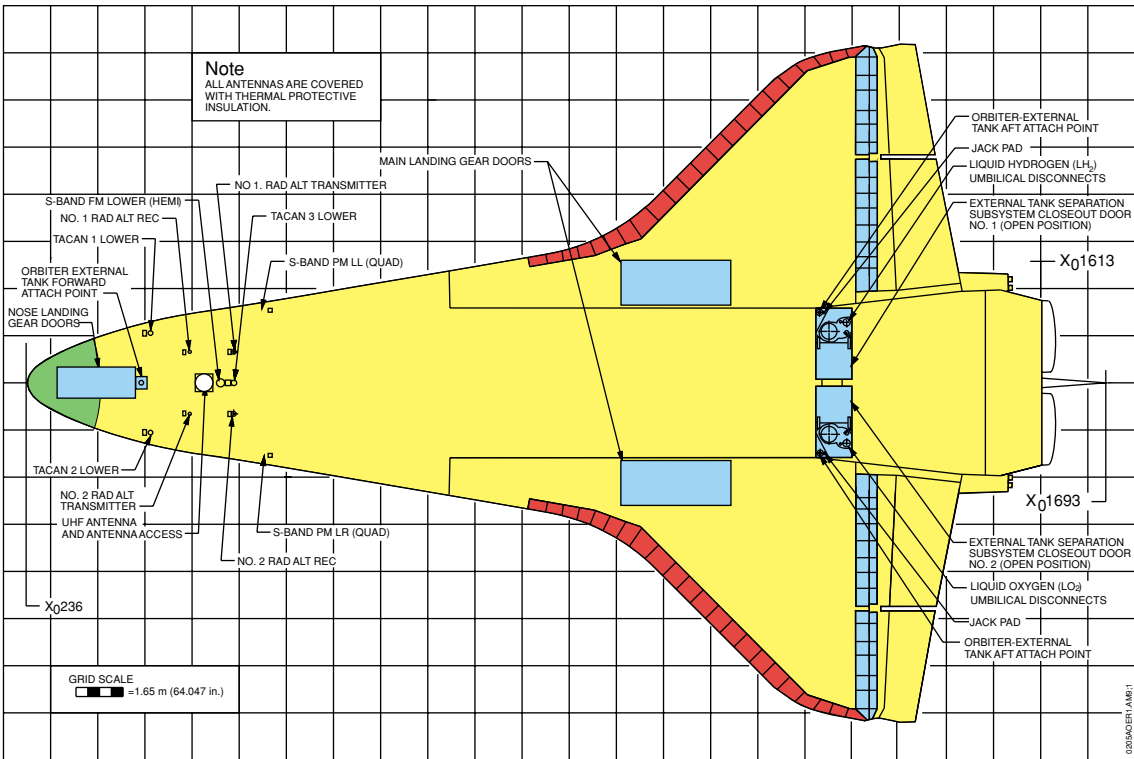
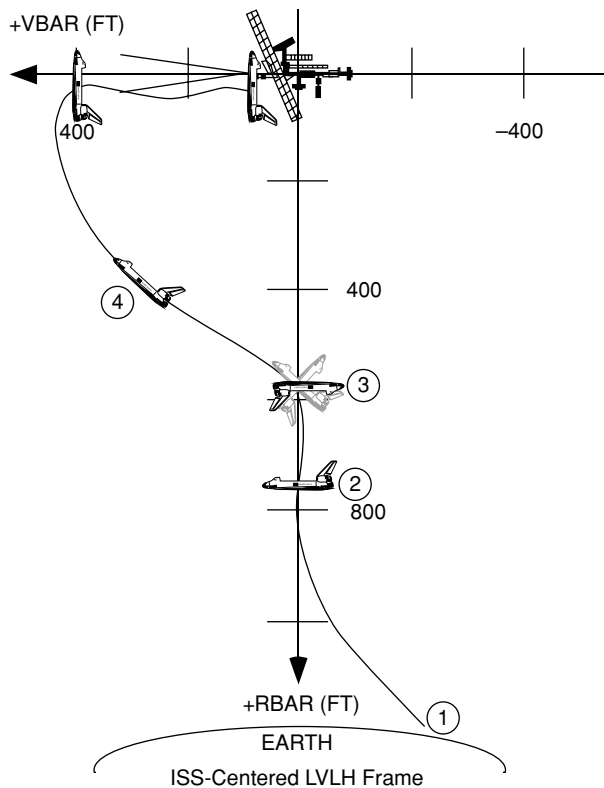


Figure 6.4-1-1. Preliminary TPS damage inspection criteria.

Because of the low visual/color contrast, 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 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



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.

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 has been 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

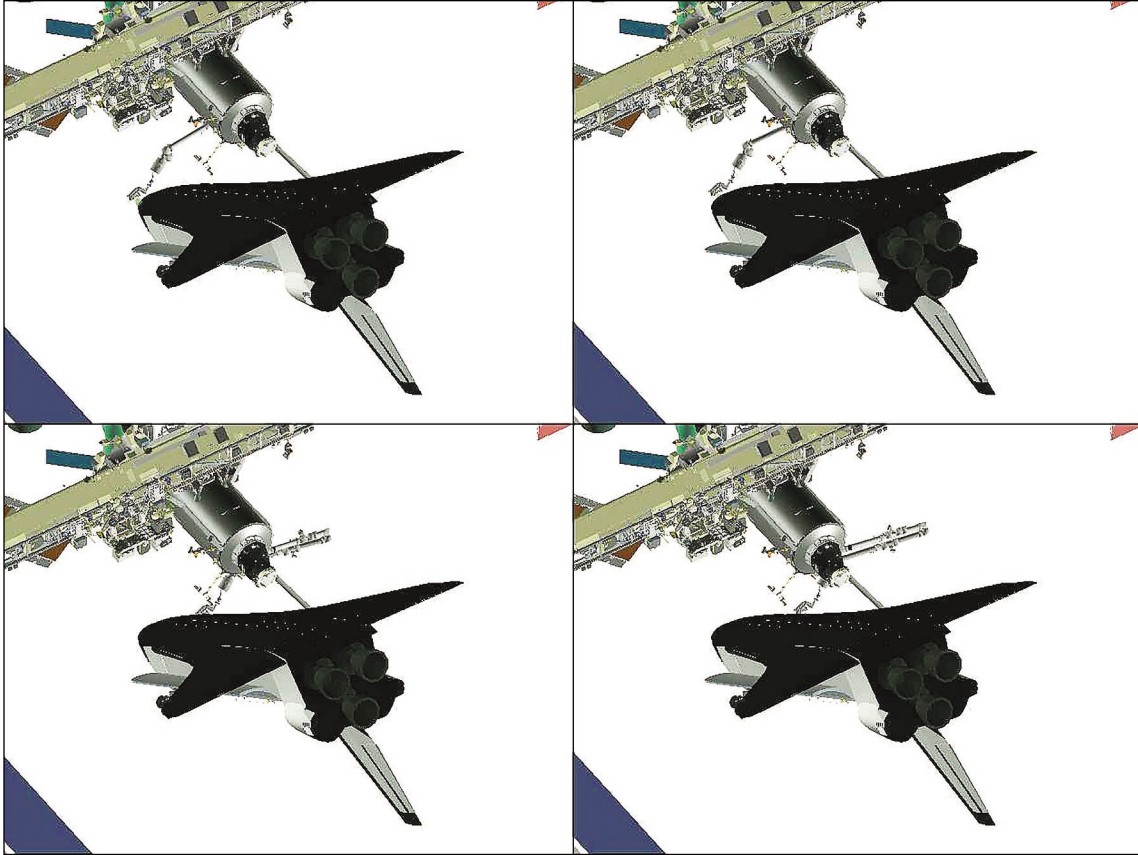


Figure 6.4-1-3. Proposed method for providing EVA access during TPS repair on an ISS flight.

process change appears to control a foaming problem observed during those tests when applying this material 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



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

arc jet, radiant heating, thermal-vacuum, and KC-135 zero-G tests are scheduled through September 2003 to confirm that this material will survive the entry environment when applied using the 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 in August 2003.

STATUS

The following has been completed:

- Quantified SRMS, SSRMS, and ISS digital still camera inspection resolution
- Feasibility analyses for docked repair technique using SRMS and SSRMS

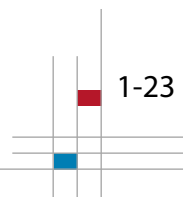
- Air-bearing floor test of overall boom to RMS interface
- Boom conceptual development
- Engineering assessment for lower surface radio frequency communication during stand-alone repair
- SAFER technique conceptual development and testing
- Feasibility testing on tile repair material
- Tile repair material transition from concept development to validation tests
- 1-G suited tests on tile repair technique
- Initial KC-135 tile repair technique evaluations

FORWARD WORK

We will perform high-level material and concept screening beginning 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.

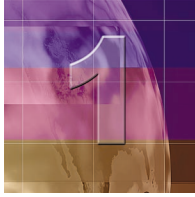
The Space Shuttle Program (SSP) has approved for return to flight the implementation (provided it is feasible) of an extension boom grappled by the SRMS with laser sensor packages attached to evaluate any damage to the TPS discovered on orbit.

In addition to planned TPS repair capability, developmental test objectives are under consideration for STS-114 to further evaluate TPS repair materials, tools, and techniques.



SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03	1-G suited and vacuum testing begins on tile repair technique
SSP	Aug 03	KC-135 testing of tile repair technique
SSP	Aug 03	Generic crew and flight controller training begins on inspection maneuver during approach to ISS
SSP	Sep 03	Thermal-vacuum tile repair tests
SSP	Sep 03	Tile repair material selection
SSP	Sep 03	Estimated start of RCC repair concept screening tests
SSP	Oct 03	Human thermal-vacuum, end-to-end tile repair tests
SSP	Oct 03	Baseline ISS flight repair technique and damage criteria
SSP	Nov 03	All Shuttle systems analyses complete for docked repair technique
JSC/Mission Operations Directorate	Dec 03	Formal procedure development complete for inspection and repair
ISS Program	Jan 04	All ISS systems analyses complete for docked repair technique
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 reentry. 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

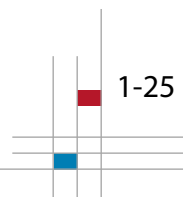
In each of the above areas, NASA is developing detailed implementation plans and feasibility assessments.

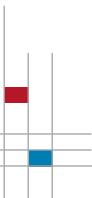
FORWARD WORK

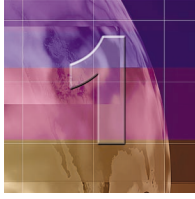
Additional analysis will be required before incorporating the results of these assessments in flight rules and flight design. Implementation strategies, which are needed to balance the risk of changes in these areas, will be developed as a part of this analysis. Decision packages for studies will be 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 data on material properties for flown reinforced carbon-carbon (RCC) components have been obtained from two panels that were destructively tested by the Program. Both panels were removed from Orbiter Vehicle (OV)-102. One panel, 10 left (10L), was tested after 19 flights and one panel, 12 right (12R), was tested after 15 flights. These limited data were compared to the analytical model and indicated 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 Space Shuttle Program (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 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/mechanical testing for material susceptibility to crack propagation during the flight envelope. Panels 9L (OV-103 with 20 flights) and 10L (OV-103 with 30 flights) will be used to determine the impact capability of the RCC.

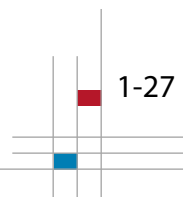
FORWARD WORK

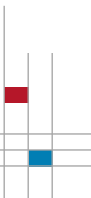
Materials and processes will be the focal technical discipline in understanding and cataloging the material properties

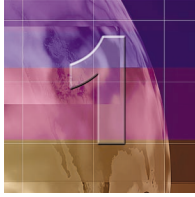
and their relation to the overall health of the subsystem. Once developed, the database will be used to direct design upgrades, mission/life adjustments, and other critical concerns as long as the leading edge structural subsystem system continues to be in service. The long-term plan will include additional RCC assets as the Program requires (reference R3.8-1).

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03	Characterization of Panel 8L test specimens for material property testing
SSP	Sep 03	Panel 9L impact test number 1
SSP	Sep 03	Testing of Panel 8L specimens
SSP	Oct 03	Panel 9L impact test number 2 if no damage detected after test number 1. Panels 9 and 10 would be available for destructive testing if damage occurs
SSP	Nov 03	Panel 9L impact test number 3 if no damage detected after test number 2. Panels 9 and 10 would be available for destructive testing if damage occurs







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. “Craze cracks,” which are inherent to the reinforced carbon-carbon (RCC) panels, allow rain water and leached zinc to penetrate the panels and cause pinholes.

NASA IMPLEMENTATION

Zinc-rich coatings are used to protect the pad structure against environmental corrosion. 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:

1. Postlaunch inspection and maintenance of the structural coating system will be enhanced, particularly on the rotating service structure. Exposed zinc primer will be recoated to prevent liberation and rainwater transport of zinc-rich compounds.
2. Postlaunch pad structural wash-downs will be assessed 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. Options to improve the physical protection of Orbiter RCC hardware will be investigated.
4. A sampling program will be implemented to monitor the effectiveness of efforts to inhibit zinc oxide migration on all areas of the pad structure.

STATUS

Enhanced inspection, structural maintenance, wash-down, and sampling options are being pursued. Changes to

applicable work authorization documents (WADs) are being formulated and will be incorporated before RTF.

Options for enhanced physical protection are being formulated and will be presented to the Program Requirements Control Board (PRCB) when available.

FORWARD WORK

The RCC Problem Resolution Team will continue to 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)	Oct 03	Complete enhanced inspection, maintenance, wash-down, and sampling plan
SSP	Nov 03	Incorporate required WAD changes
SSP	Dec 03	Present to the PRCB options for enhanced physical protection of RCC hardware at the launch pads

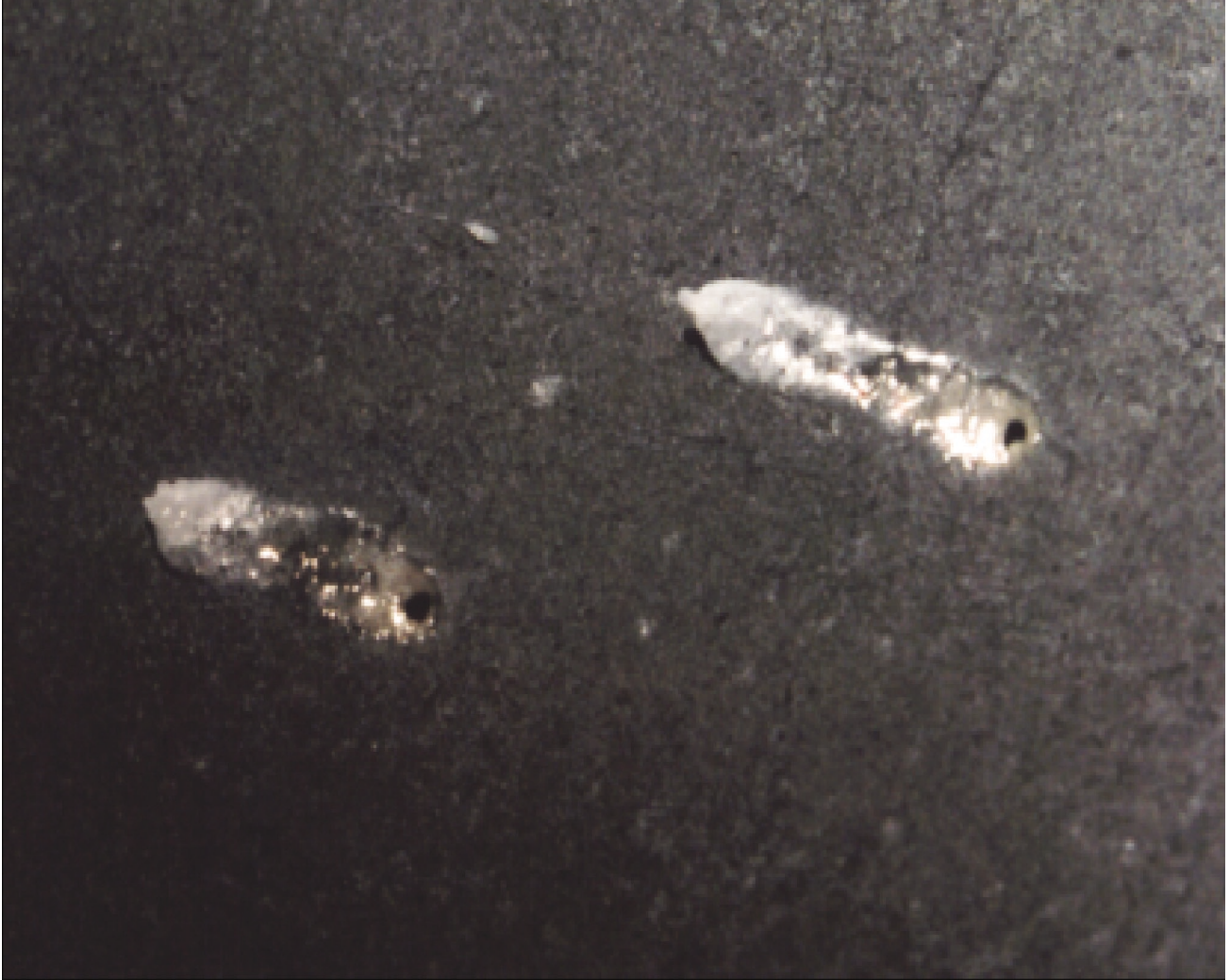
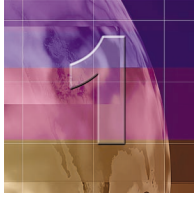


Figure 3.3-5-1. RCC pinholes.



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.

These panels will be available no later than July 2004.

STATUS

There is enough raw material available to build up to four additional ship-sets of RCC panels.

The buildup of RCC panels requires the use of carbonized rayon fabric, silicon carbide, tabular alumina, silicon metal, tetra ethyl ortho silicate [TEOS], Prepreg, and Sermabond 487. There is currently enough carbonized rayon fabric available at Lockheed Martin to build up to two ship-sets of spare panels.

For up to two additional ship-sets, materials are available with the exception of Avtex rayon. When the Program was notified that Avtex rayon yarn was no longer going to be produced because of Environmental Protection Agency restrictions, the decision was made to buy all available yarn from the manufacturer. If needed, there are 33,284 lbs. of Avtex rayon yarn in storage at Highland Industries in Cheraw, South Carolina. This yarn can be woven into fabric that can produce up to two ship-sets of additional spares. Therefore, there is enough raw material available to build four additional ship-sets of RCC panels before a redesign would become necessary to replace the Avtex rayon yarn.

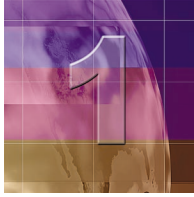
FORWARD WORK

Recent requirements for destructive testing of RCC will require the Space Shuttle Program (SSP) to procure additional panels. The SSP plans to procure additional RCC panels and support structures to support flight requirements and the continuing destructive evaluation and analysis of fleet leader items. A request will be made to the Program by October 2003 to fulfill this plan.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Oct 03	Request for implementation approval





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

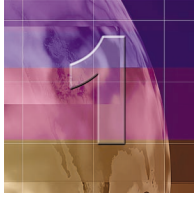
All SSP elements presented initial findings and a plan for completing their assessments to the ICB in July, and are

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	Report initial findings and plans to ICB and PRCB
SSP	Oct 03	Recommend Crater/Bumper enhancements/alternatives
SSP	Nov 03	Report final findings and recommendations to ICB and PRCB
SSP and JSC Mission Operations	Dec 03	Preliminary impact damage thresholds that trigger correction action
SSP	Feb 04	Verification/validation of new impact analysis tools
SSP	Mar 04	Reverification/validation of MMOD impact models



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.

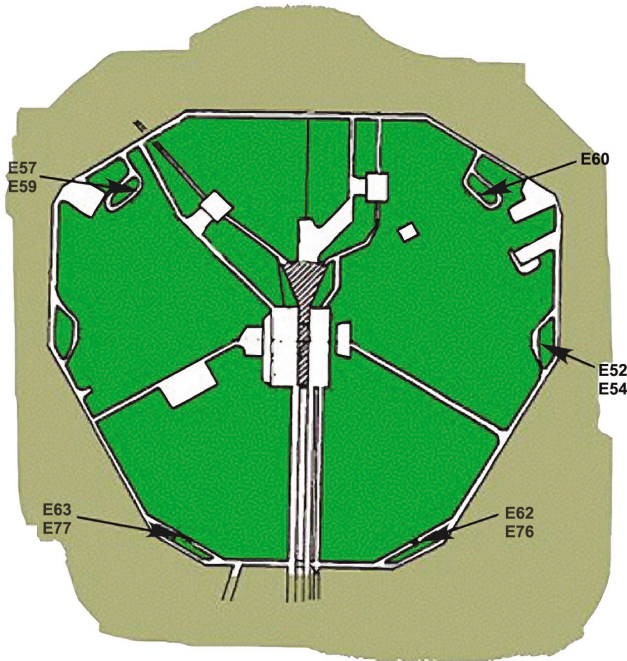


Figure 3.4-1-2. Short-range camera sites.

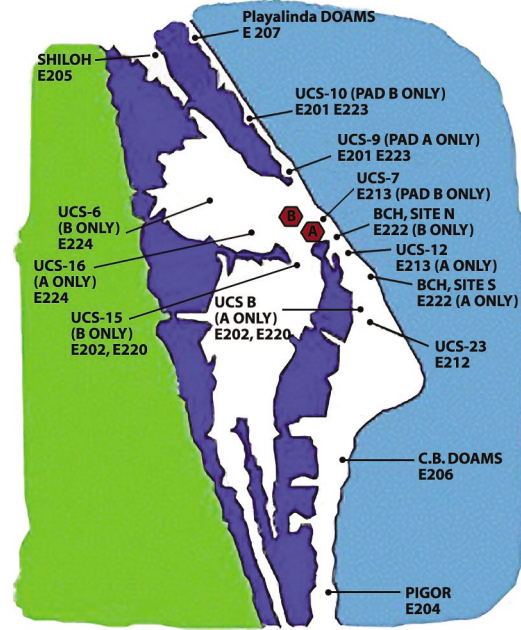


Figure 3.4-1-3. Medium- and long-range tracker sites.

NASA IMPLEMENTATION

To ensure that we can obtain three useful views of each launch, 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

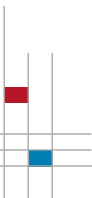
NASA is evaluating current and new camera locations, improving optics, upgrading tracking capabilities, and adjusting camera settings.

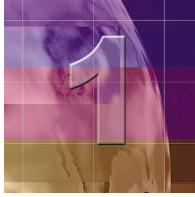
The Space Shuttle Program (SSP) will address hardware upgrades, operator training, and quality assurance of ground-based cameras per the integrated imagery requirements assessment.

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	Refurbish 14 existing trackers
SSP	Mar 04	Acquire new optics and cameras
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 has two on-board cameras that image 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.

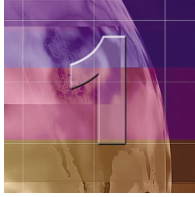
FORWARD WORK

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	Initiate Orbiter umbilical well feasibility study
SSP	Nov 03	Complete preliminary design review/critical design review on approved locations
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 during flight. 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 IMPLEMENTATION

To provide the recommended capability, 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 is being added to the ET to view the bipod area and Orbiter lower tile acreage. However, the resolution and coverage of this camera will not completely meet the Shuttle requirement to assess impact damage. Therefore, we will need to perform on-orbit inspection to ensure that we detect any damage to the Thermal Protection System (TPS). On-orbit inspection techniques are discussed in detail in our response to R6.4-1.

STATUS

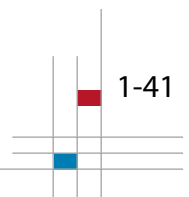
The advantages and disadvantages of externally mounted camera options on the ET and SRBs were presented to the Program Requirements Control Board (PRCB) on July 24, 2003. The approved configuration for STS-114 (figure 3.4-3-1) includes cameras mounted on the (1) ET liquid oxygen (LO₂) feedline fairing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

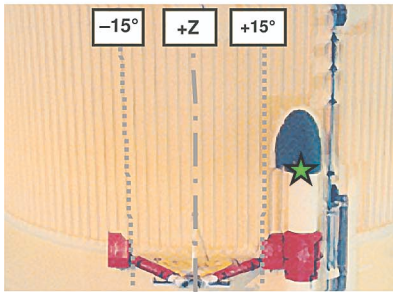
STS-115 and STS-116 (figures 3.4-3-2 and 3.4-3-3). These configurations widen the scope and improve the resolution of the available imagery. This will provide coverage of the Orbiter wing leading edge and forward section of both wings' TPS. In addition, the planned system will provide imagery of the 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.

SCHEDULE

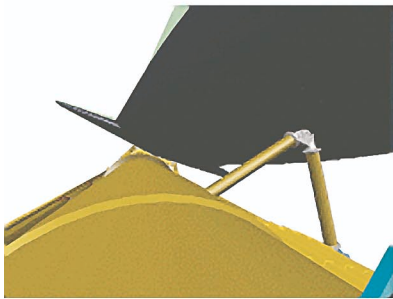
Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Jul 03	Authority to proceed with ET LO ₂ feedline and SRB forward skirt locations
SSP	Sep 03	Imagery plan to PRCB
SSP	Sep 03	Start ET and SRB hardware modifications
SSP	Oct 03	Systems Requirements Review
SSP	Nov 03	Complete design reviews on approved locations
SSP	Dec 03	Begin ET/SRB camera installations



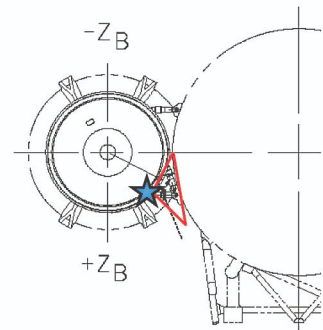
ET Mounted Camera



★ = Image for location (STS-114)



SRB Mounted Cameras



★ = Image for location (STS-114)

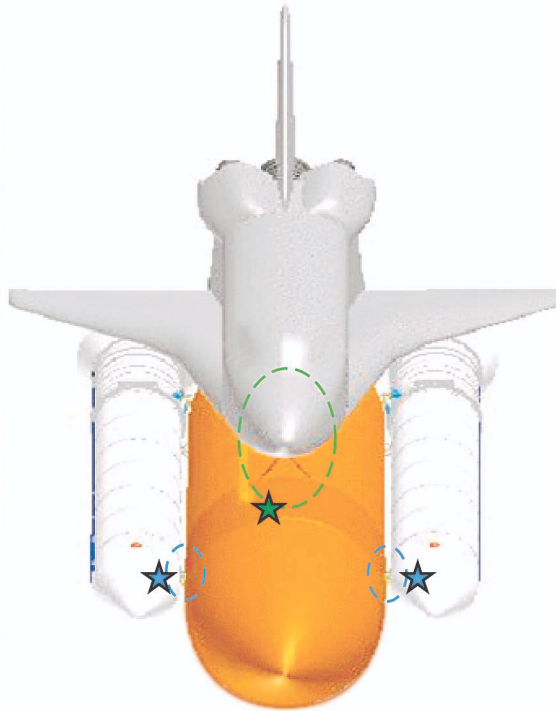
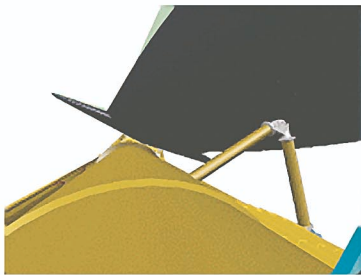


Figure 3.4-3-1. ET flight cameras (STS-114 configuration).

ET Mounted Camera



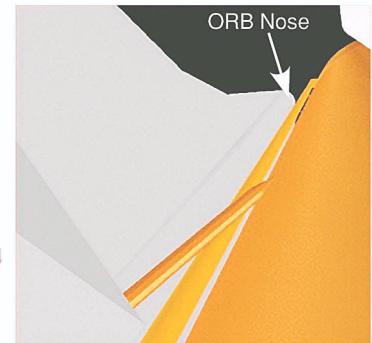
★ = Image for location (STS-115)

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

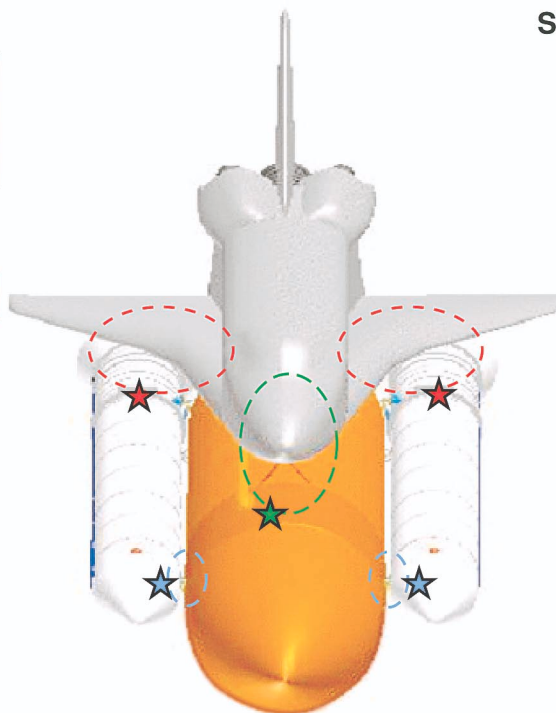
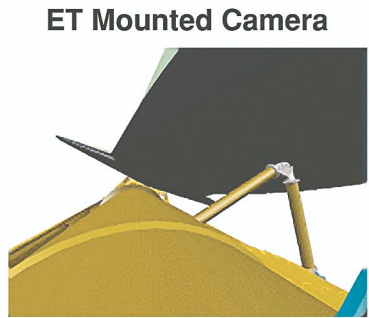
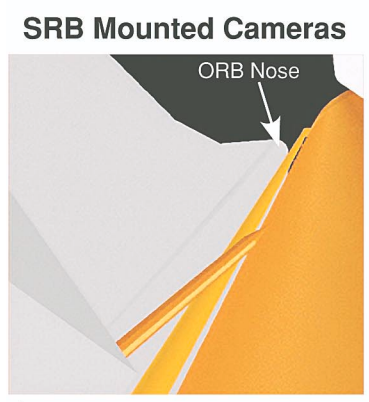


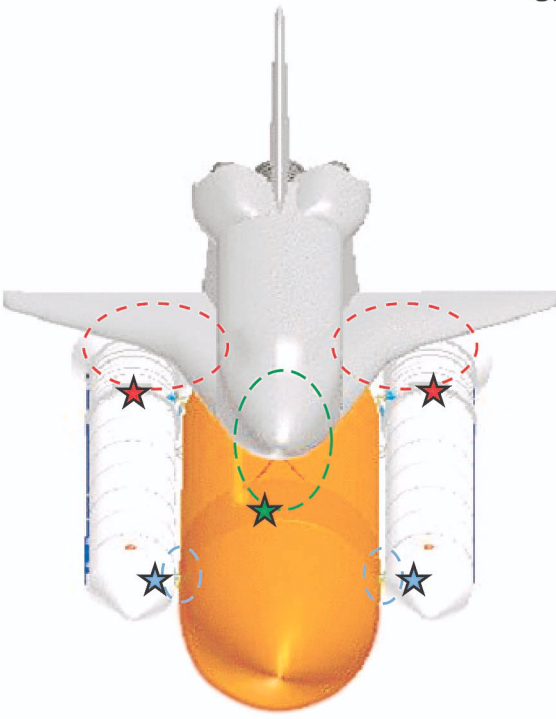
Figure 3.4-3-2. ET flight cameras (STS-115 configuration).



★ = Image for location (STS-116)

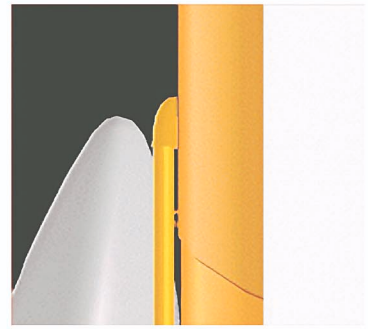


★ = Image for location (STS-116)



SRB Mounted Cameras (new)

exact location & field of view TBD

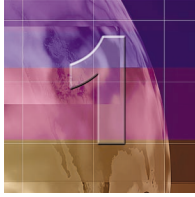


OR



Figure 3.4-3-3. ET flight cameras (STS-116 configuration).





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.

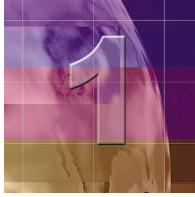
FORWARD WORK

- 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)* is a platform for collecting engineering performance data. The MADS records data that provide the engineering community with 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 have not been a formal Program requirement because MADS was intended to be only a supplemental package and 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. Its sustainability issues have been recognized by NASA for some time. The hardware assets available can only support the existing sensor suite per Orbiter. If any additional sensors are required, their associated hardware must be procured.

NASA IMPLEMENTATION

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

STATUS

MADS wideband instrumentation tape has been acquired and certified for flight. This effort will extend the operational availability of the MADS recorder. It has performed successfully on two flights, STS-109 and STS-107. The recorder maintenance and skills retention contract is being extended. The MADS recorder hardware is maintained at the vendor, Sypris. The MADS avionics sustaining engineering contracts are in place.

FORWARD WORK

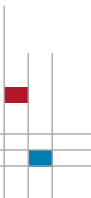
The SSP will maintain the current MADS (flight hardware and ground support equipment), including sensor and data acquisition components, until a replacement system is operational. Upgrades to the current system and additional sensor requirements are covered under the vehicle health monitoring system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

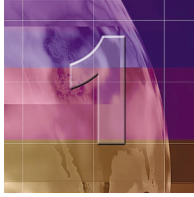
Implementation proposals will be brought to the Program Requirements Control Board for approval.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
TBD	TBD	TBD

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





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

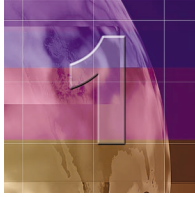
The Space Shuttle Program (SSP) will continue development of the VHMS project requirements and obtain authority to proceed for implementation.

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

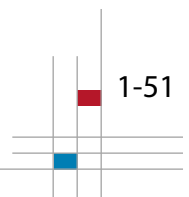
NASA is collaborating with industry and other government agencies to find the means most effective to address these concerns.

FORWARD WORK

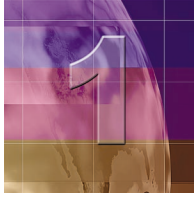
NASA will continue to seek solutions to this difficult technical issue.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	TBD	TBD







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 redesigned 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.

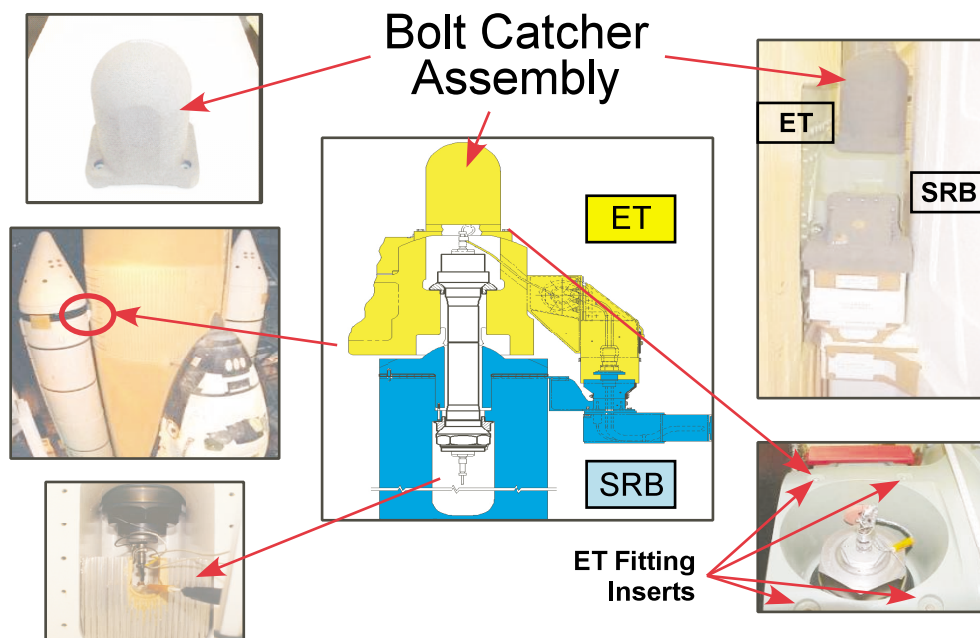
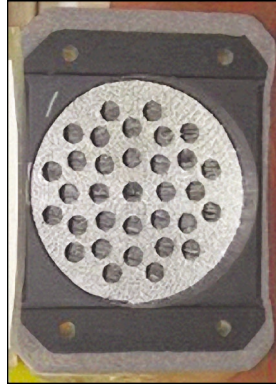
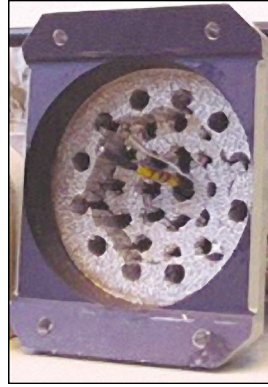


Figure 4.2-1-1. SRB/ET forward attach area.



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.

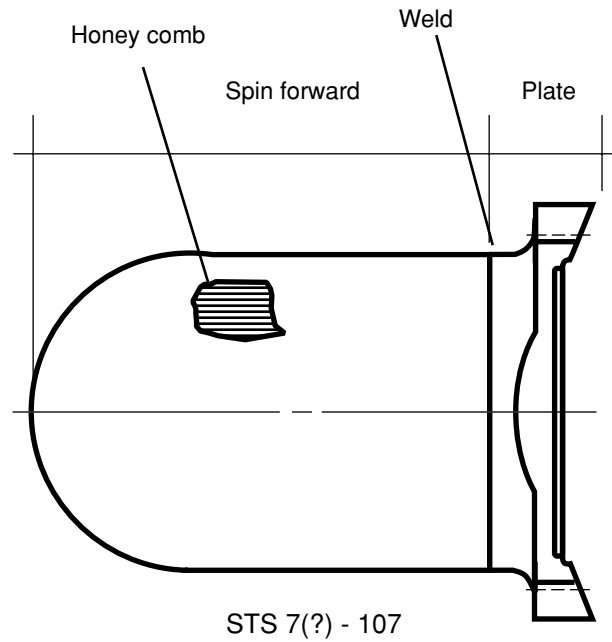


Figure 4.2-1-4. Original two-piece welded design.

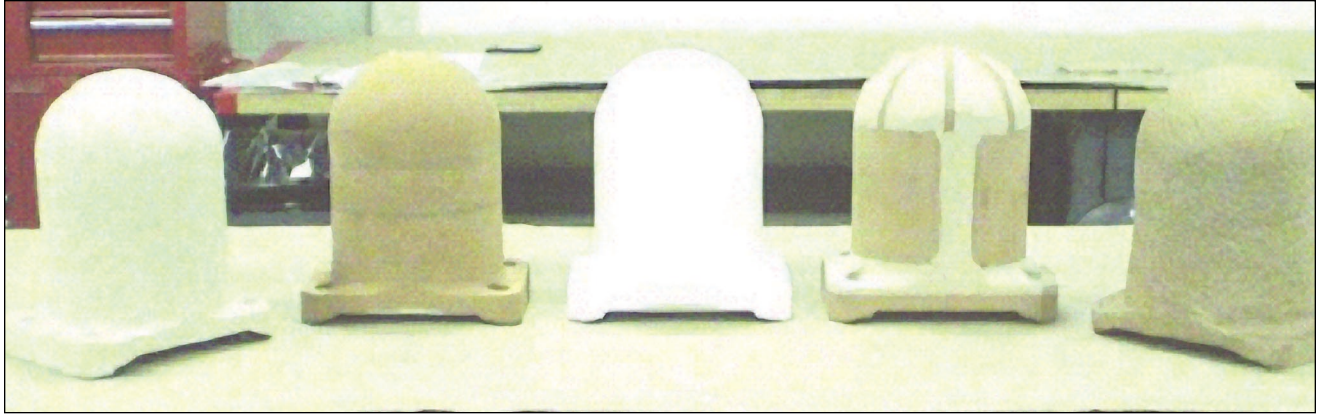


Figure 4.3-1-5. Thermal protection concepts.

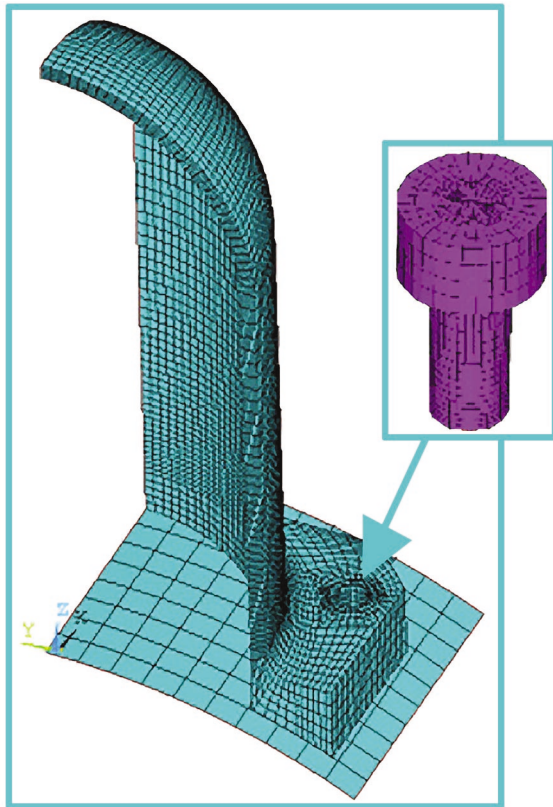


Figure 4.2-1-6. ET bolt/insert finite element model.

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 environmental exposure followed by combined environment testing.

FORWARD WORK

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

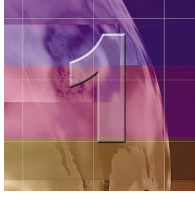
SCHEDULE

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

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





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 close-out processes currently able to 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 develop minimum requirements for all future foam processing. Included with this assessment is a review and an update of the process controls applied to foam applications, especially the manual spray applications. Numerous TPS processing parameters and requirements will be enhanced, including additional requirements for observation and documentation of processes. 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.

STATUS

Applicable ET processing procedures are under evaluation.

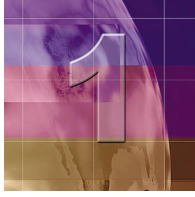
FORWARD WORK

Processing procedures and documentation will be modified as necessary.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Sep 03	Provide recommendations for enhancements to TPS processing parameters and requirements
SSP	Oct 03	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. Change the micrometeoroid and orbital debris safety criteria from guidelines to requirements.

BACKGROUND

The International Space Station (ISS) was designed for long-term micrometeoroid and orbital debris (MMOD) exposure, whereas the Shuttle was designed for short-term MMOD exposure.

MMOD is recognized as a continuing concern. NASA has previously implemented several Shuttle design and flight operational changes to reduce the MMOD risk, such as radiator isolation valve improvements and flying lower risk orientations.

NASA uses the computer application Bumper to assess the risk from MMOD impact to the Orbiter and ISS for each flight, accounting for mission duration, attitude variations, altitude, and other factors.

NASA IMPLEMENTATION

To comply with the recommendation to operate the Shuttle to the same degree of safety for MMOD as calculated for ISS, NASA will evaluate:

- Shuttle vehicle design upgrades to decrease vulnerability to MMOD.
- Operational changes (i.e., modify Shuttle orientation after docking to the ISS).

- Development of an inspection capability to detect and repair critical damage.
- 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.

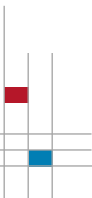
In addition to the above, NASA will change the MMOD safety criteria from guidelines to requirements.

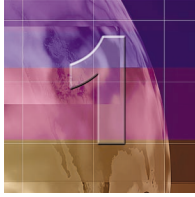
FORWARD WORK

NASA will continue our activities per the implementation plan.

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

In 2001, foreign object debris (FOD) at Kennedy Space Center was recategorized into “processing debris” and “FOD.” Processing debris became FOD if it was found during the final or flight-closeout inspection process. The categorization and subsequent use of two different definitions of debris created confusion and diminished the significance of the debris left behind during processing.

NASA IMPLEMENTATION

The term “processing debris” will be eliminated. A consistent definition of FOD will be used across all processing activities. Current metrics will be improved to reflect this change in definition. Operating procedures will reflect these changes.

NASA will perform FOD prevention surveillance during all processing activities. The NASA surveillance program will be thoroughly reviewed and improved to expand quality assurance specialist FOD spot checks.

FOD training will be modified to reflect the change in definition.

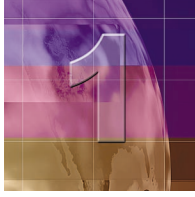
STATUS

Implementation of these preventive measures and corrective actions is under way.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Oct 03	Revised FOD definition implemented
SSP	Oct 03	NASA will conduct FOD training for both civil service and contractor
SSP	Dec 03	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

Launch 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. In this effort to optimize integration, system safety will not be compromised. Schedules associated with all activities generate very specific milestones that must be completed for mission success. If these milestones can be accomplished safely, the schedules occur on time. If a milestone is not accomplished, the schedules are extended consistent with the needs of safety.

NASA IMPLEMENTATION

Our priorities will always be flying safely and accomplishing our missions successfully.

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 the 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 and not have 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

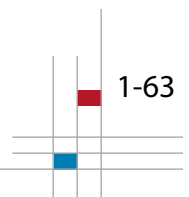
Development will continue on the tools to manage the manifest schedule margin and flexibility.

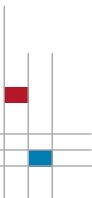
SSP will be benchmarked against a very effective system that currently exists and is well proven within the ISS Program for dealing with similar issues.

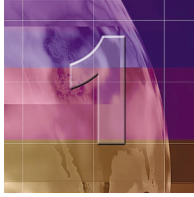
Until all of the RTF recommendations and implementations plans are identified, an STS-114 Shuttle launch schedule cannot be established. The STS-114 launch schedule and subsequent launch schedules will be based on milestones. The ISS on-orbit configuration is stable and does not drive any particular launch date.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03	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 flight 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 operated during the subsequent on-orbit flight, entry, landing, and postlanding mission phases through crew egress from the vehicle. When the flight MMT was not in session, all MMT members were on call and required to support emergency MMTs convened because of anomalies or changing flight conditions.

Previously, MMT training concentrates on the prelaunch and launch phases, including launch aborts. Training consists of both briefings and simulations.

NASA IMPLEMENTATION

To comply with this recommendation, 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 twice a year at a minimum to exercise the team's response to off-nominal scenarios. MMT simulations are currently scheduled for November 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.

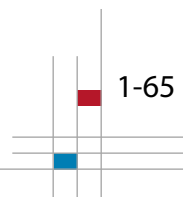
In addition to the recommendation, NASA determined through an in-depth review of the processes and functions of STS-107 and previous flight MMTs that additional rigor and discipline are required in the flight MMT process. An essential piece of strengthening for the MMT processes is ensuring all safety, engineering, and operations concerns are heard and dispositioned appropriately. 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 the requirement to conduct daily MMT meetings.

STATUS

The MMT training team is currently 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).

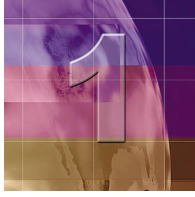
FORWARD WORK

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	Sep 03	MMT process changes to Program Requirements Change Board
SSP	Sep 03	Project/element process changes
SSP	Nov 03 Jan 04 Feb 04 Mar 04	MMT simulations
SSP	TBD	MMT member handbook development
SSP	Oct 04	MMT training plan
SSP	Nov 04	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]

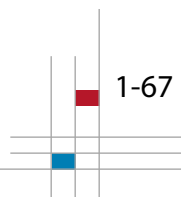
INTRODUCTION

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 organi-



zational 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.

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 October 1, 2003, and

will further augment the Office of the Chief Engineer's and 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:

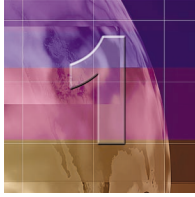
- A centralized location for the management of independent in-depth technical assessments for safety and mission assurance, engineering, and the Program. This will be supported by expert personnel and state-of-the-art tools and methods.
- Independent testing to determine the effectiveness of problem 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 Systems Integration Control Board (SICB). This board will review and approve element recommendations and actions to ensure the appropriate integration of activities in the Shuttle Program. The Orbiter Project Office is now a mandatory member of the SICB. Orbiter changes that affect multiple elements must now go through the SICB 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 SICB, will be routed from the Program Requirements Control Board back to the SICB 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.

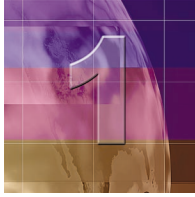
The major challenge will be to determine if the scope and quality of SEIO's work is sufficient to deliver high-quality systems engineering and integration. To assure this, a standing independent assessment team, composed of outside members with experience in integrating large, complex flight systems, 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	Approve the SSP Reorganization
SSP Systems Integration	Aug 03	Transition Cargo Integration to Mission Integration
SSP Systems Integration	Aug 03	Reform SICB with Mandatory Orbiter Membership
SSP Systems Integration	Aug 03	Release ET Bipod Redesign Systems Integration Plan
SSP Systems Integration	Sep 03	Release Initial Debris Induced Environment Computations for Use by Projects
JSC Engineering Directorate	Sep 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.

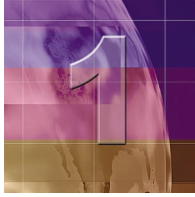
FORWARD WORK

SSP project and element organizations will compile and develop 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 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 an element of addressing the shortfalls in the existing 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.

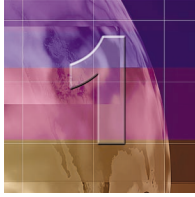
SCHEDULE

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



A950318L-06C

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

In complying with this recommendation, 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.
- Scan hardware to capture as-built configurations and create high-accuracy engineering models.
- Put an infrastructure and process in place to maintain and share the models.

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.

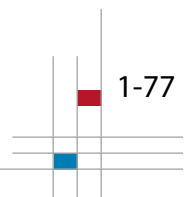
The SSP will continue to incorporate changes into the engineering drawing system.

FORWARD WORK

NASA will accelerate the development of options for consideration by the SSP on upgrading the Shuttle engineering drawing system. Currently in the feasibility phase, the work that remains to be completed includes capturing lessons-learned, scanning portions of the vehicles, evaluating software, installing data servers, and conducting a technology demonstration. At the conclusion of this phase, DSP will provide a range of options for the SSP.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Mar 04	Presentation of options







Raising the Bar – Other Corrective Actions

Because we have embraced the CAIB report, NASA has recognized that we must undertake a fundamental reevaluation of our Agency's culture and processes. Part 1 of this plan addressed the CAIB recommendations. Part 2 addresses other corrective actions. 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, we will, before return to flight, evaluate and determine appropriate actions in response to all these observations and any other suggestions we receive from a wide variety of sources.

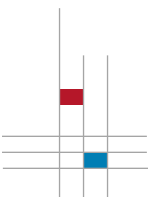
(Continued on back)



In parallel with the activities of the CAIB, NASA had begun an intensive, Agencywide effort to identify additional actions that supplement the CAIB recommendations that will further improve our space flight program as we move toward a return to safe flight.

Part 2 reflects a set of internally generated actions that complements and builds upon the CAIB recommendations. This includes two actions (SSP-1 and SSP-2) that coincide with observations of the CAIB included in its report. NASA has not yet had time to fully evaluate the CAIB observations, but we will do so.

Subsequent versions of NASA's Implementation Plan for Return to Flight and Beyond will address CAIB observations and other suggestions as they are evaluated and implementation plans are developed.





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. 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 a group of experts—including representatives from NASA, the Department of Defense, 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. Emphasis will be placed on the review of policy and evaluation of hardware processes associated with selected existing GMIPs. After completion of the assessment, the results, along with the potential effect on return to flight, will be provided to the Office of Space Flight (OSF), the Office of Safety and Mission Assurance (OSMA), and the Space Shuttle Program for disposition.

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

STATUS

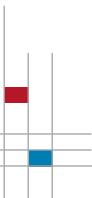
A draft of the terms of the reference document and the membership for the GMIP's Independent Assessment Team were reviewed and approved by NASA's OSF and OSMA in July 2003.

FORWARD WORK

The team is working to the schedule defined below. After the assessment is complete, a final report consisting of observations, findings, and recommendations will be provided to the OSF and OSMA for disposition.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Headquarters	Jul 03	Assessment begun
Headquarters	Sep 03	Presentation to OSF and OSMA
Headquarters	Oct 03	Final report issued





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 primary measures undertaken to improve crew safety and vehicle health also result in improving the safety to persons and property during entry overflight. NASA is committed to evaluating risk from an Orbiter's entry path over the Earth's surface. NASA will work with the U.S. Department of State if any coordination with other countries is necessary.

The overflight risk 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 those 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.

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 using sensitivity studies.

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 and vehicle risk considerations, into the entry flight rules that guide the flight control team's selection from the remaining landing opportunities.

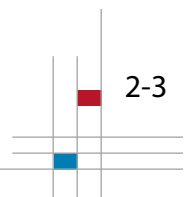
STATUS

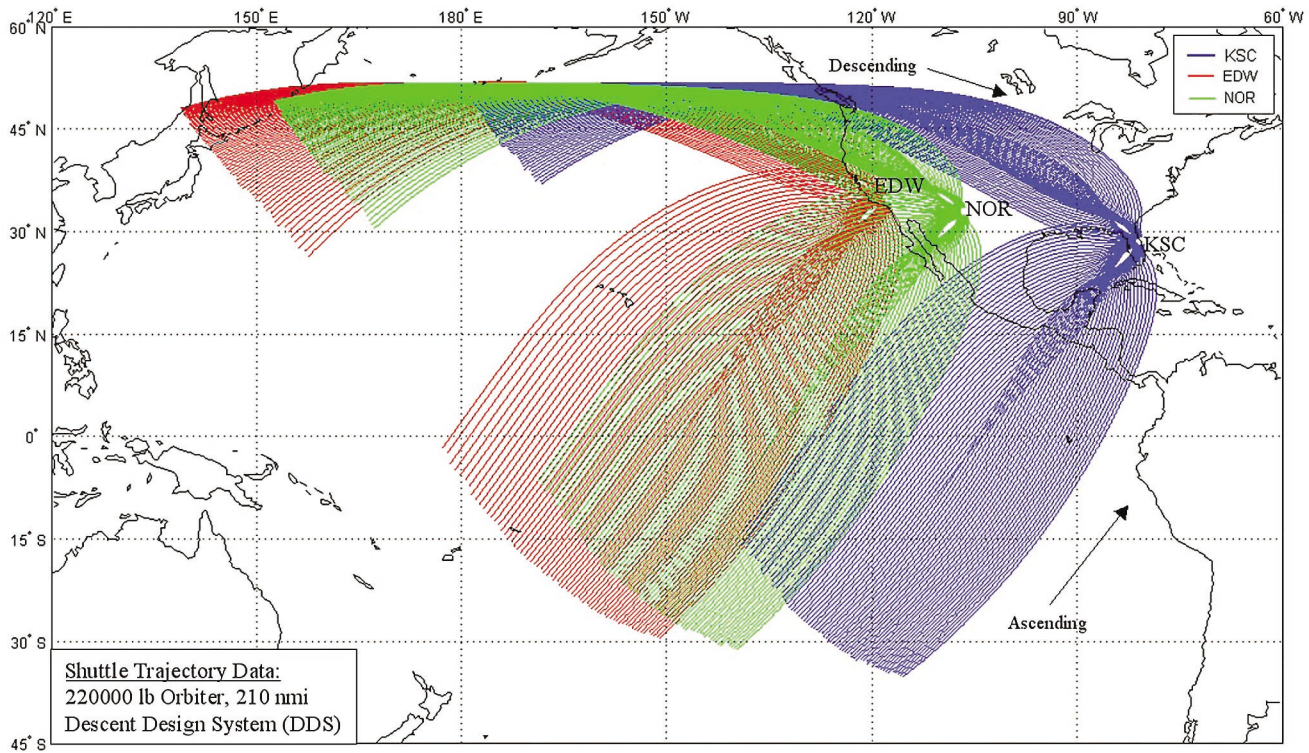
The current assessment is aimed at determining which landing opportunities present the most risk. For this preliminary relative risk assessment, more than 1200 entry trajectories were simulated for all three primary landing sites from all of the standard Shuttle orbit inclinations: 28.5° (Hubble Space 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.

FORWARD WORK

The Space Shuttle Program (SSP) has generated preliminary data to compare risk to persons and property 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	Preliminary results to RTF Planning Team and SSP Program Requirements Control Board (PRCB)
SSP	Sep 03	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 for any reason their 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 important to clarify that CSCS is not a level of planned redundancy for known unacceptable risks. Such known unacceptable risks are dealt with directly through redundant, robust controls. Rather, CSCS is a generic contingency capability planned to a limited, but credible, level that will provide another response to known, but remote, risks and unforeseen circumstances.

NASA IMPLEMENTATION

The International Space Station Program Office is beginning to assess the implications for ISS operations that would result if we used the CSCS concept. We have begun coordination with our 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. Actions such as this may be outside of the current permissible flight rules and Orbiter performance capabilities and, as such, will need to be fully assessed. NASA is assuming that STS-114 will require no new Shuttle or ISS performance capabilities to enable CSCS.

STATUS

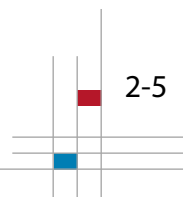
NASA has performed a preliminary feasibility assessment. The assessment results indicate that the crew could be sustained for a period of approximately 180 days. The major assumptions of the initial assessment were

1. STS-114 launch date of March 11, 2004.
2. Six remaining crew total on ISS (three crew return on Soyuz).
3. ISS systems operate nominally with no degradation/failures (e.g., oxygen generation, carbon dioxide removal, condensate collection).
4. Shuttle resources/consumables support remaining on-orbit crew until removed from ISS for uncrewed entry.
5. 1,118 liters of Shuttle fuel cell water are successfully transferred to the ISS.
6. Progress resupply vehicles supply critical consumables during the contingency period assuming current launch rates.

Internal NASA assessment of this capability is continuing.

FORWARD WORK

The CSCS concept requires further coordination with our international partners as well as further development and maturity.



SCHEDULE

Responsibility	Due Date	Activity/Deliverable
ISS Program Office	Comp Aug 03	Status International Partners at Multilateral Mission Control Boards
ISS Program Office	Sep 03	Assess ISS systems capabilities and spares plan and provide recommendations to ISS and Space Shuttle Program (SSP)
ISS Program Office	Sep 03	Obtain concurrence on use of Russian systems and vehicles
ISS Program Office and SSP	Nov 03	Develop waste management and water balance plans
ISS Program Office	Dec 03	Develop CSCS Logistics Plan
ISS Program Office and SSP	Dec 03	Develop ISS Launch Commit Criteria
ISS Program Office	Dec 03	Develop food management plan
ISS Program Office and SSP	Jan 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 and recommended resolutions for those conditions found in either the hardware/software systems, the person-machine relationship, or both, that cause loss of personnel capability, system, or life 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.

Accepted risk hazards are those hazards that, based on analysis results, have associated acknowledged risks that remain after all reasonable mitigation efforts are implemented to control the probability or consequences of occurrence. The causes of accepted risk hazards fail to meet the hazard reduction precedence sequence and, therefore, have limitations or uncertainties that could allow the hazard to occur during the life of the program. Examples of conditions associated with accepted risks are 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 as warranted if working group observations or fault-tree analysis question the classification of the risk or the efficacy of the mitigation controls.

NASA IMPLEMENTATION

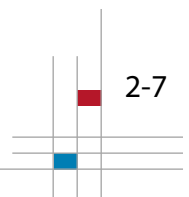
Each Space Shuttle Program (SSP) project is to perform the following assessment for each accepted risk hazard report and any additional hazard reports indicted by the STS-107 accident investigation findings:

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.

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	Ongoing	Identify and process any implementation impacts
SSP	Aug 03	Identify and review "Accepted Risk" hazard report causes
SSP	Sep 03	Analyze implementation data
SSRP	Oct 03	SSRP review element hazards and critical items list review processes Kennedy Space Center Sep 9, 10, 11 Solid Rocket Motor Sep 8 Reusable Solid Rocket Motor Sep 16, 17 Integration Sep 20 Solid Rocket Booster Sep 4
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 1,000,000 debris transport cases. These will include debris type, location, size, and release conditions (freestream Mach number, initial velocity of debris piece, etc.).

STATUS

Activity began on June 1, 2003. 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.

Transport analyses for the three highest priority cases have been completed. Work continues on assessing impact conditions and any resulting damage.

FORWARD WORK

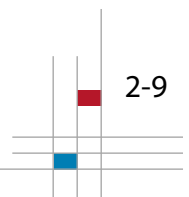
As debris sources are analyzed, the resulting damage will be assessed and critical debris sources will be identified. The Integration Control Board and Program Requirements Control Board (PRCB) will periodically review status. The following actions are in work:

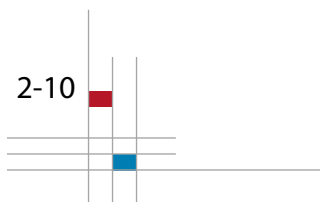
- Systems integration to deliver impact conditions map to all hardware elements.
- Hardware elements to identify potentially unacceptable damage locations.
- Systems integration to recommend hardware modifications that will eliminate and/or reduce debris sources, or hardening modifications to increase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

SCHEDULE

This is an extensive action that may take up to one 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	Elements provide debris history/sources
SSP	Sep 03–TBD	Return to Flight Debris Transport analyses
SSP	Oct 03–TBD	Other Debris Transport analyses
SSP	Dec 03	Summary Report/Recommendation to PRCB







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.

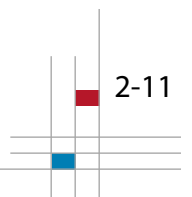
FORWARD WORK

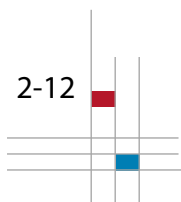
Each project and element will identify and review critical items list waivers that could be associated with ascent debris generation.

Each project and element has implemented 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, and the Solid Rocket Booster Project Office.

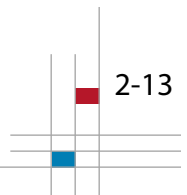
Project and PRCB recommendations currently being implemented include revision of the SSP contingency action plan, modifications to the External Tank, and evaluation of hardware qualification and certification concerns.

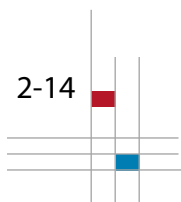
FORWARD WORK

The following working groups will report their findings and recommendations to the SSP PRCB in August and September 2003: the Orbiter Vehicle Engineering Working Group, Space Shuttle Systems Integration, and the Early Sightings Assessment Team.

SCHEDULE

An implementation schedule will be provided 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.

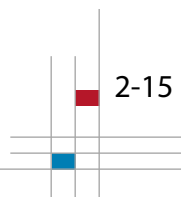
FORWARD WORK

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 to some extent 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 Kennedy Space Center Integration	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.

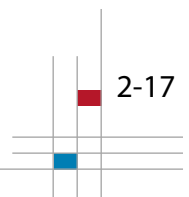
NASA IMPLEMENTATION

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	PRCB status of progress
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.

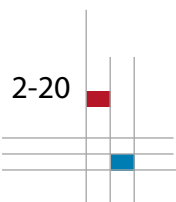
1. International roles, responsibilities, and relationships in the event of a Shuttle mishap are not well defined. Agreements associated with landing site support are in place, but lines of responsibility for accident response are vague or absent.
2. A particular success of the *Columbia* accident response 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 and to 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 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

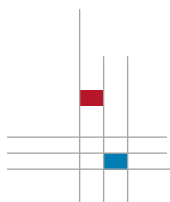


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Appendix A: NASA's Return to Flight Process





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.

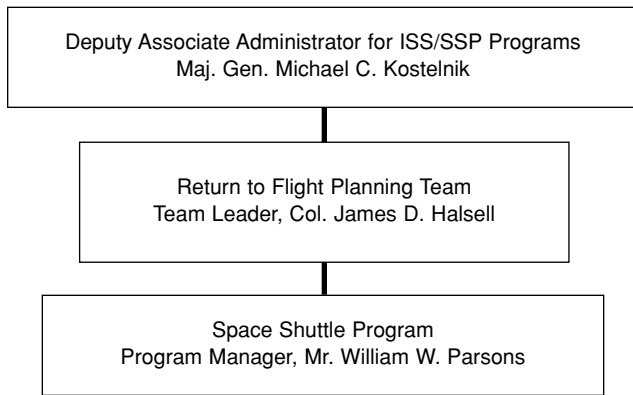


Figure A-1. RTFPT organization.

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.

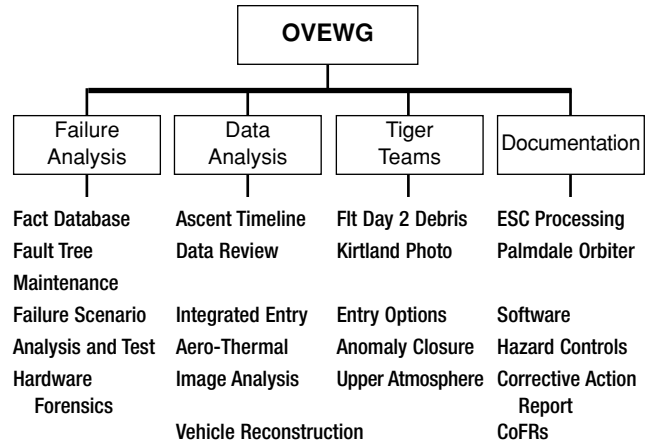


Figure A-2. OVEWG organization.

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) cochairs. 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

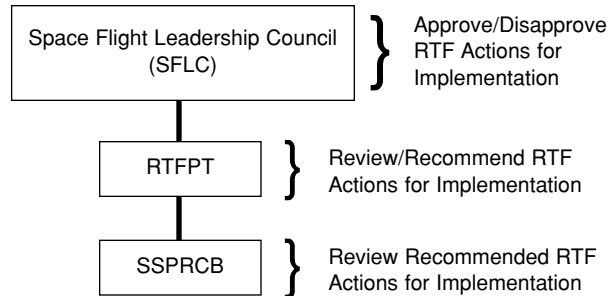


Figure A-3. Space Flight Leadership Council organization for return to flight issue review.

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.

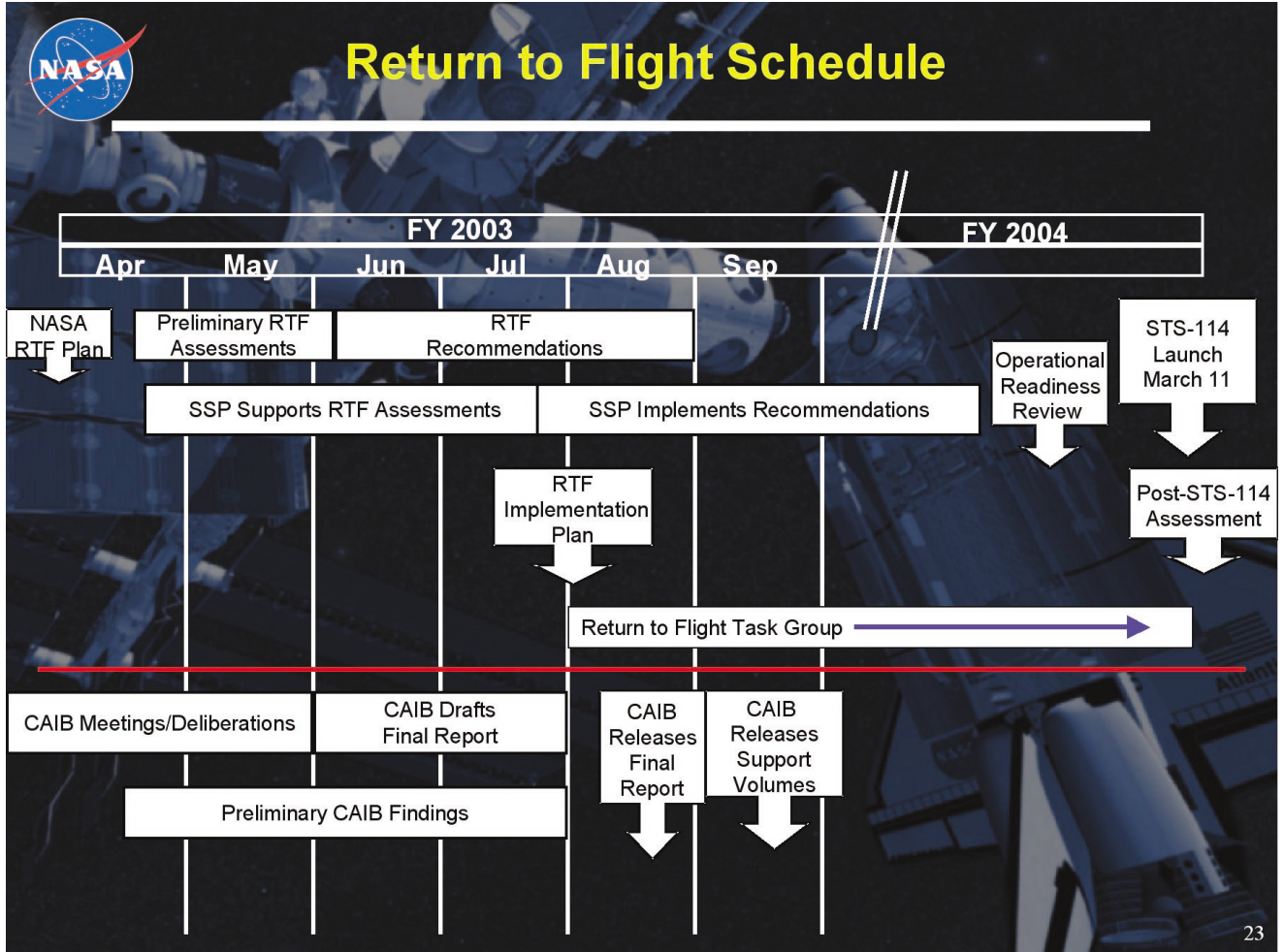
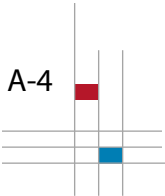


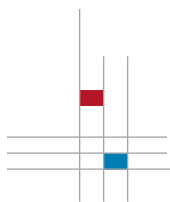
Figure A-4. RTF and RTFTG schedules overlaid with the schedule for release of the CAIB final report.





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

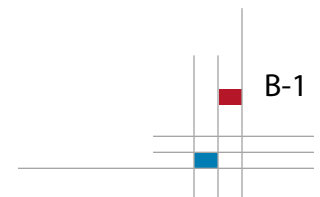
The Task Group is authorized to establish panels in areas related to its work. The panels will report their findings and recommendations to the Task Group.

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, 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.

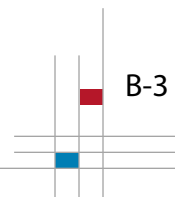
He then joined Global Associates Limited as Executive Director for Technology and Systems. From 1996 to 1997, he was President of the Signal Processing Systems Division. Most recently, from 1997 to 2001, he was Program Director, Land Level Transfer Facility, Bath Iron Works, and was responsible for the 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.

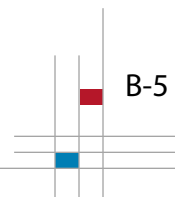
He left Rockwell in 1980 and consulted on various aerospace projects for NASA centers until 1991, when he joined American Pacific Corporation as Senior Vice President. In his current position at Kistler Aerospace (Vice President and Program Manager, 1996–present), he has primary responsibility for design 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.

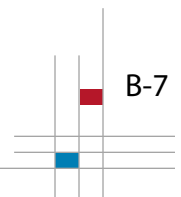
Gen. Fogleman received a Master's Degree in Military History from the U.S. Air Force Academy, a Master's Degree in Political Science from Duke University, and graduated from the U.S. Army War College. He has been awarded several military decorations including Defense Distinguished Service Medal with 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.

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.



Maj. Gen. Ralph H. Jacobson, U.S. Air Force (Ret.):
Consultant

During Maj. Gen. Jacobson's 47 years of distinguished military and civilian service, he has developed an expertise in aerospace program management, satellite operations, business, and budget management. He graduated from the U.S. Naval Academy in 1956, earned his pilot's wings in 1957, received a Master's Degree in Astronautics from the Air Force Institute of Technology in 1962, and earned a Master's Degree in Business Administration from the George Washington University in 1966.

His early Air Force assignments included tours as a tactical airlift pilot, including a one-year assignment in Vietnam; the project officer for the Titan II inertial guidance system; and an action officer on the Air Staff in the Pentagon. Beginning in 1970, he held a series of assignments in the nation's space program, which included several technical program management responsibilities and command responsibility for satellite operations.

As a Brig. Gen., he was assigned to the Space Shuttle Program Office at NASA Headquarters and later became the Air Staff Officer responsible for budget development for the Air Force Space Program. In 1983 he became Director of Special Projects, Office of the Secretary of the Air Force, from which he retired in 1987. His military decorations include the Defense, National Intelligence Community, and Air Force Distinguished Service medals and the Distinguished Flying Cross. After his military retirement, he became President and Chief Executive Officer of The Charles Stark Draper Laboratory where he served in that capacity until 1997.

He is a member of many advisory groups and boards, including the Strategic Advisory Group, U.S. Strategic Command, Sandia National Security Advisory Panel, and Space Studies Board of the National Research Council, and is a Trustee, United States Naval Academy Foundation. Jacobson is a fellow of the American Institute of Aeronautics and Astronautics as well as a member of the NASA Advisory Council Task Force on ISS Operational Readiness and a former member of the NASA Advisory Council Task Force on Shuttle-Mir Operational Readiness.

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.

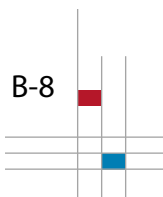
After Apollo, he became Manager of System Integration for the Space Shuttle Program; Deputy Manager, Space Shuttle Program; and then Deputy Director of the Space Shuttle Program at JSC. As Deputy Director, he was responsible for the daily engineering, processing, and operations activities of the Shuttle 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

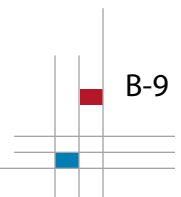
Ex-Officio Member

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. 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 conducting research on environmental policy 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.

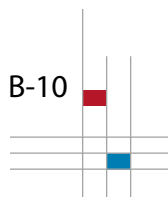
She has worked as a consultant to the U.S. Department of the Interior, the U.S. Environmental Protection Agency, the Indiana Department of Environmental Management, the International City/County Management Association, the National Science Foundation, and the National Academy of Sciences.

Dr. O'Leary is the author/editor of five books and more than 75 articles on environmental management, environmental policy, public management, dispute resolution, bureaucratic politics, and law and public policy. 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 academician 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 that 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 chair of the Public Administration Section of the American Political Science Association, and as the chair of the Section on Environment and Natural Resources Administration of the American Society for Public Administration.

**Mr. David Rasket:
Engineering Consultant**

Mr. Rasket is an expert in national security space architectures, payloads, avionics, space electrical power development, and integration in addition to his experiences as a manager in a wide variety of military and commercial programs. He is currently a consultant to the U.S. Air Force EELV (Evolved Expendable Launch Vehicle) Program Office, where he assists in defining the mission assurance program and develops enhanced program management methods. In 2002, he was responsible for the independent review of Titan IVB-30 readiness and the spacecraft/launch vehicle integration.



His public and private sector experience includes Future Imagining Architecture Space Segment IPT Lead – Boeing; FIA Mission Payload IPT Lead, Low Altitude Demonstration System Program Director, Delta IV Program Director, Director of Flight Systems – McDonnell Douglas; Vice Director, Secretary of the Air Force Special Projects – Air Force; and Deputy Director, Launch and Support Operations – Air Force.

Mr. Raspet received his Bachelor of Science degree in Physics from Mississippi State University and his Master's degree in Electro-Optical Engineering Physics from the Air Force Institute of Technology.

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 background 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.

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.

