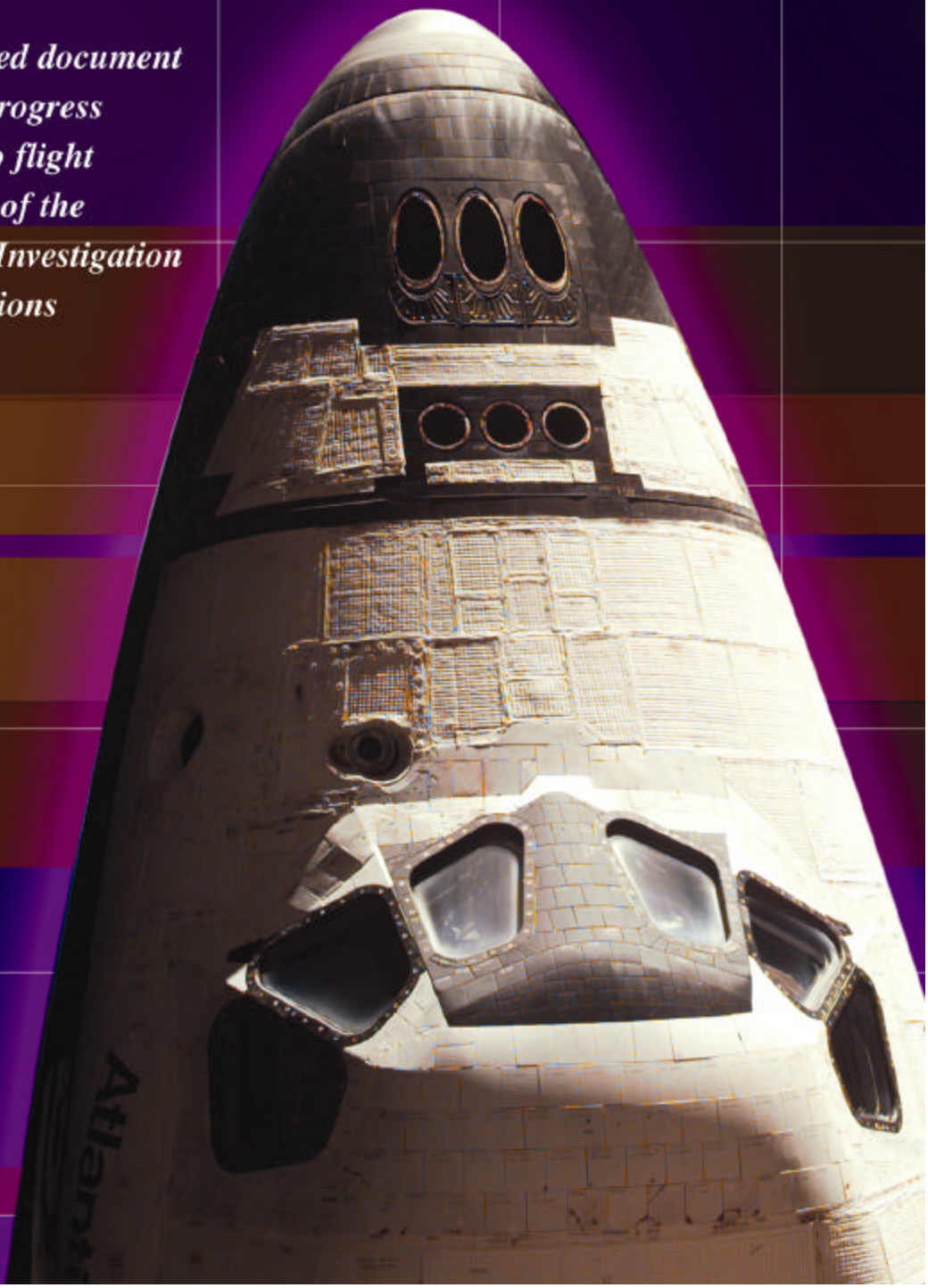
July 28, 2004
Volume 1, Revision 2.1

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

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



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

Revision 2.1 Summary
July 28, 2004

NASA's return to flight (RTF) efforts continue to evolve as we identify appropriate solutions to our RTF challenges and begin to prepare for our first flight. Our planning and work has also been affected by the Vision for Space Exploration, which has focused the Shuttle Program on the goal of completing International Space Station (ISS) assembly, and then retiring the Shuttle planned for the end of the decade.

Since the last version of *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* (Revision 2) was released in April 2004, NASA has completed its response to several of the *Columbia* Accident Investigation Board (CAIB) recommendations. We continue to make significant progress in understanding the debris environment and the material characteristics of the Orbiter and Thermal Protection System (TPS); as a result, we are able to better target critical areas for hardening prior to RTF. Even more critical to our ability to return safely to flight, we have made significant progress in reducing the debris shed from the External Tank (ET) during ascent.

Work to develop viable repair techniques and materials for the TPS is under way, and progress has been made on repairing acreage tiles and Reinforced Carbon-Carbon (RCC) cracks and small holes. However, NASA's attempts to develop a rigid overwrap for the Shuttle's wing leading edge that could be used to repair large holes encountered significant technical challenges. As a result, we have deferred development of the rigid wrap and are pursuing a broader research and development effort to identify more flexible alternatives for repairing holes in the wing's RCC that are larger than four inches in diameter.

The Space Shuttle and ISS Programs have also made progress in defining and planning for a Contingency Shuttle Crew Survival (CSCS) capability. The two programs have completed analyses that show that, for our first two flights at a minimum, it is possible to launch a rescue mission during the time that the Shuttle crew can be safely sustained on the ISS. NASA will continue to refine our planning for the unlikely event that CSCS capability must be used.

As our efforts to return the Shuttle to safe flight have matured and the required work has been identified, NASA has gained a better understanding of the costs associated with this challenging endeavor. Along with the tasks required for RTF, we have reinvigorated our safety and engineering cultures. As a result, we have continued to identify safety issues and aging Orbiter issues that require additional work. Therefore Shuttle Program RTF content and associated costs have increased in fiscal year (FY) 2004. Most of the additional FY 2004 costs for RTF/CAIB-related activities, Program operations, and sustaining activities were covered by unencumbered funds carried over from FY 2003 and offsets from reduced operations costs due to the shift in the resumption of Shuttle launches from FY 2004 to FY 2005. The total costs for RTF will not be known until the completion of the first Shuttle missions to the ISS in FY 2005. However, NASA expects that by late fall of 2004 we will have developed a better understanding of the FY 2005 financial situation. A full discussion of the status of RTF funding is provided in a following section.

Finally, NASA has begun to close out key RTF constraints with the Return to Flight Task Group (RTFTG). We have achieved conditional closure for five of the 15 RTF actions. In April, the RTFTG conditionally closed Recommendation 3.3-1, Reinforced Carbon-Carbon

Nondestructive Inspection; Recommendation 6.3-2, National Imagery and Mapping Agency Memorandum of Agreement; and Recommendation 4.2-3, Closeout Inspection. In July, they conditionally closed two more, Recommendations 4.2-5, Foreign Object Debris, and 10.3-1, Closeout Photography. The NASA Kennedy Space Center (KSC) has completed work to establish a revitalized program for identifying and preventing foreign object debris that surpasses the CAIB's recommendation. NASA has also created a robust system for photographing, archiving, and accessing closeout photography for the Space Shuttle. This system will allow key users across the Agency to quickly and easily access images of the Shuttle systems to make operational decisions during a mission and support postflight assessments. The RTFTG continues to monitor our progress on the remaining RTF actions. NASA has plans to close the remainder by the end of 2004.

A great deal of activity is currently under way and this pace will continue through the Shuttle's Return To Flight. All three Orbiters are going through processing at KSC simultaneously, ETs are being modified with the new TPS configuration, Orbiter TPS inspection and repair techniques are being honed, a wide-range of tests are under way to validate analysis efforts, and the STS-114 crew, ground controllers, and Mission Management Team are in training for the RTF mission.

We remain confident that with the hard work being performed around the Agency and in our contractor workforce, we can return the Shuttle safely to flight. We continue to work toward a first flight in the March-April 2005 launch window.

This revision supercedes all earlier iterations of this Implementation Plan.

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Appendix A – NASA's Return to Flight Process

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2-75 (Apr. 26, 2004) – 2-78 (Apr. 26, 2004)	2-75 (July 28, 2004) – 2-78 (Apr. 26, 2004)
A-1 (Apr. 26, 2004) – A-2 (Apr. 26, 2004)	A-1 (July 28, 2004) – A-2 (July 28, 2004)

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A Message From Sean O'Keefe

Over the course of seven months last year, the *Columbia* Accident Investigation Board (CAIB) thoroughly and intensively examined the cause of the *Columbia* accident and issued its exhaustive report and recommendations. In addition to identifying the problems that led to the *Columbia* accident, the CAIB emphasized the need for a clearer direction from which to drive NASA's human exploration agenda. On January 14, 2004, the President articulated a new vision for space exploration. The first step in the President's exploration vision is to return the Space Shuttle to flight as soon as practical, based on the recommendations of the CAIB. We have endeavored to fix the problems identified by the CAIB and to return the Space Shuttle safely to flight.

In this, the second complete revision of our Return to Flight Implementation Plan, we provide updates to previously released information describing how we are embracing the CAIB Report and its recommendations, and pursuing those critical actions that we have adopted to make flying the Space Shuttle safer. We will also identify, where appropriate, how our long-term planning has changed in response to the President's exploration vision that calls for the retirement of the Space Shuttle when the International Space Station is complete. Our Plan continues to be a living document, periodically updated to reflect our progress toward a safe return of the Space Shuttle to flight.

The STS-107 crew of Mike Anderson, David Brown, Kalpana Chawla, Laurel Clark, Rick Husband, Willie McCool, and Ilan Ramon devoted their lives to the NASA vision and the exploration of space, and became the inspiration for the President's exploration vision. We are committed to safely returning to flight and safely flying the Space Shuttle fleet until its retirement. To do less would diminish the life-long contributions of the STS-107 crew.

Sean O'Keefe

Return to Flight
Message from the
Space Flight Leadership Council

The recommendations, findings, and observations from the *Columbia* Accident Investigation Board Report provided NASA a roadmap to safely and successfully resume our journey into space. The Report reflects the Board's strong support for return to flight of the Space Shuttle "at the earliest date consistent with the overriding objective of safety." NASA has fully accepted the Board's findings and observations and is working diligently to comply with each and every one of its recommendations, as well as to "raise the bar" in a number of relevant areas.

The new Vision for Space Exploration announced by President Bush on January 14, 2004, further reinforced the importance for the Space Shuttle Program to find the problem, fix the problem, and safely return to flight. The first step of this grand vision is safely returning the Space Shuttle to flight to complete the assembly of the International Space Station by the end of the decade.

NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond outlines the latest plans and progress we have made in response to the Report. It remains a "living document" to be continually updated to record NASA's progress toward safe return to flight. Recommendations and actions identified as return to flight by the Board or NASA will be completed before resuming Space Shuttle flight operations. Also documented are all changes to action plans as a result of the new Vision for Space Exploration.

As we continue to progress toward a safe return to flight, we do so with the STS-107 crew, Mike Anderson, David Brown, Kalpana Chawla, Laurel Clark, Rick Husband, Willie McCool, and Ilan Ramon, in our hearts and minds. Their legacy will continue to inspire us on the road ahead. We strive for excellence in all aspects of our work, strengthening our culture, and enhancing our technical capabilities in order to improve the safety of human space flight.

NASA will return to flight: smarter, stronger, and safer!

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

William F. Readdy
Associate Administrator
for Space Flight

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Appendix A – NASA's Return to Flight Process

Appendix B – Return to Flight Task Group

Return to Flight 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, while taking into account the Vision for Space Exploration.

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 to 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 Program, 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, and 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 U.S. Navy course on the *Challenger* launch decision, a NASA decision-making class, and seminars by outside safety, management, communications, and culture consultants.

Returning Safety 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 gases 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 cause 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 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 nondestructive 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 part of the Shuttle Service Life Extension.
- Is revalidating the operational environments (e.g., loads, vibration, acoustic, and thermal environment) 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 grave Forest Service helicopter crew, Jules F. Mier, Jr., and Charles Krenek, 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.

NASA Space Shuttle Return to Flight (RTF) Suggestions

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

The first e-mail suggestion was received on September 8, 2003. Since then, NASA has received a total of 1932 messages, averaging 72 messages per week. NASA responds to each message individually, including answering any questions contained in the suggestion, and providing information about where the message will be forwarded for further review and consideration.

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

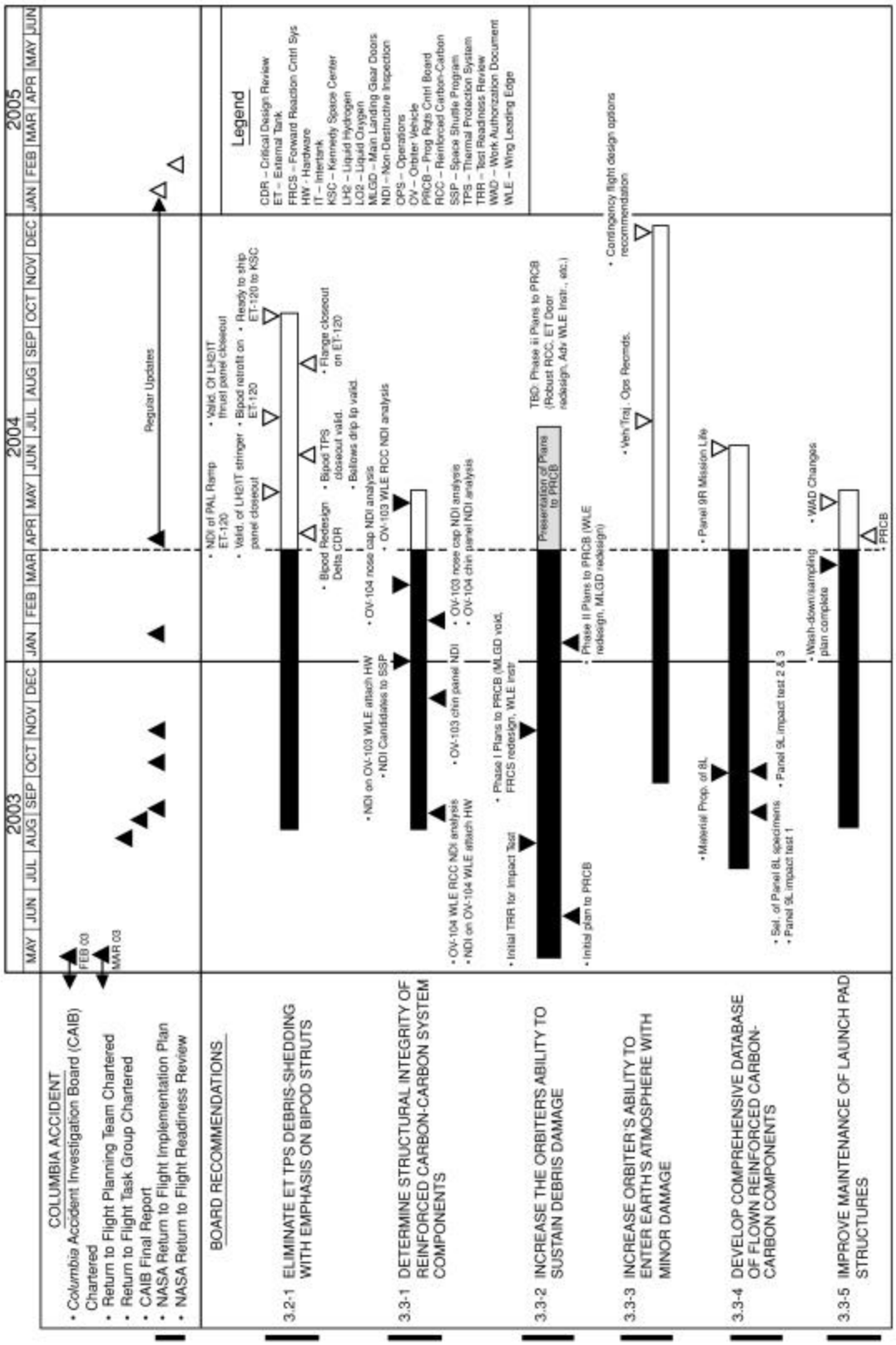
NASA organizations receiving suggestions are asked to review the message and use the suggestion as appropriate in their RTF activities. When a suggestion is forwarded, the recipient is encouraged to contact the individual who submitted the suggestion for additional information to assure that the suggestion's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

Table 1 provides a summary of the results. The table includes the following information: (1) the categories of suggestions; (2) the number of suggestions received per category; and (3) examples of RTF suggestion content from each category.

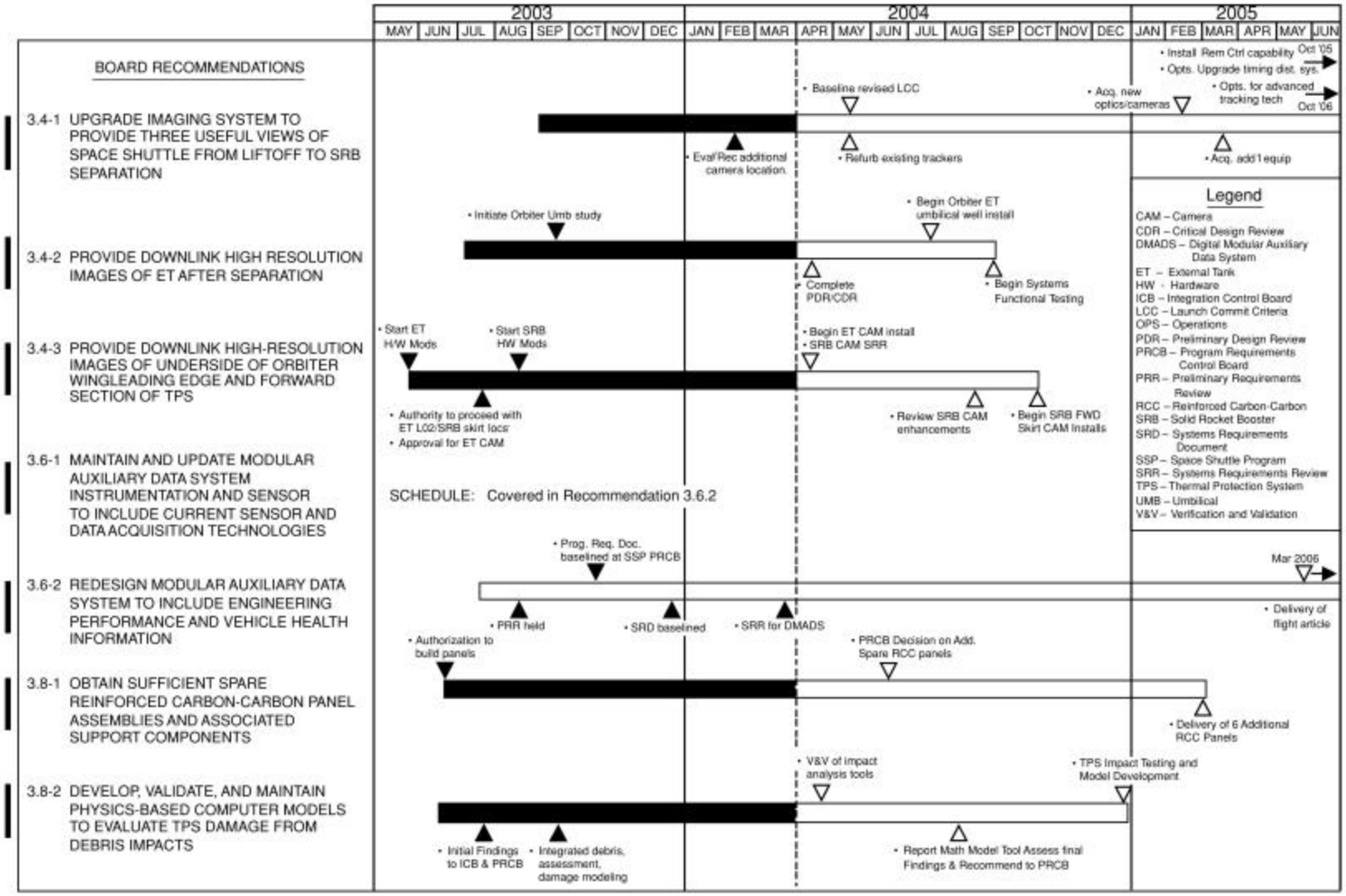
Synopsis of Return to Flight Suggestions

Category	No. of Suggestions	Example Suggestion Content
Orbiter	573	(1) Develop a redundant layer of Reinforced Carbon-Carbon panels on the Orbiter wing leading edge (WLE). (2) Cover the WLE with a titanium skin to protect it from debris during ascent.
External Tank	526	(1) Insulate the inside of the External Tank (ET) to eliminate the possibility of foam debris hitting the Orbiter. (2) Shrink wrap the ET to prevent foam from breaking loose.
General Space Shuttle Program	267	(1) Simulate Return to Launch Site scenarios. (2) Orbit a fuel tank to allow the Orbiter to refuel before entry and perform a slower entry. (3) Establish the ability to return the Shuttle without a crew on board.
Imagery/Inspection	130	(1) Use the same infrared imagery technology as the U.S. military to enable monitoring and tracking the Space Shuttle during night launches. (2) Use a remotely controlled robotic free-flyer to provide on-orbit inspection. (3) Bring back the Manned Maneuvering Unit to perform on-orbit inspection of the Orbiter.
Systems Integration	106	(1) Mount the Orbiter higher up on the ET to avoid debris hits during launch. (2) Incorporate temporary shielding between the Orbiter and ET that would fall away from the vehicle after lift off.
Crew Rescue/Ops	69	(1) Implement a joint crew escape pod or individual escape pods within the Orbiter cockpit. (2) Have a second Shuttle ready for launch in case problems occur with the first Shuttle on orbit. (3) Have enough spacesuits available for all crewmembers to perform an emergency extravehicular activity.
Aerospace Technology	65	Quickly develop a short-term alternative to the Space Shuttle based on existing technology and past Apollo-type capsule designs.
Public Affairs	52	NASA needs to dramatically increase media coverage to excite the public once again, to better convey the goals and challenges of human space flight, and to create more enthusiasm for a given mission.
NASA Culture	50	(1) Host a monthly employee forum for discussing ideas and concerns that would otherwise not be heard. (2) Senior leaders need to spend more time in the field to keep up with what is actually going on.
NASA Safety and Mission Assurance	46	(1) Learn from the Naval Nuclear Reactors Program. (2) The Government Mandatory Inspection Point review should not be limited to just the Michoud Assembly Facility and Kennedy Space Center elements of the Program.
Space Shuttle Program Safety	20	(1) Develop new Solid Rocket Boosters (SRBs) that can be thrust-controlled to provide a safer, more controllable launch. (2) Use rewards and incentives to promote the benefits of reliability and demonstrate the costs of failure.
International Space Station	12	(1) Adapt an expandable rocket booster to launch Multi-Purpose Logistics Modules to the International Space Station (ISS). (2) Add ion engines to the ISS to give it extra propulsion capability.
Leadership and Management	10	(1) Employees need to be trained while still in their current job to prepare them for increasing positions of responsibility. (2) Institute a rotational policy for senior management, similar to that of the U.S. Armed Forces.
NASA Engineering and Safety Center	5	(1) Use a group brainstorming approach to aid in identifying how systems might fail. (2) NESC needs to get involved during a project's start as well as during its mission operations.
Solid Rocket Boosters	1	Ensure that the SRB hold-down bolts are properly reevaluated.
Total (As of March 15, 2004)	1932	

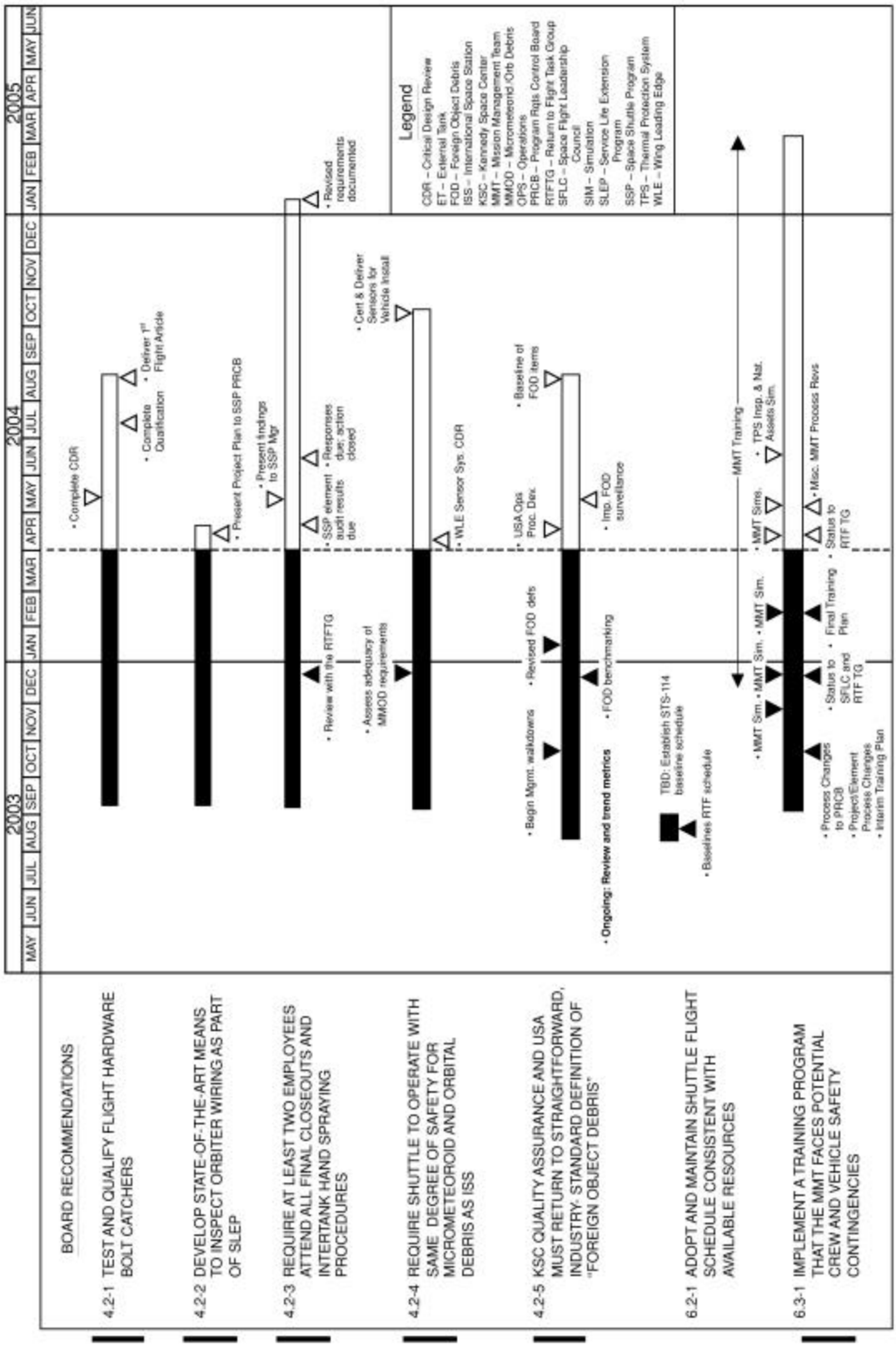
CAIB Recommendations Implementation Schedule



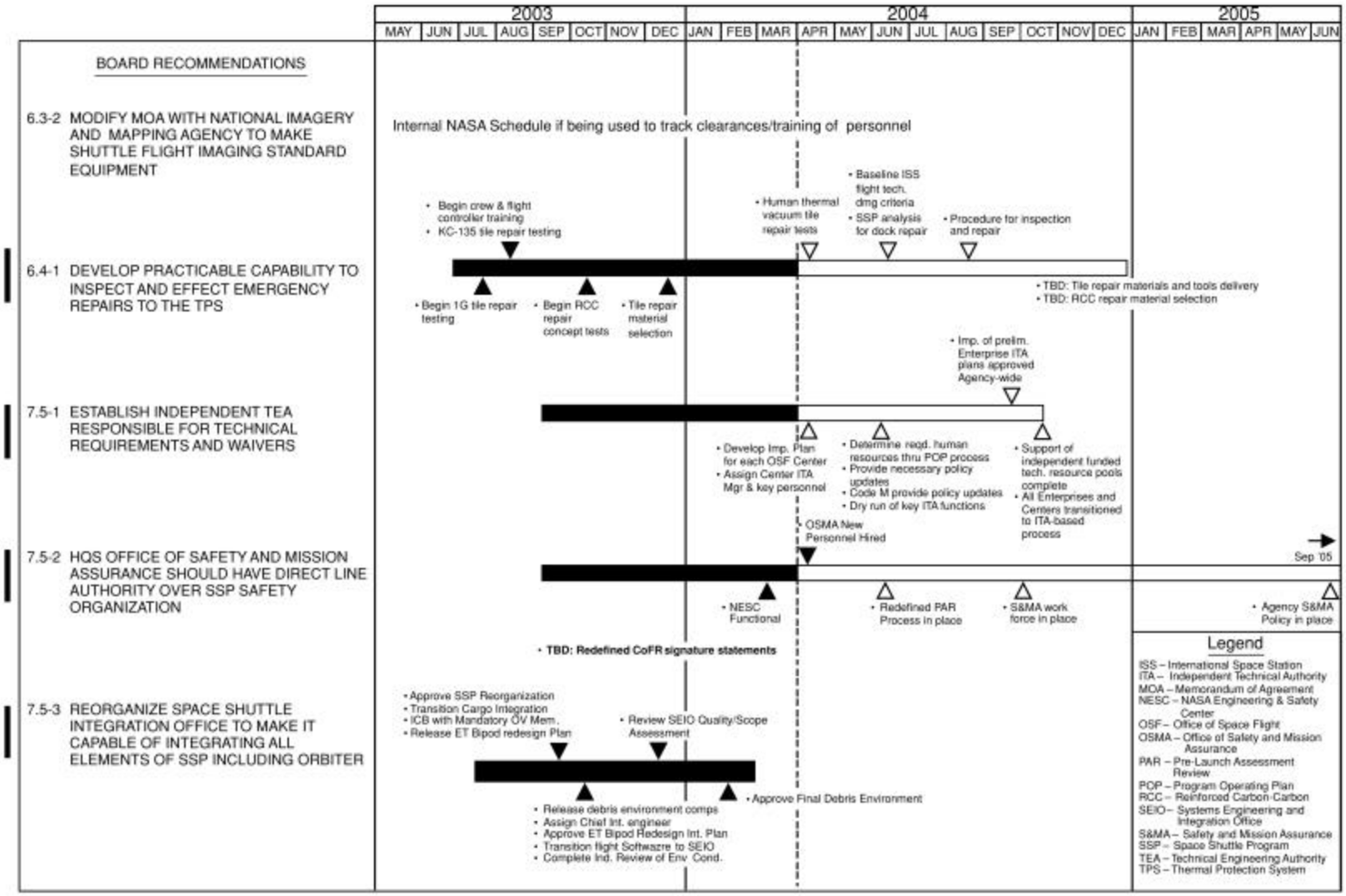
CAIB Recommendations Implementation Schedule



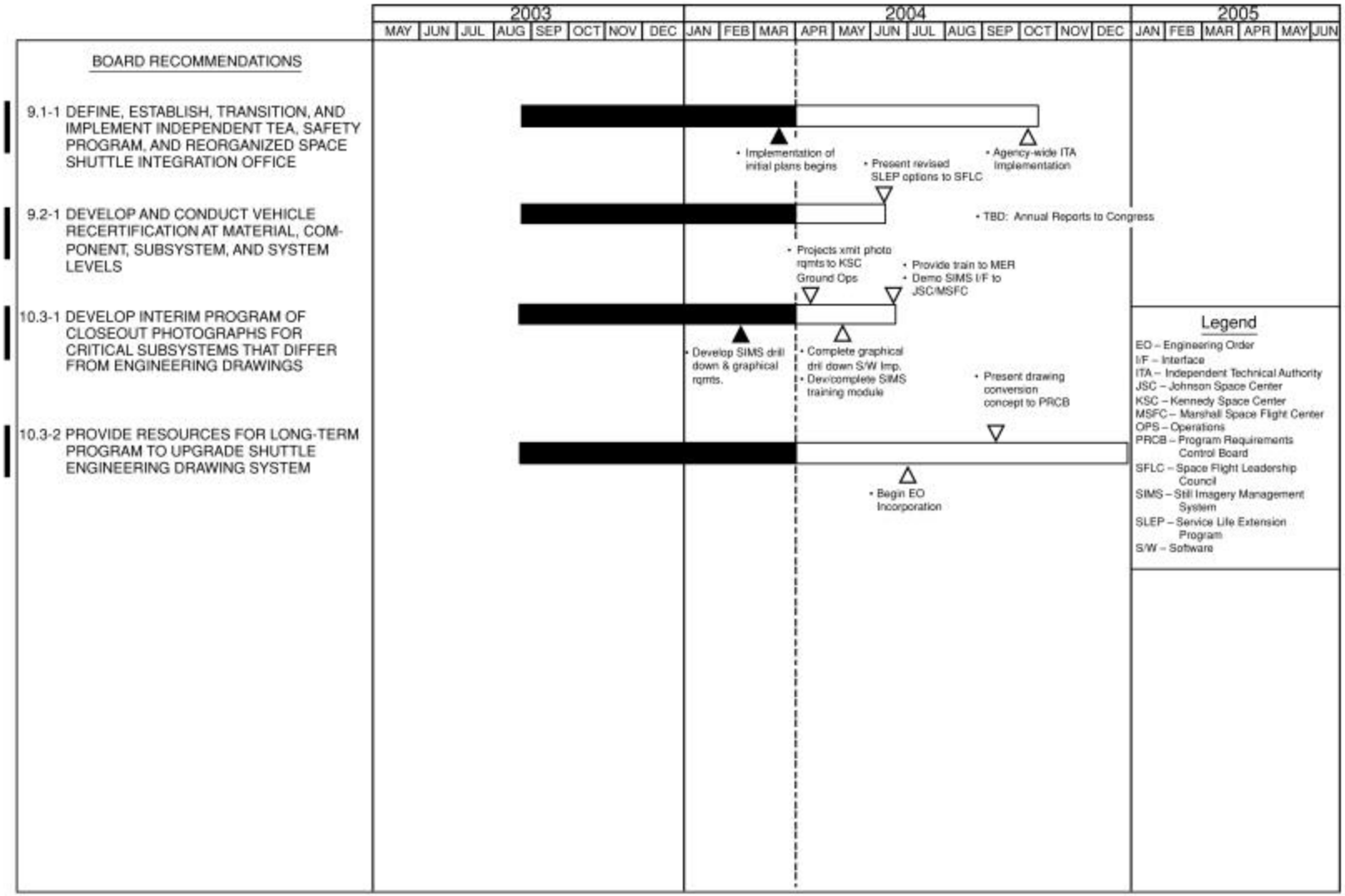
CAIB Recommendations Implementation Schedule



CAIB Recommendations Implementation Schedule



CAIB Recommendations Implementation Schedule



Return to Flight Cost Summary

Acting on preliminary *Columbia* Accident and Investigation Board (CAIB) recommendations and internal Space Shuttle Program (SSP) initiatives, NASA began incurring costs for return to flight (RTF) activities in fiscal year (FY) 2003. Initial cost estimates were based on RTF plans still in formulation and showed that NASA could need up to $94M in additional budget authority in FY 2003 and $265M in FY 2004. In response, NASA reprogrammed $43M from the Shuttle Service Life Extension Program and requested $50M in supplemental funding from Congress for *Columbia*-related activities. As FY 2003 came to a close, it became apparent that a large portion of the planned RTF work and associated costs would carry over into FY 2004, as the predicted launch date for the first mission back to the Space Station moved from the fall of 2004 to the spring of 2005. The Program entered FY 2004 with $533M in funding to carry over of which $139M was unencumbered and available to apply to RTF content.

At the start of FY 2004, NASA RTF plans were still evolving, and multiple paths were being investigated to provide the best technical response to the CAIB recommendations. The RTF budget estimates provided in FY 2003 were updated and the revised estimates were published in January 2004. NASA cautioned that since RTF content was still changing, the cost estimates for all years would also change. In its initial operating plan for FY 2004, NASA also noted that RTF engineering efforts were still dynamic and additional funds might be required to accommodate the changing RTF content before the end of the fiscal year. Through the second quarter of FY 2004, RTF technical efforts proceeded rapidly. Approval of specific RTF activities through the Shuttle Program Requirements Control Board (PRCB) meant that the maturity of the technical solutions was increasing, allowing for more accurate cost projections. All financial performance indicators showed that sufficient funds would be available to cover all critical path work in FY 2004, but that the costs for FY 2005 would likely exceed the FY 2005 budget requested for the Program. With a considerable amount of RTF work still to be reviewed and approved by the PRCB and the Space Flight Leadership Council and a potential for cost variations in the hundreds of millions of dollars, additional time will be required to assess funding needs for FY 2005 and beyond.

Through the third quarter of this fiscal year, RTF planning gave way to RTF execution and the Program came within the 12-month processing cycle for the first launch in 2005. In addition to the original RTF requirements, the *Columbia* experience led the Program to introduce a higher level of engineering and technical rigor. Many potential risks have been reevaluated and mitigated, resulting in a safer Shuttle system overall. Across the board, fight hardware is now subjected to greater levels of test, teardown, inspection, repair, and recertification for flight, and all elements of the Program are reassessing the adequacy of industrial processes, safety controls, integrated hazard analyses, and flight hardware test protocols. As a result, Program operations and sustaining engineering spending for FY 2004 and cost projections for FY 2005 have increased along with RTF costs.

As stated in the April 26 update to the Implementation Plan, earlier cost estimates did not include all RTF elements under consideration, additional requirements that may be derived from the continuing evaluation of the CAIB recommendations, costs incurred by other Agency activities in support of RTF, and Program budget reserve. This update takes into account all known potential costs, but does not include a budget reserve that could be needed to address unknown challenges that may arise after the first two flights in FY 2005. An integrated Program budget reserve approach will be addressed in the Agency's FY 2006 budget request. Table 1 shows current RTF/CAIB estimates through FY 2005.

Table 1. Return to Flight Budget Estimates/Implementation Plan Map for New Estimates Including Threats*

As of July 21, 2004

		(Cost in Millions)			Recommendation Numbers Map to Implementation Plan																														
		FY 03	FY 04	FY05**	CAIB #3.2-1	CAIB #3.3-1	CAIB #3.3-2	CAIB #3.3-3	CAIB #3.3-4	CAIB #3.3-5	CAIB #3.4-1	CAIB #3.4-2	CAIB #3.4-3	CAIB #3.6-1	CAIB #3.6-2	CAIB #3.8-1	CAIB #3.8-2	CAIB #4.2-1	CAIB #4.2-2	CAIB #4.2-3	CAIB #4.2-4	CAIB #4.2-5	CAIB #6.2-1	CAIB #6.3-1	CAIB #6.3-2	CAIB #6.4-1	CAIB #7.5-1	CAIB #7.5-2	CAIB #7.5-3	CAIB #9.1-1	CAIB #9.2-1	CAIB #10.3-1	CAIB #10.3-2	SSP Recommendation
(1)	**Total Initiated SSP RTF Activities**	**42**	**465**	**643**																															
RE/RP	Orbiter RCC Inspections & Orbiter RCC-2 Shipsets Spares	2	38	7		X	X									X							X												
RE/RP	On-orbit TPS Inspection & EVA Tile Repair	20	68	130								X							X																X
AC	Orbiter Workforce	0	5	37																		X						X							X
RE/RP	Orbiter TPS Hardening	0	28	34			X																												
AC	Orbiter/GFE		7	4																															
AC	Orbiter Contingency		8	12																															
RE/RP	Orbiter Certification / Verification	0	47	26	X			X	X							X						X								X					X
RE/RP	External Tank Items (Camera, Bipod Ramp, etc.)	11	14	94	X							X								X															
RE/RP	SRB Items (Bolt Catcher, ETA Ring Invest., Camera)	1	8	26					X				X					X							X										
RE/RP	Ground Camera Ascent Imagery Upgrade	8	40	58							X								X	X					X										
AC/RE	KSC Ground Operations Workforce		32	36						X							X			X					X										X
RE/RP	Other (System Intgr. JBOSC Sys, SSME Tech Assess)	0	67	177		X	X	X	X																	X	X	X	X						X
RE/RP	Stafford - Covey Team	0	3	1																															X
		(2)	(3)																																
	Other RTF Related* **																																		
	NASA Engineering and Safety Center (NESC)		45	77																							X	X	X						

RE = Reestimated Item; RP = Rephased; AC = Added Content

(1) The "Total SSP RTF Activities" budget line identified above represents an update to the estimates reflected in NASA's letters to the committees dated January 30, 2004. This update includes added scope of work and improved estimates. Although there is a greater level of technical maturity, requirements are still evolving, and cost estimates for those activities are dynamic and are still under evaluation to confirm the estimated cost and associated out-year phasing. Congress will be kept informed as we refine these requirements and associated cost estimates.

(2) In the last RTF update, NASA assumed an estimate of $94M in budget authority for FY 2003 could be needed. Since that time it became apparent that $52M of FY 2003 planned work and associated cost were carried into FY 2004.

(3) The updated FY 2004 RTF cost estimate of $465M includes $319M of activities that have been approved for implementation. The remaining $146M of RTF activities are pending approval. As soon as these additional activities are definitized, they will be shared with Congress.

*These estimates could change due to improved estimates, additional tasks, and added scope as we better understand the implementation of RTF recommendations.

**Cost estimates for FY 2005 and beyond will be refined as the Program comes to closure on RTF technical solutions and the RTF plan is finalized.

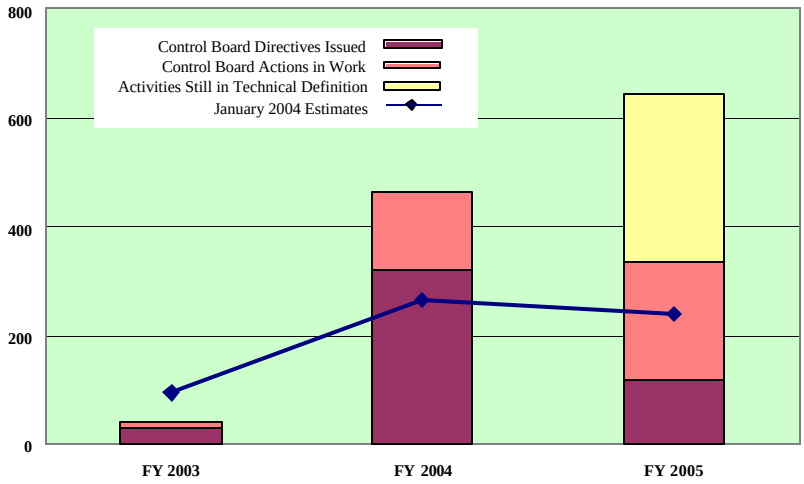
***The NASA Engineering and Safety Center (NESC) is funded through NASA's Corporate G&A. The NESC at NASA's Langley Research Center in Hampton, Va., provides comprehensive examination of all NASA programs and projects. The Center thus provides a central location to coordinate and conduct robust engineering and safety assessment across the entire Agency.

The following Chart 1 and associated Table 2 show the relative maturity of the estimates for known RTF content based on PRCB approval of technical content. Actions approved with PRCB directives issued have mature cost estimates, while those with control board actions in work are less mature. Both the content and cost estimates for RTF work that has not yet been reviewed by the control board are very preliminary and subject to considerable variation. The total cost for RTF will not be known until completion of the first Shuttle missions to the Space Station in FY 2005.

Cost estimates for FY 2005 and beyond will be refined as the Space Shuttle Program comes to closure on RTF technical solutions and the RTF plan is finalized. NASA expects that by late fall of 2004, a better understanding of the FY 2005 financial situation will be developed.

While all critical RTF work is continued, NASA will address any remaining FY 2005 shortfall first by seeking lower-priority offsets within the Shuttle Program, then by identifying funds for transfer from lower-priority or under-performing activities outside the Program.

Chart 1. July 2004 Return to Flight Estimates



	FY 2003	FY 2004	FY 2005
Estimates Published in January 2004	***94***	***265***	***238***
Total Board Actions/Pending Board Action:	**42**	**465**	**643**
Value of Control Board Directives Issued	**31**	**319**	**117**
Estimates for Control Board Actions Work	**11**	**146**	**217**
Estimates for Activities Still in Technical Definition			**309**

Table 2. July 2004 Return to Flight Estimates

	FY 2003	FY 2004	FY 2005
TOTAL RTF	42	456	643
RTF Activities – Control Board Directive	31	319	117
RTF Activities – Been to Control Board/No Directive	11	146	217
RTF Activities – In Review Process	0	0	309
RTF Activities – Control Board Directive	31	319	117
Orbiter RCC Inspections & Orbiter RCC-2 Shipping Spares	2	38	0
On-orbit TPS Inspection & EVA Tile Repair	20	68	34
Orbiter TPS Hardening		28	1
Orbiter Certification/Verification		47	
Orbiter Other (GFE/Contingency)		15	16
External Tank Items (Camera, Bipod Ramp, etc.)		6	1
SRB Items (Bolt Catcher, ETA Ring Invest., Camera, other)	1	8	
Ground Camera Ascent Imagery Upgrade	8	40	3
Rudder Speed Brakes		5	11
Other (System Intgr. JB OSC Sys., Full Cost, Additional FTEs, etc.)		62	50
Stafford-Covey Team	0	3	1
RTF Activities – Been in Central Board/No Directive	11	146	217
Orbiter Workforce (Ground Ops)		5	5
External Tank Items (Camera, Bipod Ramp, etc.)	11	109	92
Ground Camera Ascent Imagery Upgrade			52
Orbiter Workforce (Ground Ops, USA, Boeing, Logistics Eng.)			32
KSC Ground Ops Workforce		32	36
RTF Activities – In Review Process	0	0	309
Orbiter RCC Inspections & Orbiter RCC-2 Shipsets Spares			
On-orbit TPS Inspection & EVA Tile Repair			
Orbiter TPS Hardening			
Orbiter Certification/Verification			
SRB Items (Bolt Catcher, Camera, other)			
Ground Camera Ascent Imagery Upgrade			
Increased SSME Testing			
SSME CAIB Impacts			
Other (System Intgr. JB OSC Sys., Full Cost, Additional FTEs, etc.)			

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 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 area 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; this activity 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.

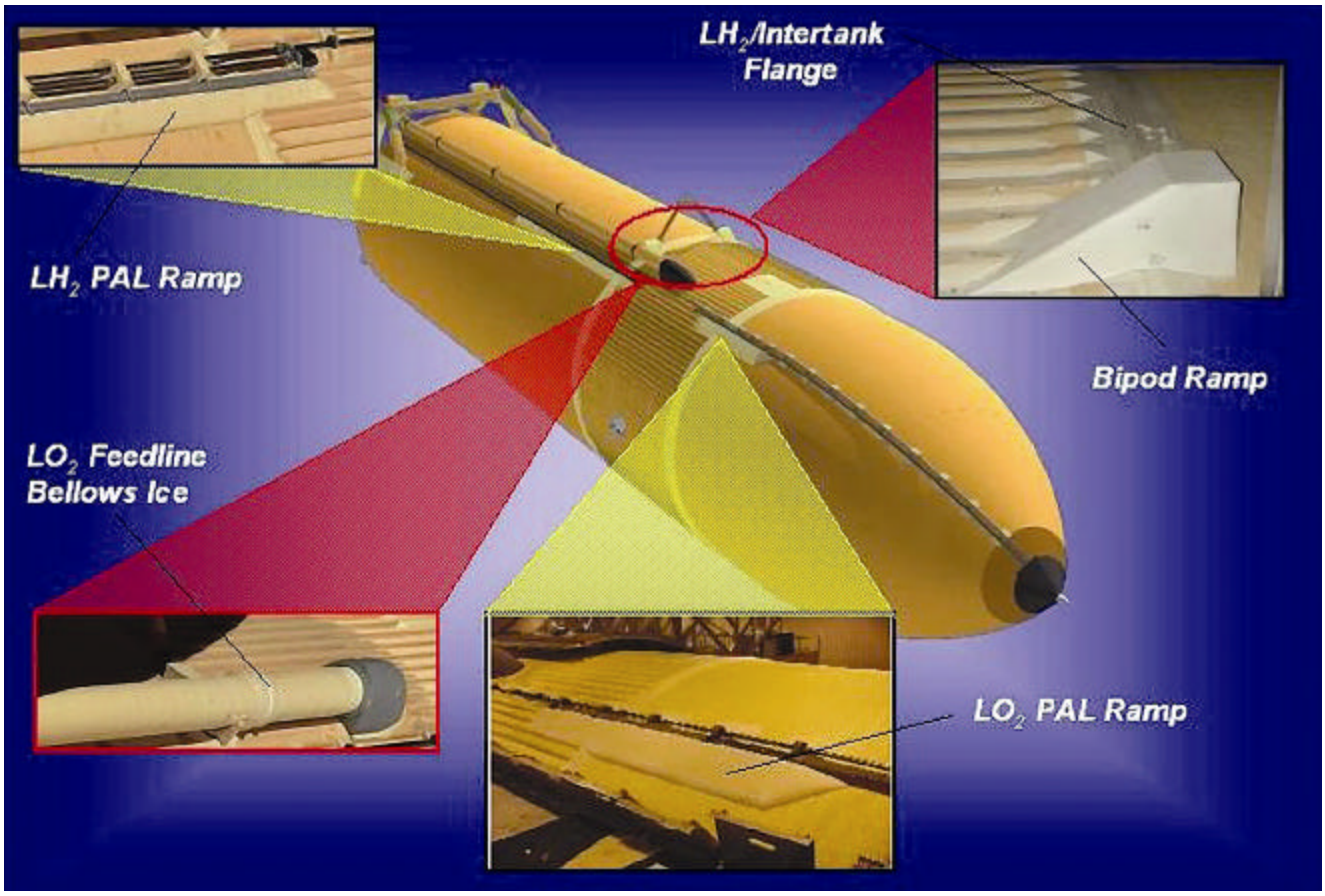


Figure 3.2-1-1. Primary potential ET debris sources being evaluated.

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

Liquid Oxygen (LO_2) Feedline Bellows Background

Three ET LO_2 feedline sections incorporate bellows to allow feedline motion. The bellows 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 occurred on STS-4. The foam loss was associated with a repair operation; a recurrence of such a loss has been precluded by limiting repairs allowed on PAL ramps. However, the PAL ramps are covered with large, thick, manually sprayed foam applications (using a less complex

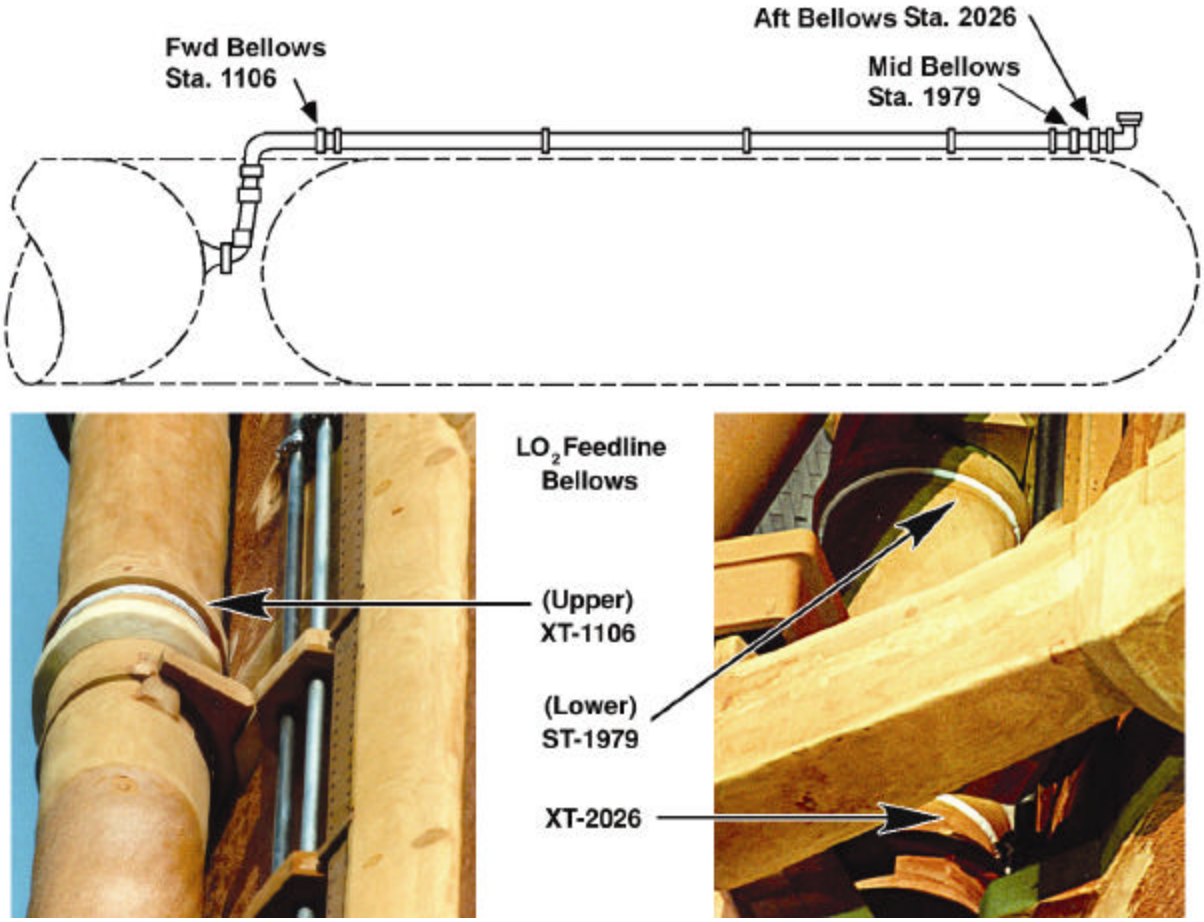


Figure 3.2-1-3. LO_2 feedline bellows.

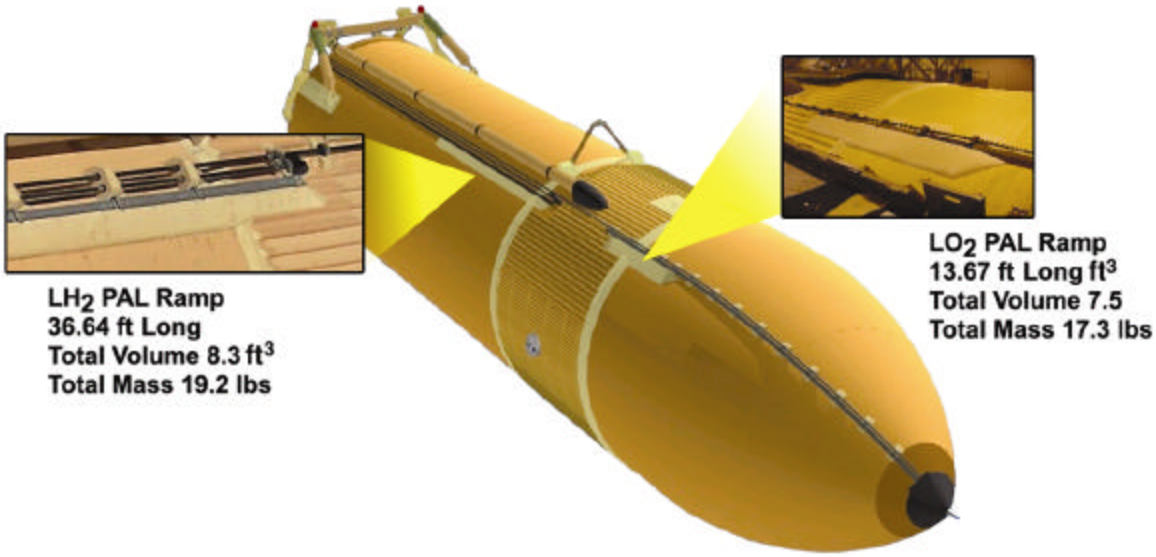


Figure 3.2-1-4. PAL ramp locations.

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

ET Liquid Hydrogen (LH_2) Intertank Flange Background

The ET LH_2/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.

There is a history of foam loss from this area. The divots from the LH_2/intertank flange area typically weigh less than 0.1 lb. and emanate from within the critical debris zone, which is the area of the ET where debris loss could adversely impact the Orbiter or other Shuttle elements.

NASA IMPLEMENTATION

NASA has initiated a three-phase approach to eliminate the potential for debris loss from the ET. Phase 1 includes those activities that will be performed before return to flight. Phase 2 includes debris elimination enhancements that can be incorporated into the ET production line as the enhancements become available, but are not considered mandatory for RTF. Phase 3 represents potential long-term development activities that will be examined to achieve the ultimate goal of eliminating the possibility of debris loss. Implementation of Phase 3 efforts will be weighed against plans to retire the Shuttle after the completion of the International Space Station (ISS) assembly planned for the end of the decade.

As part of the Phase 1 effort, NASA is enhancing or redesigning the areas of known critical debris sources (figure 3.2-1-1). This includes redesigning the forward bipod fitting, eliminating ice from the LO_2 feedline bellows, and eliminating debris from the LH_2/intertank flange closeout. In addition to these known areas of debris, NASA is reassessing all TPS areas to validate the TPS configuration, including both automated and manual spray applications. Special consideration is being given to the LO_2 and LH_2 PAL ramps due to their size and location. This task includes assessing the existing verification data, establishing requirements for additional verification data, and evaluating methods to improve process control of the TPS application. NASA is also 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 other sites. As part of this effort, NASA is developing nondestructive investigation (NDI) techniques to conduct ET TPS inspection without damaging the fragile insulating foam. During Phase 1, NDI will be used on the LO_2 and LH_2 PAL ramps.

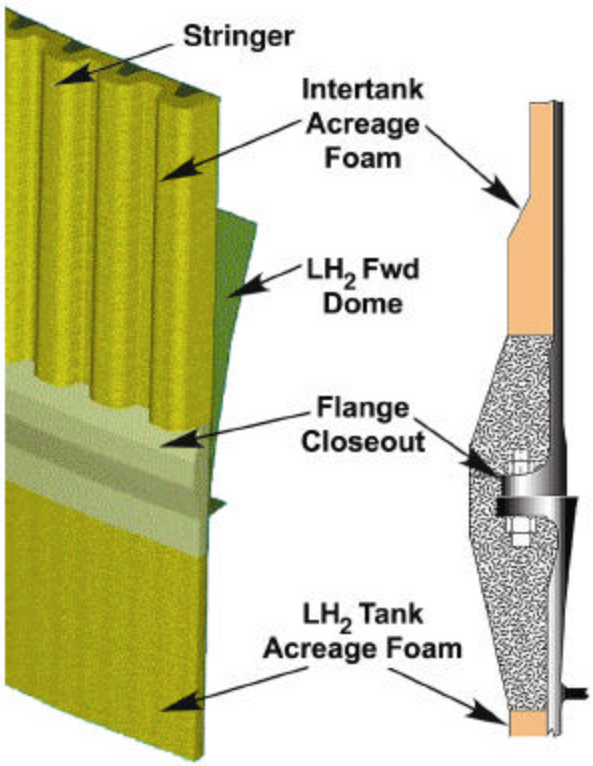


Figure 3.2-1-5. External Tank LH_2 flange area.

Phase 2 efforts will include pursuing the automation of critical manual TPS spray processes, redesigning or eliminating the LO_2 and LH_2 PAL ramps, and enhancing the NDI screening tool. Efforts will also be made to enhance the TPS material to reduce its debris loss potential and to enhance the TPS thermal analysis tools to better size and potentially eliminate TPS on the vehicle.

The Phase 3 effort, if implemented, will examine redesigning the ET to eliminate the debris shedding potential at the source. This could include items such as developing a "smooth" LO_2 tank without external cable trays or pressurization lines, developing a smooth intertank in which an internal orthogrid eliminates the need for external stringers, and implementing a protuberance tunnel in the LH_2 tank. These changes could provide a tank with a smooth outer mold line that eliminates the need for complex TPS closeouts and manual sprays.

ET Forward Bipod Implementation Approach

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

LO_2 Feedline Bellows Implementation Approach

NASA evaluated three concepts to eliminate ice formation on the bellows (figure 3.2-1-7). Analysis and testing eliminated the flexible bellows boot as a potential solution since it could not eliminate ice formation within the available volume. The heated gaseous nitrogen (GN_2) or gaseous helium purge options were also eliminated since they did not reduce the potential for foam divot formation. NASA selected the condensate drain "drip lip" with integral gasket for RTF retrofit. We will use a combination of analysis and testing to verify the effectiveness of the baselined design solution.

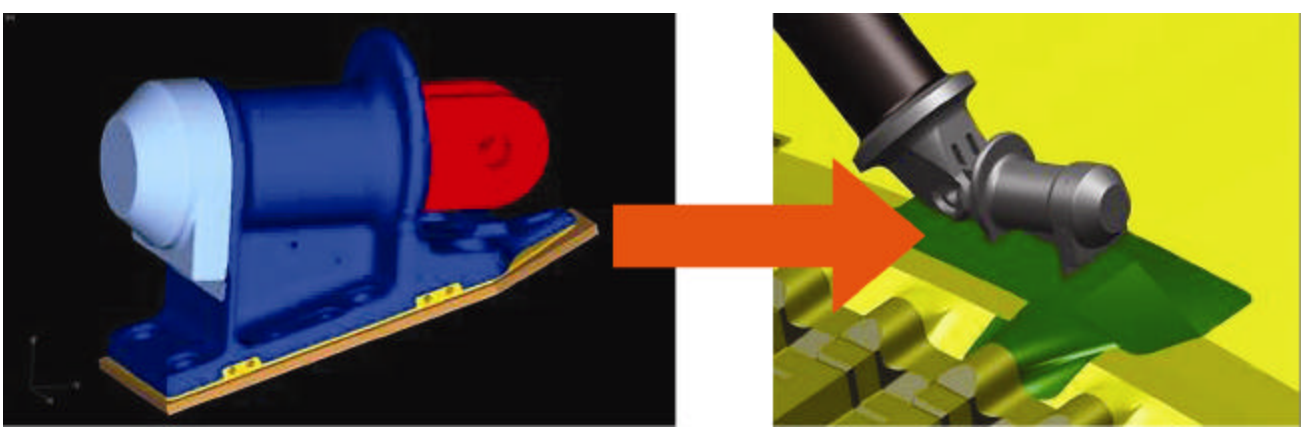


Figure 3.2-1-6. ET forward bipod redesign.

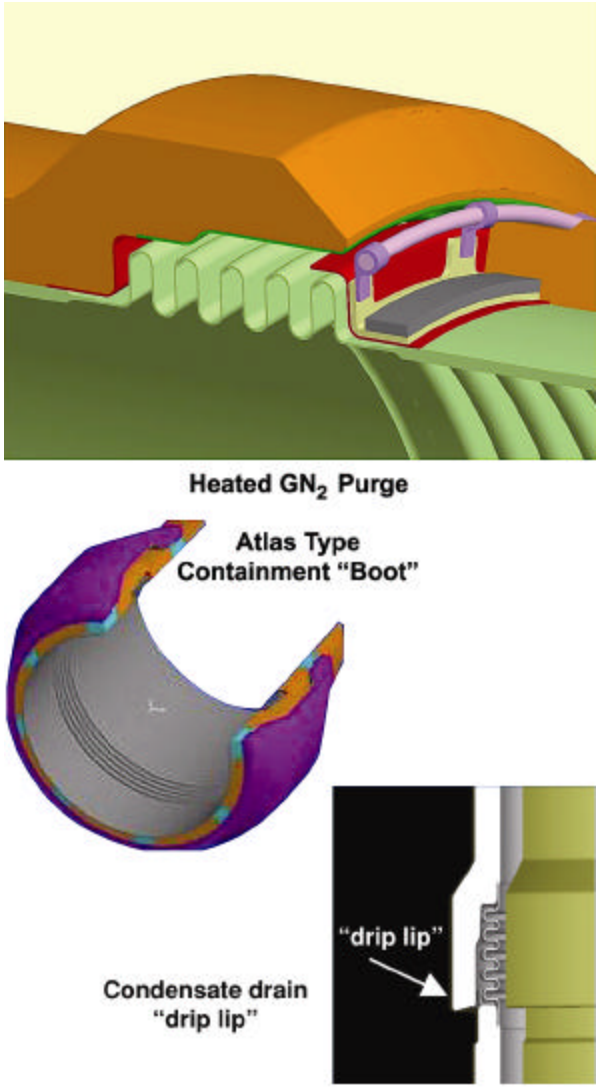


Figure 3.2-1-7. LO_2 feedline bellows design concepts.

LH_2/Intertank Flange Closeout Implementation Approach

NASA has conducted tests to determine the cause of foam liberation from the LH_2/intertank flange area. Migration of gaseous or liquid nitrogen from inside the intertank to voids in the foam was shown to be the root cause for LH_2/intertank flange foam losses during ground testing. Several design concepts have been evaluated to ensure that the LH_2/intertank flange closeouts will not generate critical debris in flight. These concepts ranged from active purge of the intertank crevice to enhanced foam application procedures. The selected design solution incorporates an enhanced three-step manual closeout process to eliminate voids and seal leak paths from inside the intertank region to the foam. Also, additional material will be injected into the volume inside the intertank crevice to fill that area, significantly reduce liquid nitrogen formation there, and prevent any nitrogen that does form from migrating into the foam.

A recent update to the Level II debris transport analyses has expanded the critical debris zone that must be addressed, and significantly reduced the allowable debris mass in this region. The debris allowable has been reduced from a mass of 0.2 lb. in this region to approximately 0.04 lb. The critical debris zone has been expanded from $\pm 67.5^{o}$ from the top of the External Tank (the top of the tank directly faces the underside of the Orbiter) to greater than $\pm 80^{o}$ from the top of the tank. As a result, a new closeout process for the thrust panel of the intertank flange region needs to be developed. The plan is to apply the new closeout to the entire thrust panel, expanding the enhanced closeout region to $\pm 112^{o}$ from the top of the tank (Figure 3.2-1-8).

PAL Ramps Implementation Approach

There has been only one PAL ramp foam loss event in the history of the Shuttle, on STS-4. The foam loss was related to a repair operation; its reoccurrence has been precluded by limiting repairs on all PAL ramps. However, the ET PAL ramp configurations will also be assessed to reduce or eliminate them as potential sources of TPS debris.

Due to the size and location of the PAL ramps, NASA has placed them at the top of the priority list for TPS verification reassessment and NDI. NASA will work to increase confidence in the existing design before RTF. Phase 2 implementation will remove or reduce the size of the PAL ramps. NASA's 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. Four options are being evaluated for redesign: no ramps, foam mini-ramp, trailing edge fence, and leading edge fence (figure 3.2-1-9).

TPS (Foam) Verification Reassessment Implementation Approach

NASA has developed a certification plan for both manual and automated TPS applications in the critical debris zones. This assessment will be performed by evaluating

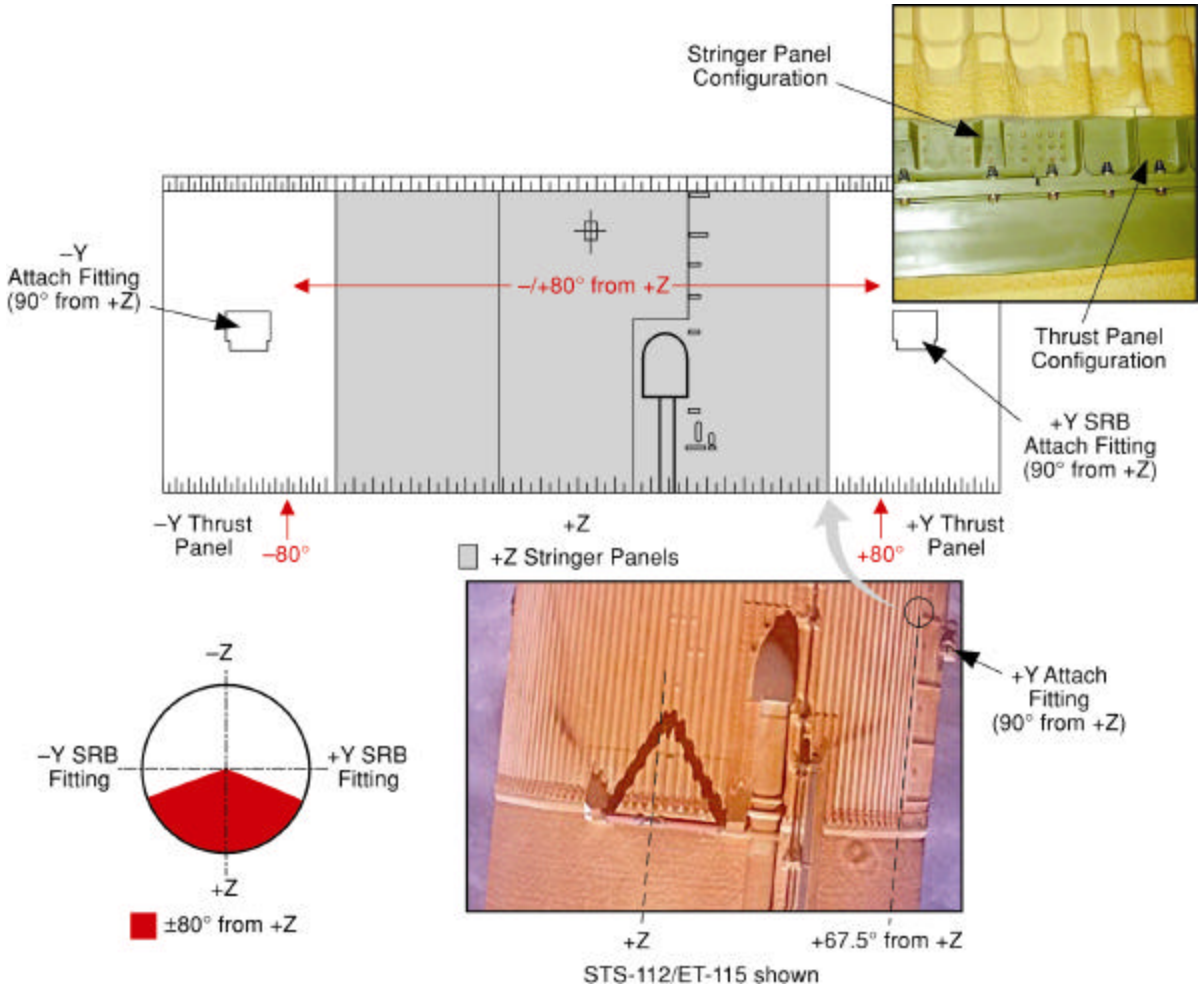


Figure 3.2-1-8. LH_2 intertank flange expanded debris zone.

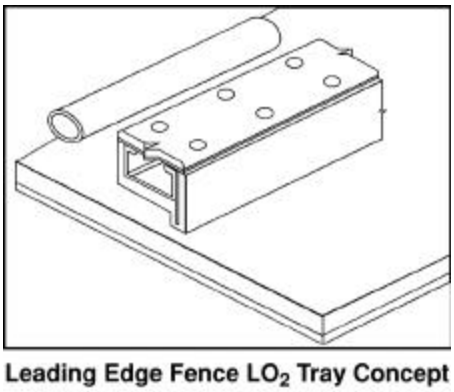
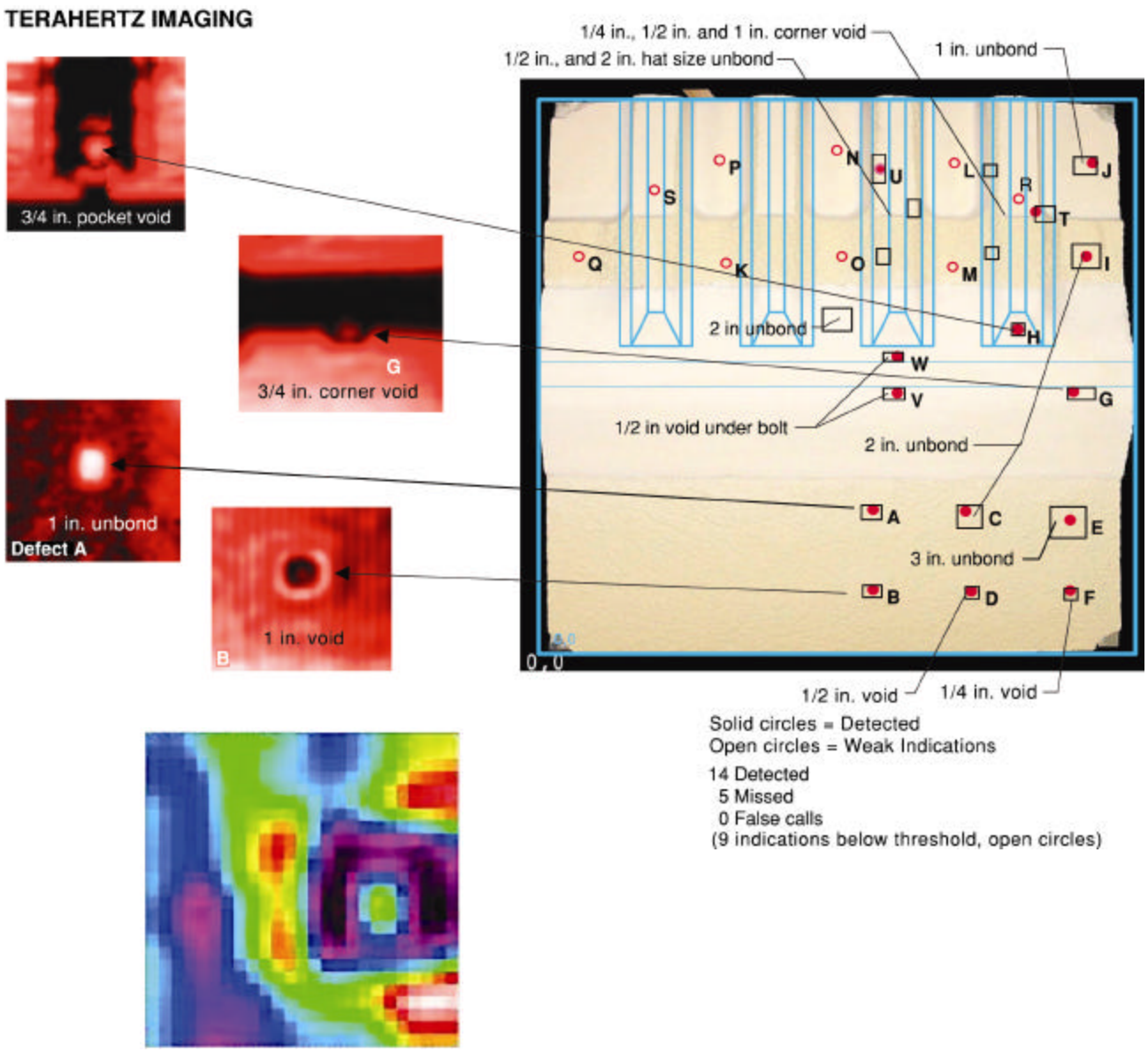


Figure 3.2-1-9. Leading edge fence LO_2 tray concept.

existing verification data and will include a review and update of the process controls applied to foam applications, especially the manual spray applications that have a greater risk of foam loss. As part of this update, NASA will ensure that at least two certified production operations personnel attend all final closeouts and critical hand-spraying procedures to ensure proper processing (ref. Recommendation 4.2-3).

NDI of Foam Implementation Approach

NASA is pursuing development of TPS NDI techniques to improve our confidence in the foam application processes. If successful, advanced NDI will provide an additional level of process verification. The initial focus for RTF will be on applying NDI to the PAL ramps.



1-in. Spray-on Foam Insulation (SOFI) to Al delamination imaged with Backscatter Radiography

Figure 3.2-1-10. Terahertz images.

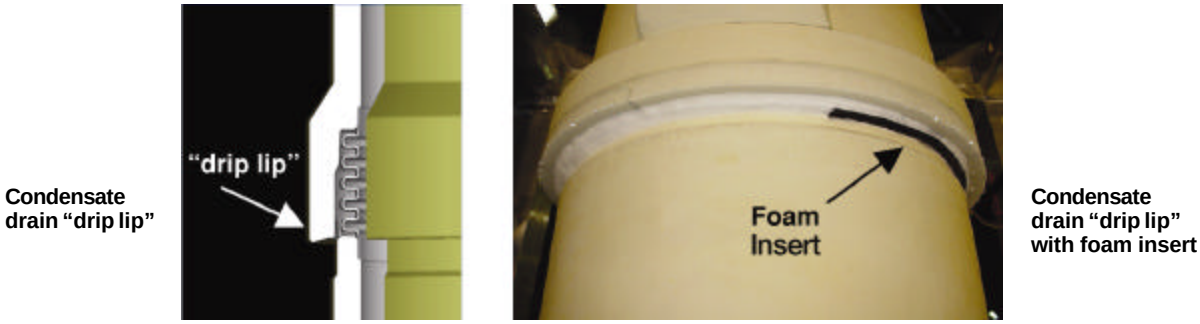


Figure 3.2-1-11. LO_2 feedline bellows "drip lip" with foam insert.

During Phase 1, NASA surveyed state-of-the-art technologies, evaluated their capabilities, down-selected, and began developing a system to detect critical flaws in ET insulation systems. At an initial screening, test articles with known defects, such as voids and delaminations (figure 3.2-1-10), were provided to determine detection limits of the various NDI methods.

After the initial screening, NASA selected the Terahertz and backscatter radiation technologies and conducted more comprehensive probability of detection (POD) tests for those applicable NDI methods. The Phase 2 activities will optimize and fully certify the selected technologies for use on the ET.

STATUS

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

ET Forward Bipod Status

NASA has successfully completed a Systems Design Review (SDR) and a Preliminary Design Review (PDR). The Critical Design Review (CDR) was held in November 2003, with a Delta CDR held in March 2004. The Delta CDR Board meeting completing the review is planned for April 2004. No significant issues remain for the bipod redesign implementation. Thermal verification tests on prelaunch ice prevention have been conducted, with an automated heater control baselined and validated based on bipod web temperature measurements. Structural verification tests have confirmed the performance of the modified fitting in flight environments. Wind tunnel testing has verified the TPS closeout performance when exposed to ascent aerodynamic and thermal environments. Remaining open work includes finalizing the TPS process control and verification approach for the foam application, and conducting an integrated bipod test using hydrogen and the tank fluid and a prototype ground control system.

LO_2 Feedline Bellows Status

NASA selected the TPS "drip lip" option to address ice formation on the LO_2 feedline bellows. The drip lip diverts condensate from the bellows and significantly reduces ice formation. This drip lip with a gasket insert (figure 3.2-1-11) was chosen as the baseline option due to the reduced implementation complexity and the ability to support both forward and aft bellows. The drip lip design is nearly complete; however, development testing remains to select the optimum gasket design and material.

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

LH_2/Intertank Flange Closeout Status

NASA has successfully determined the root cause of foam loss. Gaseous nitrogen used as a safety purge in the intertank came into contact with the extremely cold hydrogen tank dome and condensed into liquid. The liquid nitrogen migrated into the foam and then filled voids in the foam caused by unacceptable variability in the manual foam application. During ascent, the liquid nitrogen returned to a gaseous state, pressurizing the voids and causing the foam to detach.

NASA evaluated the foam loss in this region with extensive, rigorous testing and analysis. First, a series of 1′×1′ aluminum substrate panels with induced voids of varying diameters and depths below the foam surface were subjected to the vacuum, heat profiles, and backface cryogenic temperatures experienced during launch.

These tests were successful at producing divots in a predictable manner.

Follow-on testing was conducted on panels that simulated the liquid hydrogen intertank flange geometry and TPS closeout configuration to replicate divot formation in a flight-like configuration. Two panel configurations were simulated (figure 3.2-1-x), a 3-stringer configuration and a 5-stringer configuration. The panels were subjected to flight-like conditions, including front face heating, back-face cryogenics and heating (consisting of a 1.5-hour chill-down, 5-hour hold, and 8-minute heating), ascent pressure profile, and flange deflection. These tests were successful at demonstrating the root cause failure mode for foam loss from the LH_2 tank/intertank flange region.

Typical 2 ft by 2 ft Test Article

Typical 3 ft by 5 ft Test Article

Figure 3.2-1-12. LH_2/intertank flange test panel configurations .

With this knowledge, NASA evaluated the LH_2/intertank closeout design to minimize foam voids and nitrogen leakage from the intertank into the foam (figure 3.2-1-5). Several design concepts were initially considered to eliminate debris, including incorporating an active helium purge of the intertank crevice to eliminate the formation of liquid nitrogen and developing enhanced foam application procedures.

Testing indicated that a helium purge would not completely eliminate the formation of foam divots, since helium, too, could produce enough pressure in the foam voids to cause divot formation. As a result, the purge solution was eliminated from consideration.

NASA is now pursuing two other solutions. First, NASA is developing a material to fill the crevice void and processes that will ensure appropriate application of the material in this difficult-to-reach area. This material will reduce or eliminate nitrogen condensation that leads to foam divots.

Second, NASA is making progress in enhancing the TPS closeout in the LH_2 intertank area to reduce the presence of defects within the foam by using a three-step closeout procedure. This approach greatly reduces or eliminates void formations in the area of the flange joining the LH_2 hydrogen tank to the intertank.

In addition, a study has been performed at both KSC and the Michoud Assembly Facility (MAF) to reduce the potential for TPS damage during ground processing. The study identified a series of recommendations, including reducing access to critical areas of the ET, installing debris safety barriers, improving the work platforms in the area, and investigating a topcoat that would more readily show handling damage. Testing performed on eight panels using the enhanced closeout configuration

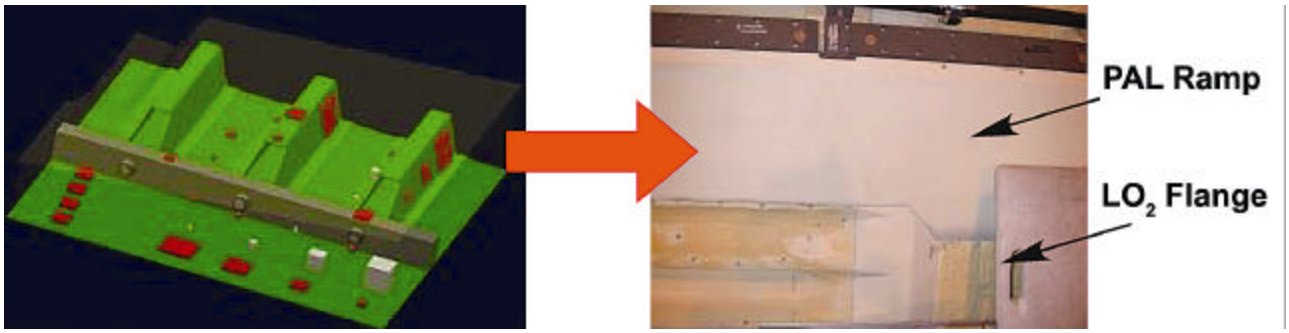


Figure 3.2-1-13. PAL ramp/flange test panel.

demonstrated the effectiveness of the closeout; there were no foam cracks or divots formed in any of the tests.

NASA now understands the failure mechanism of the foam and will implement redundant solutions. The external three-step enhanced closeout procedure reduces foam loss to a level below acceptable limits by removing critical voids in the foam. Also, the internal volume fill reduces the foam failures to small divots that are within the debris allowables by eliminating the mechanism by which the voids in the foam are pressurized and divots are formed. With these redundant solutions, NASA will be able to certify the safety of the ET foam in the flange area that connects the hydrogen tanks to the intertank.

PAL Ramps Status

Because the PAL ramps (figure 3.2-1-12) have an excellent flight history, NASA's baseline approach for RTF is to develop sufficient certification data to accept the debris risk of the existing design. This will be accomplished by evaluating the available verification data and augmenting it with additional tests, analyses, and/or inspections. This will include dissecting several existing PAL ramps to understand the void sizes produced by the existing PAL ramp TPS process. If NASA is unable to obtain sufficient data to recertify the existing PAL ramps, the Agency will remove the PAL ramp and replace it with an improved-process manual spray application. In addition, an automated PAL ramp spray is being evaluated for Phase 2 activities.

Concept design activities are in work to eliminate the PAL ramps as part of the Phase 2 activity. Redesign options include eliminating the PAL ramps altogether, implementing smaller mini-ramps, or incorporating a cable tray aero block fence on either the leading or trailing edge of the tray. NASA conducted subscale wind tunnel testing of the candidates that indicated a good potential for eliminating the foam PAL ramps. Additional wind tunnel tests are planned for this spring and summer.

TPS (Foam) Verification Reassessment Status

The SSP has established a TPS Certification Plan for the ET RTF efforts. This plan relies on a combination of inspections, tests, analyses, and demonstrations to certify each TPS application within the critical debris zone. All TPS applications will undergo visual inspection, verification of the sprays to specific acceptance criteria, and validation of the acceptance criteria. A series of materials properties tests is being performed to provide data for analysis reflecting a statistical lower bound for hardware performance. Acceptance testing, including raw and cured materials at both the supplier and the MAF, is being used to demonstrate the as-built hardware integrity is consistent with design requirements and test databases. Mechanical property tests, including plug pull, coring, and density, are being performed on the as-built hardware.

NASA is also conducting stress analysis of foam performance under flight-like structural loads and environmental conditions, with component strength and fracture tests grounding the assessments. Production-like demonstrations are being performed upon completion of all design and development efforts to verify and validate the acceptability of the production parameters. Dissection of equivalent or flight hardware is under way to determine process performance. TPS defect testing is being conducted to determine the critical defect sizes for each application. In addition, a variety of bond adhesion, cryoflex, storage life verification, cryo/load/thermal tests, and acceptance tests are under way to fully certify the TPS application against all failure modes. Finally, a Manual Spray Enhancement Team has been established to provide recommendations for improving the TPS closeout of manual spray applications.

NDI of Foam Status

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

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

The Terahertz Imaging and Backscatter Radiography systems were selected for further probability of detection (POD) testing based on the results of the initial proof-of-concept tests. The microwave system will still be evaluated during the Phase 2 development activity. This additional POD testing has been completed, but the results are still being analyzed. The preliminary results,

however, indicate that these technologies are not yet reliable enough to be used to certify TPS applications over complex geometries, such as the bipod or intertank flange regions. The technologies will continue to be developed to support PAL ramp evaluation and for Phase 2 implementation.

FORWARD WORK

- Finalize critical characteristics that could cause catastrophic damage to the Orbiter.
- Complete Delta CDR Board of bipod fitting redesign and complete the TPS verification testing.
- Implement the "drip lip" design option for the oxygen tank feedline bellows and establish the gasket design.
- Assess the data requirements to certify current PAL ramps design and develop concept designs for PAL ramps.
- Complete the TPS certification activities, including generating the materials properties, obtaining the dissection results, determining the critical debris size for each application, and completing the required assessments.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Apr 04	Complete bipod redesign Delta CDR Board
SSP	May 04	Perform NDI of PAL ramp on ET-102 (1st RTF rank)
SSP	May 04	Complete validation of LH_2/IT stringer panel closeout
SSP	Jun 04	Complete bipod TPS closeout validation
SSP	Jun 04	Complete bellows "drip lip" validation
SSP	Jul 04	Complete validation of LH_2IT thrust panel closeout
SSP	Jul 04	Complete bipod retrofit of ET-120
SSP	Sep 04	Complete flange closeout on ET-120
SSP	Oct 04	Ready to ship ET-120 to KSC

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. 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 authorized 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 developing an assessment plan for other steps to improve Orbiter hardening.

Initially, a Space Shuttle Program (SSP)-chartered planning team identified 17 specific design options that fell into eight broad design families. Further testing and analysis, combined with new data from the ongoing *Columbia* Accident Investigation Board investigation, led NASA to hone its criteria for defining and prioritizing Orbiter hardening options. Each TPS enhancement option was evaluated against the damage history, vulnerability, and criticality potential of the area and the potential safety, operations, and performance benefits of the enhancement. The team focused on those changes that achieve the following goals: increased impact durability for ascent and micrometeoroid and orbital debris impacts; increased temperature capability limits; reduced leak paths; added entry redundancy; increased contingency trajectory limits; and reduced contingency operations. These candidates were presented to the SSP PRCB, which prioritized them, eliminating seven from further consideration. Some of the remaining ten options required breaking down into smaller elements. The result was a final set of 15 Orbiter hardening options grouped into eight different design families. These results were presented to the PRCB in June 2003, including forward action plan recommendations for the revised design families (see table 3.3-2-1).

The SSP has established a plan to determine the impact resistance of both Reinforced Carbon-Carbon (RCC) and tiles in their current configurations. The SSP is also working to identify all debris sources from all Space Shuttle elements including the External Tank (ET), the Solid Rocket Boosters, and the Orbiter. Additional detail on this work can be found in SSP-14, Critical Debris Size. The SSP Systems Engineering and Integration Office is providing transport analyses to identify potential velocity, impact location, and impact angle for the debris sources. In parallel, an impact test program is being conducted to determine the impact resistance of RCC and tile using various debris sources under conditions that encompass the full range of parameters provided by the transport analysis. The data generated from this testing will be used to correlate an accurate set of analytical models to further understand the damage threat. Further testing will be conducted on specific Orbiter insulation configurations that were identified during the investigation, including the leading edge structural subsystem access panels (located directly behind the RCC) and the edge tile configuration of the main landing gear doors (MLGD).

STATUS

NASA has fully complied with the *Columbia* Accident Investigation Board (CAIB) Recommendation 3.3-2 and initiated an Orbiter hardening program to increase the Orbiter's capability to sustain minor debris damage. Orbiter hardening options that are constraints to return to flight (RTF) have either been implemented or are being implemented at this time. Other feasible hardening options that are approved by the SSP will be implemented on the vehicle when opportunities become available.

For each of the redesign options, NASA is developing a detailed feasibility assessment that will include cost and schedule for either full implementation or for the next proposed phase of the project. The Orbiter hardening options have been grouped into three categories based on the implementation phasing. The three phases are defined as follows:

Family	Redesign Proposal	Phase
WLESS	"Sneak Flow" Front Spar Protection (RCC #5 – 13)	I
	"Sneak Flow" Front Spar Protection (RCC # 1 – 4, 4 – 22)	II
	Lower Access Panel Redesign/BRI 20 Tile Implementation	III
	Insulator Redesign	III
	Robust RCC	III
Landing Gear and ET Door Thermal Barriers	Main Landing Gear Door Corner Void	I
	Main Landing Gear Door Enhanced Thermal Barrier Redesign	II
	Nose Landing Gear Door Thermal Barrier Material Change	III
	External Tank Door Thermal Barrier Redesign	III
Vehicle Carrier Panels – Bonded Stud Elimination	Forward RCS Carrier Panel Redesign – Bonded Stud Elimination	I
Tougher Lower Surface Tiles	Tougher Periphery (BRI 20) Tiles around MLGD, NLGD, ETD, Window Frames, Elevon Leading Edge and Wing Trailing Edge	III
	Tougher Acreage (BRI 8) Tiles and Ballistics SIP on Lower Surface	III
Instrumentation	TPS Instrumentation	III
Elevon Cove	Elevon Leading Edge Carrier Panel Redesign	III
Tougher Upper Surface Tiles	Tougher Upper Surface Tiles	III
Vertical Tail	Vertical Tail AFSI High Emittance Coating	III

Table 3.3-2-1. Eight Design Families Targeted for Enhancement.

Phase I options will be implemented before RTF. Phase II options will be implemented as soon as opportunities arise. Phase III consists of potential long-term options that will increase the Orbiter's impact resistance capability. These will be implemented as material development is completed and opportunities become available.

Phase I work includes elimination of MLGD corner void, elimination of Forward Reaction Control System (FRCS) bonded studs, and wing spar protection for the most vulnerable RCC panels 5 through 13. The interim MLGD corner void elimination modification was completed on Orbiter Vehicle (OV)-103 and OV-104; this modification will improve thermal protection in the forward and aft outboard corners of the MLGD cavity. OV-105 will receive the same interim modification unless NASA is able to proceed to the planned final modification with redundant thermal barriers. FRCS-bonded studs will be replaced with mechanically fastened studs for all three vehicles. This will ensure stronger attachment points for key carrier panels. This replacement is complete on OV-103. OV-104 and OV-105 are scheduled to receive the same modification in the next few months. The design for wing spar protection modification behind RCC panels 5 through 13 is complete. This modification will increase the Orbiter's ability to successfully enter the Earth's atmosphere with minor wing leading edge (WLE) damage. OV-103 and OV-104 will initially receive this modification. On OV-105, all 22 RCC panel locations on both wings will receive wing spar protection during the current Orbiter Major Modification.

Phase II work includes MLGD-enhanced thermal barrier redesign and wing spar protection for all remaining RCC panels. The designs to modify the wing spar protection behind RCC panels 1 through 4 and 14 through 22 on OV-103 and OV-104 will be finalized at the end of August 2004.

All Phase III options are under review by the SSP at this time with two exceptions that have been approved and are in development: toughened lower and upper surface tiles and Robust RCC. Work is continuing on the analysis and preliminary design phase for these two items and will be completed by January 2005. A feasibility study of the Robust RCC option will conclude in the June/July 2004 timeframe. SSP has approved the proposal to continue into formulation phase of the Robust RCC option, which will conclude in early 2005.

NASA's Orbiter Debris Impact Assessment Team is making significant progress in determining the actual damage resistance of current materials. Testing is nearly complete to establish the material properties of tile, RCC, and potential debris that may impact the TPS. These data will help NASA build models that determine damage thresholds. Impact testing of foam against tile is more than 75% complete. Ice impact testing against tile is 25% complete. The first series of ice impacts against RCC is scheduled to begin in early August. Work on the analytical models is progressing on schedule.

Damage assessment tests are ongoing at the Langley Research Center in Virginia. These tests are designed to show the structural strength of RCC after impact. Combined with thermal data from ablative testing of damaged RCC coupons at the Johnson Space Center Arc Jet Facility, the Langley data will allow development of a set of analytical models that will determine the amount of RCC damage that must be repaired to return safely to Earth. Thermal models and testing to predict damaged tile capabilities are also in work.

Initial tests of ablator material against tile showed unacceptable levels of damage; however, there is no operational history of ablator impacts, and the SSP believes that the Shuttles can be certified for no release of ablators during ascent. Consistent with these findings, SSP is formulating a new requirement that will allow no release of ablator or metal debris.

FORWARD WORK

NASA 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. NASA will review its response to this CAIB recommendation with the Stafford Covey Return to Flight Task Group.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 03 (Completed)	Initial plan reported to PRCB
SSP	Aug 03 (Completed)	Initial Test Readiness Review held for Impact Tests
SSP	Nov 03 (Completed)	Phase I Implementation Plans to PRCB (MLGD corner void, FRCS carrier panel redesign—bonded stud elimination, and WLE impact detection instrumentation)
SSP	Jan 04 (Completed)	Phase II Implementation Plans to PRCB (WLE front spar protection and horse collar redesign, MLGD redundant thermal barrier redesign)
SSP	Jul 04	Conclude feasibility study of the Robust RCC option
SSP	Aug 04	Finalize designs for modified wing spar protection between RCC panels 1–4 and 14–22 on OV-103 and OV-104
SSP	Jan 05	Complete analysis and preliminary design phase for upper and lower surface tiles and robust RCC
SSP	TBD	Phase III Implementation Plans to PRCB (include robust RCC, ET door thermal barrier redesign, elevon cove leading edge carrier panel redesign, etc.)

Columbia Accident Investigation Board

Recommendation 3.3-1

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

Note: The Stafford Covey Return to Flight Task Group held a plenary session on April 15, 2004, in Houston, Texas. NASA's progress toward answering this recommendation was reviewed and the Task Group agreed that the actions taken were sufficient to conditionally close this recommendation.

BACKGROUND

Current on-vehicle inspection techniques are 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 a destructive test program that periodically sacrifices flown RCC panels to verify by test that the actual material properties of the panels are within the predictions of the mission life model.

The RCC NDI techniques currently certified include X-ray, ultrasound (wet and dry), eddy current, and computer-aided tomography (CAT) scan. Of these, only eddy current can be done without removing components from the vehicle. While eddy current testing is useful for assessing the health of the RCC outer coating and detecting possible localized subsurface oxidation and mass loss, it reveals little about a component's internal structure. Since the other certified NDI techniques require hardware removal, each presents its own risk of unintended damage. Only the vendor is fully equipped and certified to perform RCC X-ray and ultrasound. Shuttle Orbiter RCC components are pictured in figure 3.3-1-1.

NASA IMPLEMENTATION

The Space Shuttle Program (SSP) is pursuing inspection capability improvements using newer technologies to allow comprehensive NDI of the RCC without removing it from the vehicle. A technical interchange meeting held in May 2003 included NDI experts from across the country. This meeting highlighted five techniques with potential for near-term operational deployment: (1) flash thermography, (2) ultrasound (wet and dry), (3) advanced eddy current, (4) shearography, and (5) radiography. The SSP must still assess the suitability of commercially available equipment and standards for flight hardware. Once an appropriate in-place inspection method is fielded, the SSP will be able to positively verify the structural integrity of RCC hardware without risking damage by removing the hardware from the vehicle.

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

RCC structural integrity and mass loss estimates will be validated by off-vehicle NDI of RCC components and destructive testing of flown WLE panels. All WLE panels, seals, nose caps, and chin panels 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 eddy current 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 size inherent in these metallic components. This NDI will be performed on select components from OV-103 and OV-104. Destructive evaluation of select attach hardware from both vehicles will also be undertaken. Additional requirements will be established, if necessary, upon completion of initial inspections.

STATUS

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

OV-104: The nose cap, chin panel, and all WLE RCC panel assemblies were removed from the vehicle and shipped to the vendor for complete NDI. The data analysis from this suite of inspections was completed in March 2004. Vendor inspection of all WLE panels and the analysis of the final panel are complete. Eddy current inspections of the nose cap and chin panel were completed before these components were removed, and the results compare favorably to data collected when the components were manufactured, indicating mass loss and coating degradation are within acceptable limits. Off-vehicle infrared thermography inspection at KSC is being performed to compare with vendor NDI. All findings will be cleared on a case-by-case basis through the KSC Material Report (MR) system.

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

OV-105: All OV-105 RCC components (WLE, nose cap, and chin panel) will be removed and inspected during its OMDP, which began in December 2003. Off-vehicle infrared thermography inspection at KSC is being performed to compare with vendor NDI. All findings will be cleared on a case-by-case basis through the KSC MR system.

RCC Structural Integrity: Three flown RCC panels with 15, 19, and 27 missions respectively have been destructively tested to determine actual loss of strength due to oxidation. The testing of this flown hardware to date confirms the conservativeness of the RCC material A-Allowables values used for design and projected mission life.

RCC Attach Hardware: The RCC Problem Resolution Team was given approval for a plan to evaluate attach hardware through NDI and destructive testing. Detailed hardware NDI inspection (dye penetrant, eddy current) to address environmental degradation (corrosion and embrittlement) and fatigue damage concerns have been performed on selected OV-103/104 WLE panels in the high heat and fatigue areas. No degradation or fatigue damage concerns were found.

FORWARD WORK

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

The near-term advanced on-vehicle NDI techniques are in development, as are process and standards for their use. Decisions on long-term NDI techniques (those requiring more than 12 months to develop) will be made after inspection criteria are better established. Data storage, retrieval, and fusion with CATIA CAD models is planned to enable easy access to NDI data for archiving and disposition purposes.

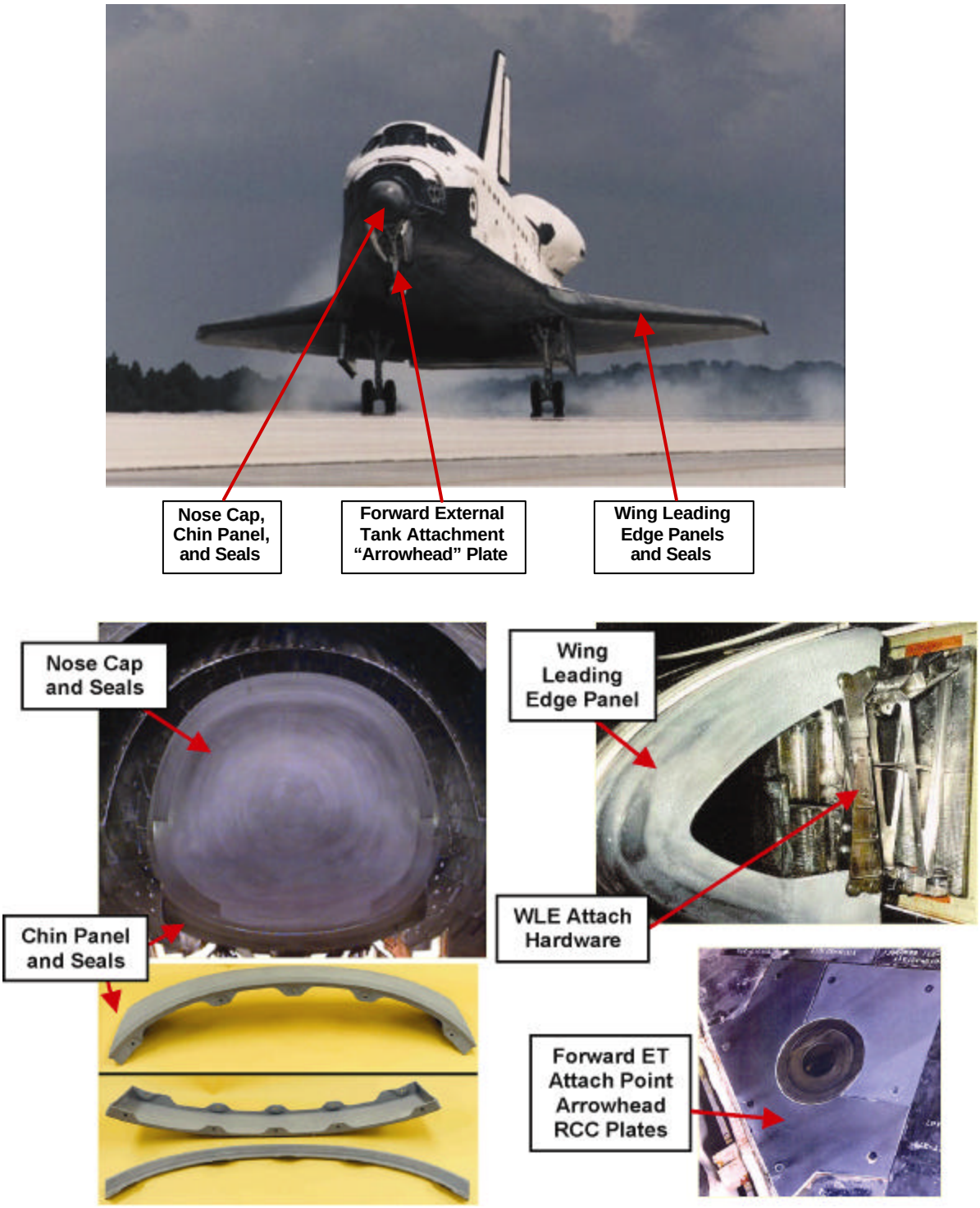


Figure 3.3-1-1. Shuttle Orbiter RCC components.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Sep 03 (Completed)	OV-104 WLE RCC NDI analysis complete
SSP	Oct 03 (Completed)	Completion of NDI on OV-104 WLE attach hardware
SSP	Dec 03 (Completed)	OV-103 chin panel NDI
SSP	Jan 04 (Completed)	Report viable on-vehicle NDI candidates to the SSP
SSP	Jan 04 (Completed)	Completion of NDI on OV-103 WLE attach hardware
SSP	Feb 04 (Completed)	OV-103 nose cap NDI analysis
SSP	Feb 04 (Completed)	OV-104 chin panel NDI analysis
SSP	Apr 04 (Completed)	OV-104 nose cap NDI analysis
SSP	Jul 04	OV-103 WLE RCC NDI analysis

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 accepts, that an on-orbit Thermal Protection System (TPS) inspection and repair capability is an important part of the overall TPS risk mitigation plan. Currently, Shuttle flights are planned only to the International Space Station (ISS), and, as outlined in the Vision for Space Exploration, NASA will retire the Space Shuttle fleet following assembly of the ISS.

There are additional risks associated with creating and deploying a fully autonomous inspection capability without ISS resources. Therefore, NASA has decided to focus its development of TPS inspection and repair on those capabilities that enhance the Shuttle's suite of assessment and repair tools while taking full advantage of ISS resources.

The Space Flight Leadership Council has directed the Space Shuttle Program (SSP) to focus its efforts on developing and implementing inspection and repair capability appropriate for the first return to flight missions using ISS resources as required. NASA will focus its efforts on mitigating the risk of multiple failures (such as an ISS mission failing to achieve the correct orbit or dock successfully, or the Orbiter being damaged during or after undocking and suffering critical TPS damage) through maximizing the Shuttle's ascent performance margins to achieve ISS orbit, using the docked configuration to maximize inspection and repair capabilities, and flying protective attitudes following undocking from the ISS. However, NASA will continue to analyze the relative merit of different approaches to mitigating the risks identified by the *Columbia* Accident Investigation Board.

This approach to avoiding unnecessary risk has also led NASA to recognize that autonomous missions carry a higher risk than ISS missions. A brief summary of the additional risks associated with autonomous missions is described below:

1. *Lack of Significant Safe Haven*. The inability to provide a "safe haven" while inspection, repair, and potential rescue are undertaken creates additional risk in autonomous missions. NASA estimates that a typical Space Shuttle flight crew of seven astronauts could stay aboard the ISS for up to 68 days if required to do so by an emergency situation on the Space Shuttle. This safe haven capability allows the flight crew and ground teams to consider all options, determine the best course of action, take the time required to understand the cause of the failure and affect repairs, or send an appropriate rescue vehicle with the right equipment to bring the crew home. For an autonomous mission, however, the crew would be limited to an additional on-orbit stay of no more than two to four weeks, depending on how remaining consumables are rationed.

2. *Unprecedented Double Workload for Ground Launch and Processing Teams*. Because the rescue window for an autonomous mission is only two to four weeks, NASA would be forced to process two vehicles for launch simultaneously to ensure timely rescue capability. Any processing delays to one vehicle would require a delay in the second vehicle. The launch countdown for the second launch would begin before the actual launch of the first vehicle.

This short time period for assessment is a serious concern. It would require two highly complex processes to be carried out simultaneously, and it would not permit thorough assessment by the launch team, the flight control team, and the flight crew.

3. *No Changes to Cargo or Vehicle Feasible*. Because of the very short timeframe between the launch of the first vehicle and the requirement for a rescue flight, no significant changes could reasonably be made to the second vehicle. This means that it would not be feasible to change the cargo on the second Space Shuttle to support a repair to the first Shuttle, add additional rescue hardware, or make vehicle modifications to avoid whatever situation caused the need for a rescue attempt in the first place. Not having sufficient time to make the appropriate changes to the rescue vehicle or the cargo could add significant risk to the rescue flight crew or to crew transfer. The whole process would be under acute schedule pressure and undoubtedly many safety and operations waivers would be required.

4. *Rescue Mission*. Space Shuttles routinely dock with the ISS, and Soyuz evacuation procedures are supported by extensive training, analysis, and documentation. A rescue from the ISS, with multiple hatches, airlocks, and at least one other vehicle available (Soyuz), is much less complex and risky than that required by a stranded Space Shuttle being rescued by a second Space Shuttle. When NASA first evaluated free-space transfer of crew, which would be required to evacuate the Shuttle in an autonomous mission, many safety concerns were identified. This analysis would need to be done again, in greater detail, to identify all of the potential issues and safe solutions.

5. *TPS Repair*. NASA's current planned TPS repair method for an ISS-based repair uses the ISS robotic arm to stabilize an extravehicular activity (EVA) crew person over the worksite. This asset is not available for an autonomous mission, so NASA would have to finish development of an alternate method for stabilizing the crewmember. Such a concept is in development targeting 2006, when it will be needed for ISS-based repairs also. Solving this problem before 2006 represents a challenging undertaking.

NASA IMPLEMENTATION

Note: the remainder of this section refers to inspection and repair during nominal Shuttle missions to the ISS.

Taken together, TPS inspection and repair represent one of the most challenging and extensive return to flight tasks. NASA's near-term TPS risk mitigation plan calls for: Space Shuttle vehicle modifications to eliminate the liberation of critical debris; fielding improved ground and vehicle-based cameras and impact sensors for debris detection and damage assessment; on-orbit TPS surveys using the 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 EVA are under development. The combination of these capabilities will help to ensure a low probability that critical damage will be sustained, while increasing the probability any damage that does occur can be detected and the consequences mitigated in flight.

NASA's long-term TPS risk mitigation steps will refine and improve all elements of the near-term plan, ensuring an effective inspection and repair capability.

Inspection

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

A combination of Shuttle and ISS assets will be capable of imaging critical TPS damage in all areas. The Orbiter

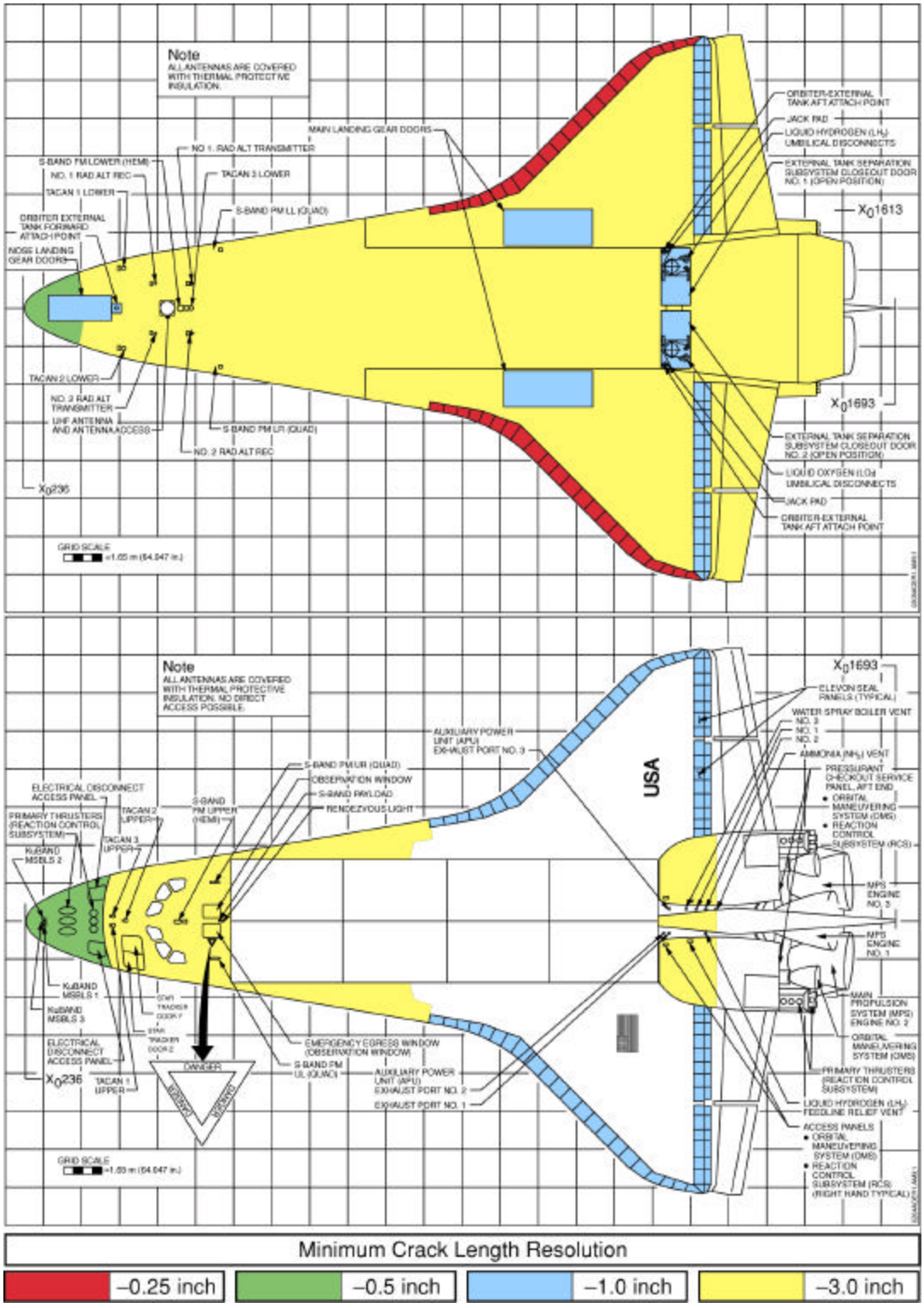


Figure 6.4-1-1. Preliminary TPS damage inspection criteria.

Boom Sensor System (OBSS) Project is currently developing a sensor system that will be flown on the first flight and used to inspect the wing leading edge (WLE) and the nose cap. The system will also be used to inspect and measure the depth of any critical TPS damage that other inspection devices, such as Station-based cameras, have detected. The OBSS consists of sensors on the end of a boom system that is launched installed on the starboard sill. The boom (figure 6.4-1-2) will be used in conjunction with the SRMS to inspect the WLE RCC and nose cap prior to docking with ISS. After the Orbiter is docked to ISS, the OBSS will be used to further inspect any suspect areas on the Orbiter. In addition, the boom will have the capability to support an EVA crewmember if needed to support the inspection activities.

In February 2004, the SSP established an Inspection Tiger Team to review all inspection capabilities and to develop a plan to most effectively integrate these capabilities before return to flight. The tiger team succeeded in producing a comprehensive in-flight inspection, imagery analysis, and damage assessment strategy that will be implemented through the existing flight-planning process. The best available cameras and laser sensors suitable for detecting critical damage in each TPS zone will be used in conjunction with digital still photographs taken from ISS during the Orbiter's approach. The pitch-around maneuver required to facilitate this imagery has been developed and is pictured in figure 6.4-1-3. Shuttle crews are currently training to fly this maneuver. The tiger team strategy also laid the foundation for a more refined impact sensor and imagery system following the first two successful flights. This plan is being enhanced to clearly establish criteria for transitioning from one suite of

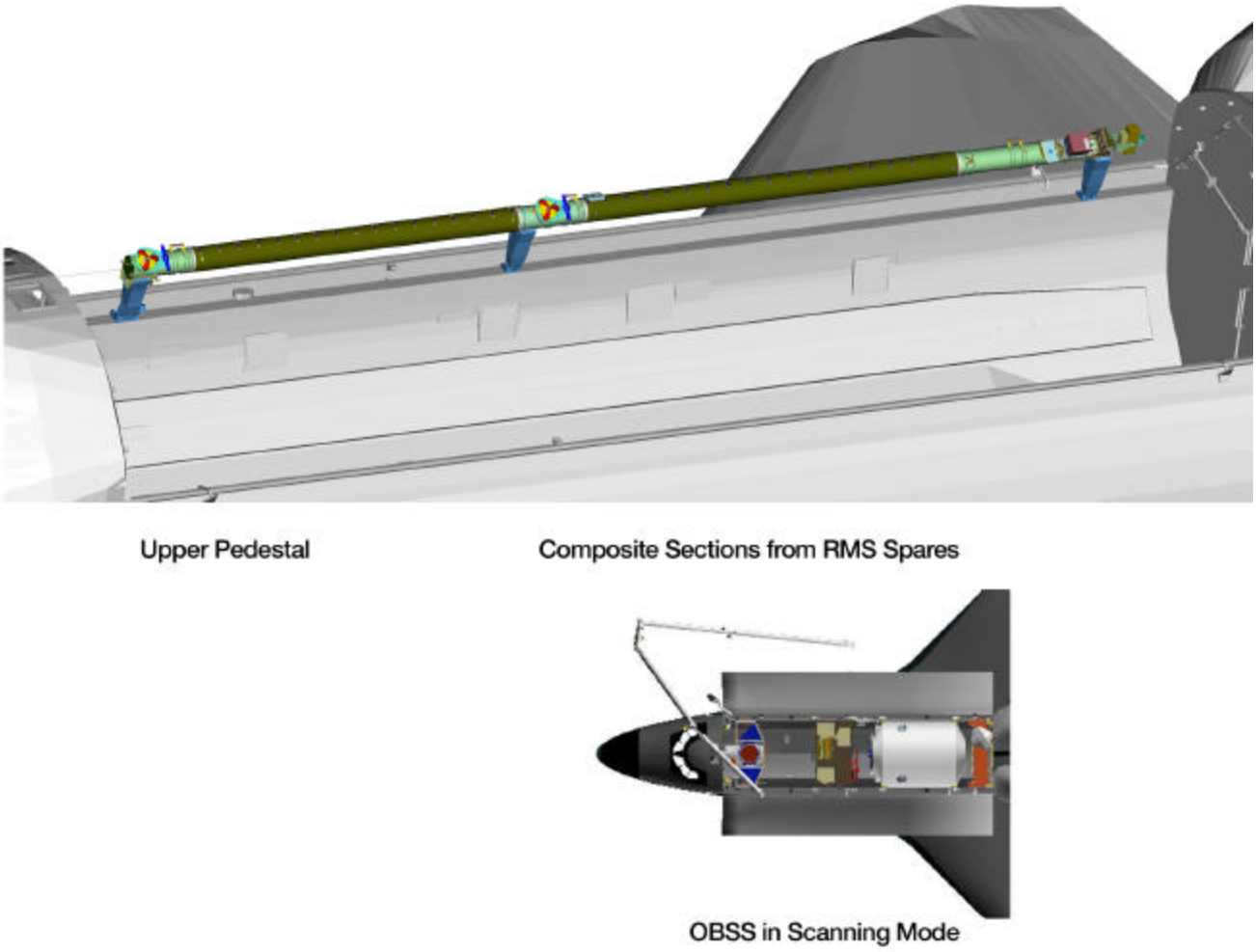
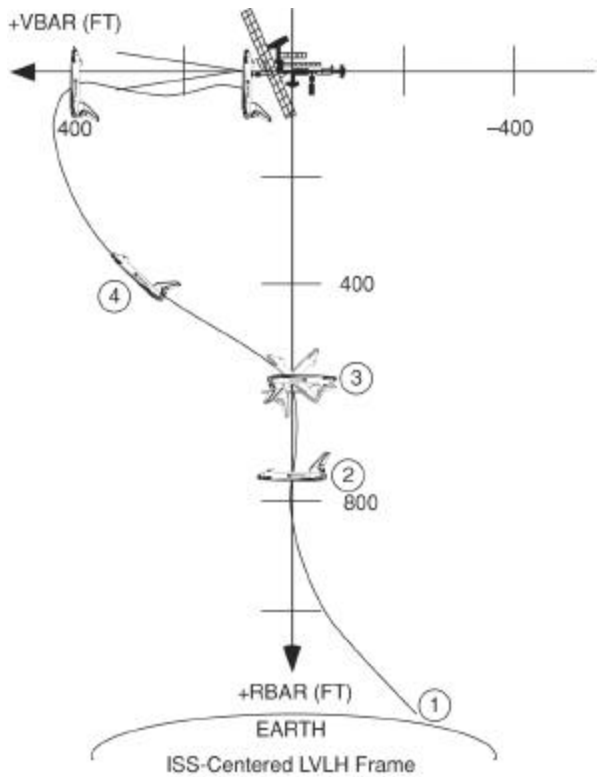


Figure 6.4-1-2. Orbiter Boom Sensor System (OBSS).



	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 6.4-1-3. Orbiter pitch-around for inspection and approach to ISS.

inspection capabilities to another, and the timeline for these transitions.

Along with the work of the tiger team, the Shuttle Engineering and Integration Office began development of a TPS Readiness Determination Operations Concept. Most critically, this document will specify the process for collecting, analyzing, and applying the diverse inspection data in a way that ensures effective and timely mission decision-making.

Repair

TPS Repair Access

NASA has developed a combined SRMS and SSRMS "flip around" operation to allow TPS repairs while the Shuttle is docked to the ISS; this operation involves turning the Shuttle into a belly-up position that provides arm access to the repair site. As depicted in figure 6.4-1-4, 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 used to position the crewmember 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. This technique provides access to all TPS surfaces without the need for new equipment. The procedure will work through ISS flight 1J (which will add the Japanese Experiment Module to the ISS on orbit assembly). After ISS flight 1J, the ISS grapple fixture required to support this technique will be blocked, and new TPS repair access techniques will need to be developed.

RCC Repair

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 RCC repair project is pursuing three complementary repair concepts that together will enable repair of a wide variety of potential RCC damage: Plug Repair; Rigid Wrap Repair; and Crack Repair. Plug Repair consists of an insert intended to repair holes in the WLE with sizes from 0.5 in. to 4 in. in diameter. The Rigid Wrap is a complete overwrap for a given RCC panel intended to repair any catastrophic damage detected on a given panel (figure 6.4-1-5). Crack Repair uses a material application intended to fill cracks and small holes in the WLE. All three concepts are expected to have limitations in terms of damage characteristics, damage location, and testing/analysis. Schedules for design, development, testing, evaluation, and production of these concepts are in work.

This effort is still in the concept definition phase and is much less mature than the tile repair material study. NASA is evaluating concepts across six NASA centers, 11 contractors, and the United States Air Force Research Laboratory.

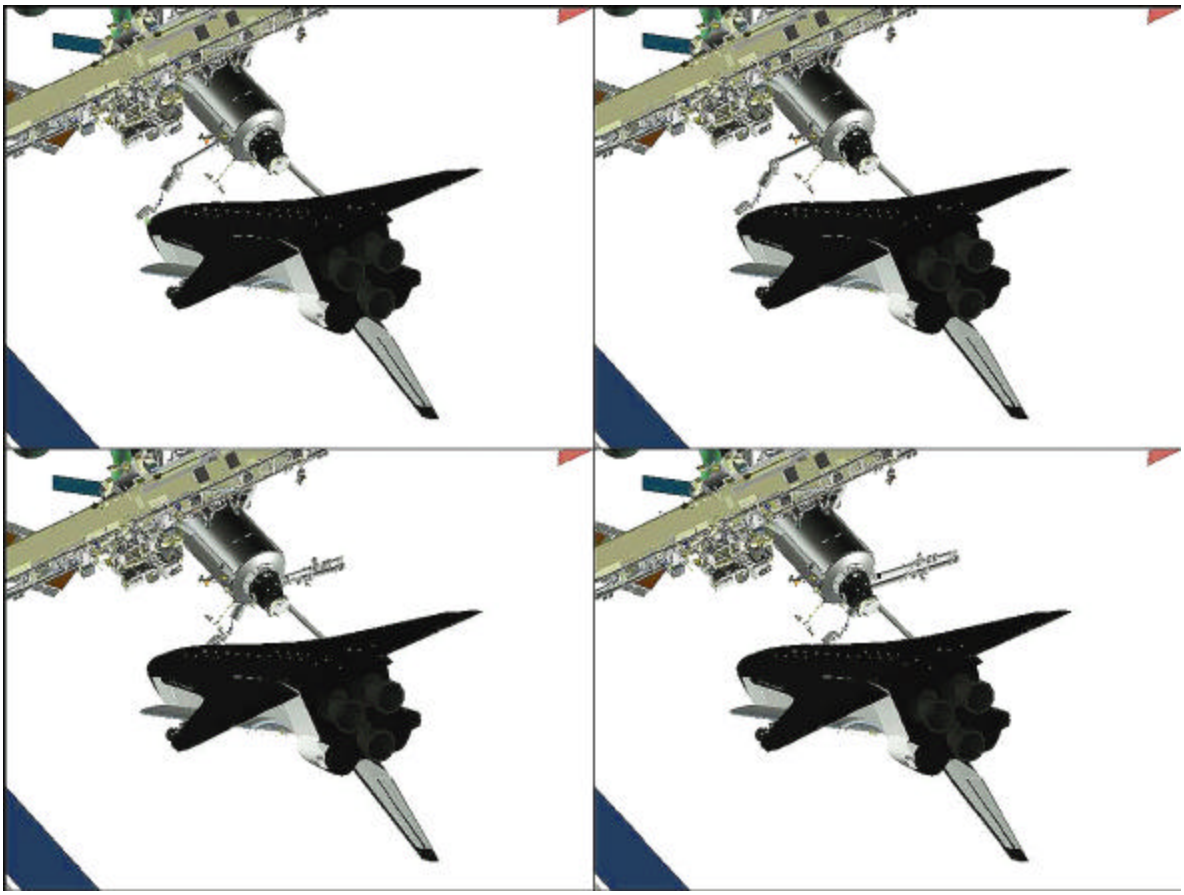


Figure 6.4-1-4. Proposed method for providing EVA access during TPS repair on an ISS flight.

Although we are aggressively pursuing RCC repair, it is too early in development to forecast a completion date.

Tile Repair

NASA has made significant progress in developing credible tile repair processes and materials. An existing, silicone-based, cure-in-place ablator has shown positive results in development testing. A manufacturing process change appears to control a foaming problem observed during early 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. This tile repair material has now transitioned to characterization and qualification testing. 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. Additional arc jet, radiant heating, thermal-vacuum, and KC-135 zero-gravity tests are scheduled to confirm that this material will survive the entry environment when applied using the proposed repair techniques. Assuming the continued testing of the existing ablator is successful, the tile repair materials and tools should be ready in the December 2004–March 2005 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. The photos in figure 6.4-1-6 show a test sample of this material before and after an arc jet test run to 2300°F. Figure 6.1-4-7 shows

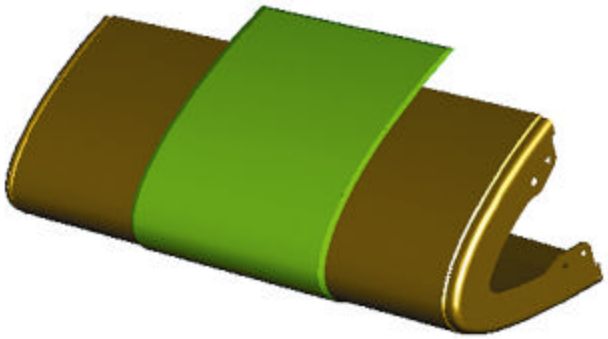


Figure 6.4-1-5. Wrap concept design.

Figure 6.4-1-6. Tile repair material before, during, and after arc jet testing at 2300°F.

a side view of a plug (similar to a wall anchor) that is ready to insert and results from arc jet testing.

NASA is developing EVA tools and techniques for TPS repair. NASA has already developed prototype specialized tools for applying and curing tile repair materials. The lessons learned from this process will enable similar development of RCC repair tools in the future. We are also beginning to develop new and innovative EVA techniques for working with the fragile Shuttle TPS system while ensuring that crew safety is maintained. EVAs for TPS repair represent a significant challenge; the experiences gained through the numerous complex ISS construction tasks performed over the past several years are contributing to our ability to meet this challenge.

STATUS

The following actions have been completed:

- Quantified SRMS, SSRMS, and ISS digital still camera inspection resolution
- Feasibility analyses for docked repair technique using SRMS and SSRMS
- Air-bearing floor test of overall boom to SRMS interface
- OBSS conceptual development, design requirements, and preliminary design review
- Engineering assessment for lower surface radio frequency communication during EVA repair
- Simplified Aid for EVA Rescue (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
- Review of all Shuttle systems for compatibility with the docking repair scenario

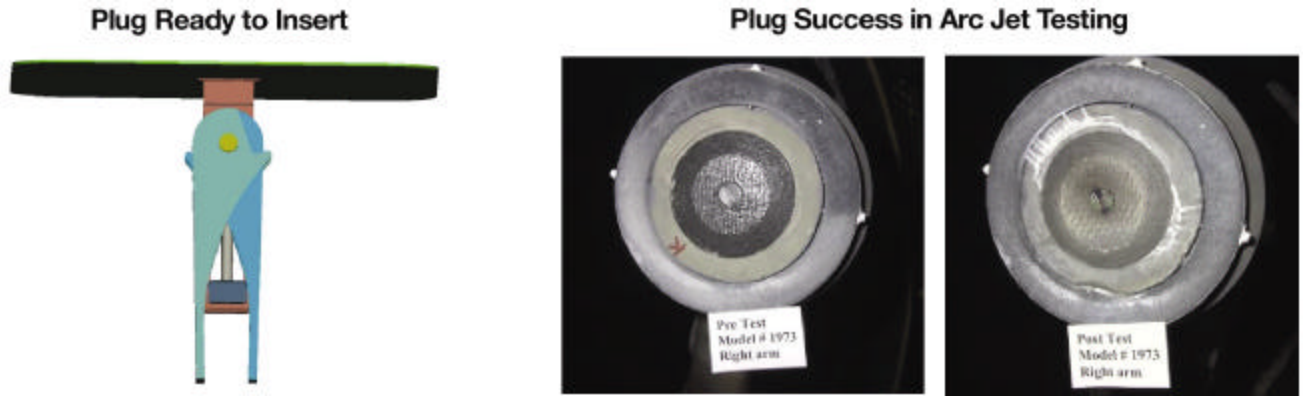


Figure 6.4-1-7. Plug success in arc jet testing.

Figure 6.4-1-8. Integrated operations concepts for inspection and repair.

- Inspection Tiger Team strategy formulated
- Selected three complementary RCC repair techniques for further development
- Developed the inspection and repair of the RCC and tile operations concept (figure 6.1-4-8)

Initial development of the RCC rigid wrap indicated significant technical challenges. As a result, the SSP recommended that the rigid wrap be deferred in favor of an expanded research and development project to develop alternative repair techniques for large holes. On June 9, 2004, the Space Flight Leadership Council approved the SSP recommendation and directed the SSP to develop plug and crack repair to the greatest extent practicable for the March 2005 launch of STS-114.

FORWARD WORK

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

NASA will continue to develop OBSS hardware development and operational procedures.

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

Final detailed analyses are in work to optimize Shuttle attitude control and redocking methods during repair.

Detailed procedures for techniques and systems configuration will be published as part of the Flight Operations Review data package in August 2004.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	1-G suited and vacuum testing begins on tile repair technique
SSP	Aug 03 (Completed)	Generic crew and flight controller training begins on inspection maneuver during approach to ISS
SSP	Aug 03 (Completed)	KC-135 testing of tile repair technique
SSP	Oct 03 (Completed)	Start of RCC repair concept screening tests
SSP	Dec 03 (Completed)	Tile repair material selection
SSP	Jun 04 (Completed)	Baseline ISS in-flight repair technique and damage criteria
SSP	Jul 04	Human thermal-vacuum, end-to-end tile repair tests
JSC/Mission Operations Directorate	Aug 04	Formal procedure development complete for inspection and repair
SSP ISS Program	Feb 05	All modeling and 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 enter 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's efforts to define minor and critical damage using Reinforced Carbon-Carbon (RCC) foam impact tests, arc jet tests, and wind tunnel tests are covered in SSP Action 14.

NASA IMPLEMENTATION

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 deorbit, and trajectory shaping. Additionally, NASA is considering contingency flight design options including expanding entry design constraints and expanding the angle-of-attack profile.

STATUS

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

Review of the STS-107 investigation evaluations on different entry trajectory options has been completed. Evaluations of options within certification were repeated with entry trajectory conditions consistent with International Space Station missions. Similar trends were noted. Both studies showed only minor improvements in the entry thermal environment for RCC. A preliminary evaluation of contingency flight design options has begun. This high-level evaluation shows the potential for more noticeable improvements to the entry thermal environment; however, an understanding of increased risk in other entry trajectory parameters, as well as a better understanding of thermal effects on the overall vehicle, is needed to formulate recommendations.

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	Jul 04	Vehicle/trajectory design operational adjustment recommendation
SSP	Dec 04	Contingency flight design options recommendation

Columbia Accident Investigation Board

Recommendation 3.3-4

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

BACKGROUND

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

NASA IMPLEMENTATION

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

STATUS

Panel 8L (OV-104 with 26 flights) has been tested and the data are being distributed to the teams performing the analysis of material properties. As expected, data so far have shown slightly degraded properties when compared with new material, but well above the allowables used in the mission life models for RCC. Material property data will also be collected from the remnants of panels 10L and 12R. Panel 6L (OV-103 with 30 flights) will be used to perform thermal and mechanical testing for material susceptibility to crack propagation during the flight envelope. Panel 9L (OV-103 with 27 flights) was severely cracked during a series of full-scale, damage threshold determination impact tests and the cracked sections will be cut out and used for damage tolerance assessment in the arc jet facility. A new panel 9L along with panel 10L (OV-103 with 30 flights) will be used to determine the impact capability of the RCC. Panel 9R (with 30 flights) from OV-103 will be destructively tested, using methods similar to those used on Panels 10L and 12R, to compare its material properties to the analytical model and to add to the database.

FORWARD WORK

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

SCHEDULE

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

Columbia Accident Investigation Board

Recommendation 3.3-5

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

Note: NASA has closed this recommendation through the formal Program Requirements Control Board (PRCB) process. The following summary details NASA's response to the recommendation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board recommendation.

BACKGROUND

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

NASA IMPLEMENTATION

Before return to flight (RTF), Kennedy Space Center (KSC) will enhance the launch pad structural maintenance program to reduce RCC zinc oxide exposure to prevent zinc-induced pinhole formation in the RCC (figure 3.3-5-1). The enhanced program has four key elements. KSC will enhance the postlaunch inspection and maintenance of the structural coating system, particularly on the rotating service structure. Exposed zinc primer will be recoated to prevent liberation and rainwater transport of zinc-rich compounds. Additionally, 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. NASA will also investigate options to improve the physical protection of Orbiter RCC hardware and implement a sampling program to monitor the effectiveness of efforts to inhibit zinc oxide migration on all areas of the pad structure.

In the long term, the RCC Problem Resolution Team will continue to identify and assess potential mechanisms for RCC pinhole formation. Options for an enhanced pad wash-down system will be implemented on Pad A in fiscal year (FY) 2005 and on Pad B in FY 2006.

STATUS

NASA is pursuing enhanced inspection, structural maintenance, wash-down, and sampling options to reduce zinc leaching. Changes to applicable work authorization documents are being formulated and will be incorporated before RTF. The options developed were presented to the Space Shuttle PRCB in April 2004 and approved for implementation.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Dec 03 (Completed)	Complete enhanced inspection, maintenance, wash-down, and sampling plan
SSP	Apr 04 (Completed)	Present to the PRCB

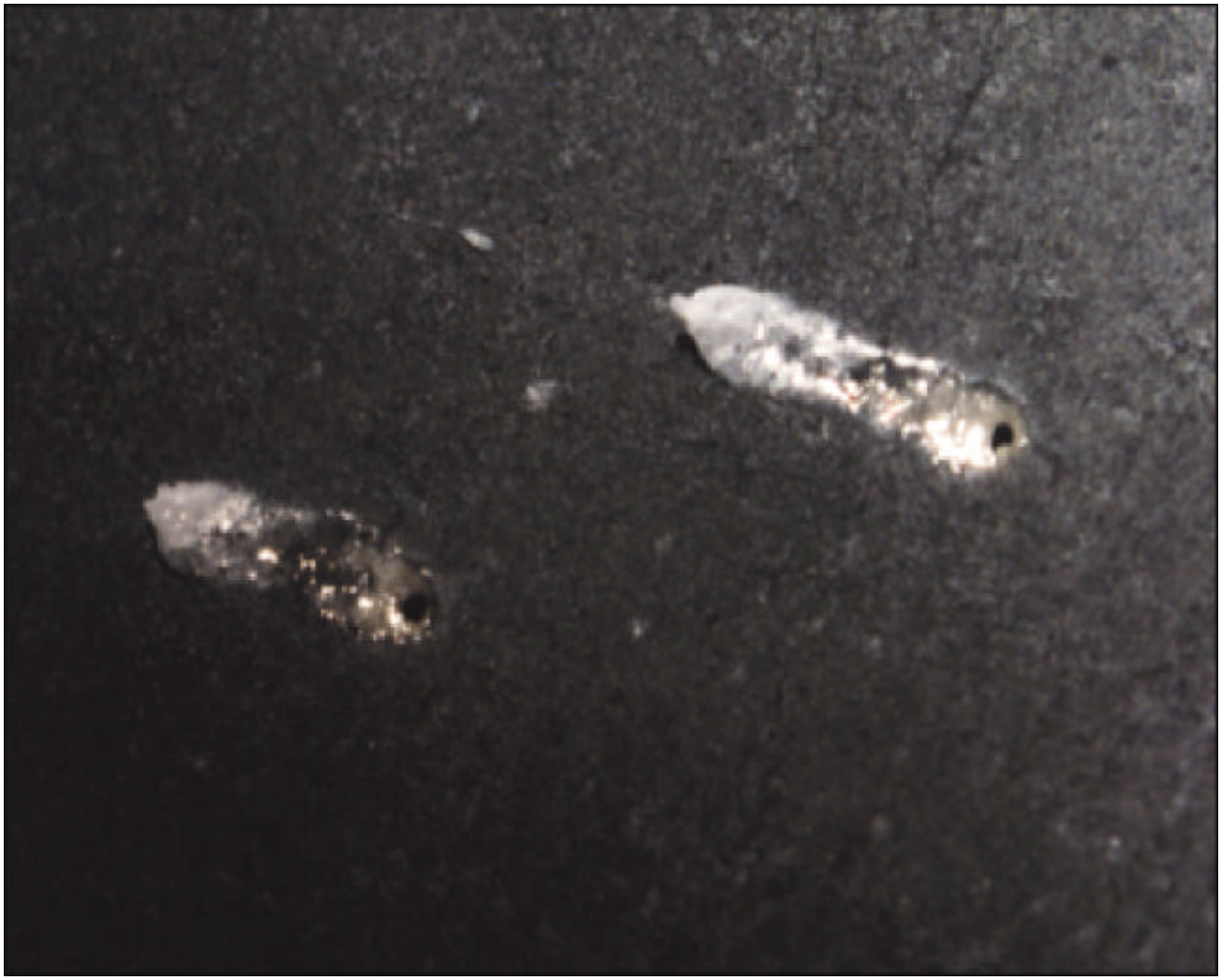


Figure 3.3-5-1. RCC pinholes.

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, as high as 100 flights depending on the specific location. The "hot" panels (6 through 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, six additional panel assemblies are required to have a complete spare ship-set. The last of these panels will be available no later than March 2005. Additional panel assemblies over and above the one ship-set required will be considered.

STATUS

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

FORWARD WORK

The Space Shuttle Program (SSP) Leading Edge Subsystem Prevention/Resolution Team has developed a prioritized list of additional spare panels over and above the one ship-set of spare panels currently required to support the Program. The total procurement will be based on the requirements for the spare ship-set, impact tolerance testing, and the development of damage repair techniques. The manufacturing schedule options will be presented to the Logistics Operations Configuration Control Board in April 2004 for decision.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 03 (Completed)	Authorization to build six panels to complete ship-set
SSP	Jun 04	Program Requirements Control Board decision on additional space RCC panels
SSP	Mar 05	Delivery of six additional panels

Columbia Accident Investigation Board

Recommendation 3.8-2

Develop, validate, and maintain physics-based computer models to evaluate Thermal Protection System damage from debris impact. 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 upgrades 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

In addition to improving Crater and other predictive impact models, 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.

The SSP elements will investigate the adequacy of existing analysis tools to ensure that limitations or constraints in 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 such as 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 analytical capability.

An integrated analysis and testing approach is being used to develop the models 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.

Most SSP models and tools have been reviewed for accuracy and completeness. The remaining reviews will be completed within the next several months.

FORWARD WORK

All SSP elements presented initial findings and plans for completing their assessments to the ICB in July 2003, and are continuing to evaluate the adequacy of their math models and tools. We will assess the adequacy of Bumper (ref. 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 (Completed)	Report math models and tools assessment initial findings and plans to ICB and PRCB
SSP	Sep 03 (Completed)	Integrated plan for debris transport, impact assessment, and TPS damage modeling
SSP	Aug 03/ Aug 04	Report math models and tools assessment final findings and recommendations to ICB and PRCB
SSP	Dec 03 (Completed)	Reverification/validation of MMOD risk models
SSP	Apr 04	Verification/validation of new impact analysis tools
SSP	Dec 04	TPS impact testing and model development

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 is developing an integrated suite of improved imagery, radar, on-orbit inspection, and on-board 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 under development includes:

- Ground-based ascent imagery
- Aircraft-based ascent imagery
- Land-based and ship-based tracking radar, including high-resolution radar capable of tracking debris during ascent (SSP-12)
- 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. 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 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 is improving ground assets for viewing launch activities. These evaluations include various still and motion imagery capabilities, the best location for each camera, and day versus night coverage.

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

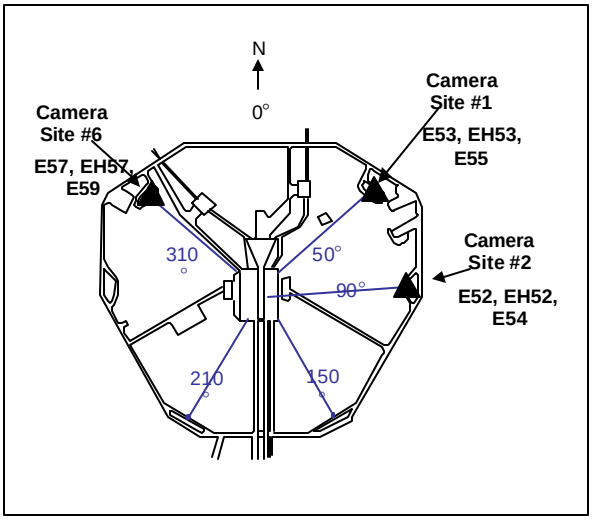


Figure 3.4-1-2. Short-range camera sites.

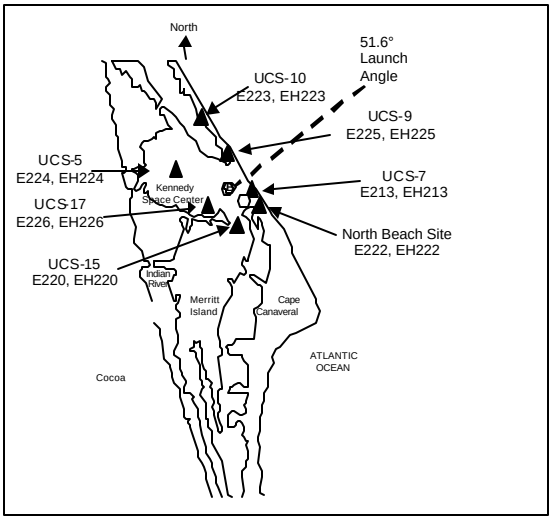


Figure 3.4-1-3. Medium-range tracker sites.

NASA IMPLEMENTATION

To ensure that three useful views of the Shuttle vehicle can be obtained during ascent, initially 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 on fixed mounts, while others are mounted on mobile trackers. NASA, with the U.S. Air Force, will optimize the camera configuration for each flight. We will evaluate the locations 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, medium-range, and long-range tracking cameras are as shown in figures 3.4-1-2, 3.4-1-3, and 3.4-1-4, respectively. Existing cameras will be moved, modernized, and augmented to comply with new requirements.

STATUS

NASA has begun shipping the 14 existing trackers to the vendor for refurbishment. This work will be ongoing, beyond return to flight, until refurbishment of all trackers is complete (expected completion 2006). Trackers and optics will be borrowed from other ranges to support launch until the refurbished assets are delivered.

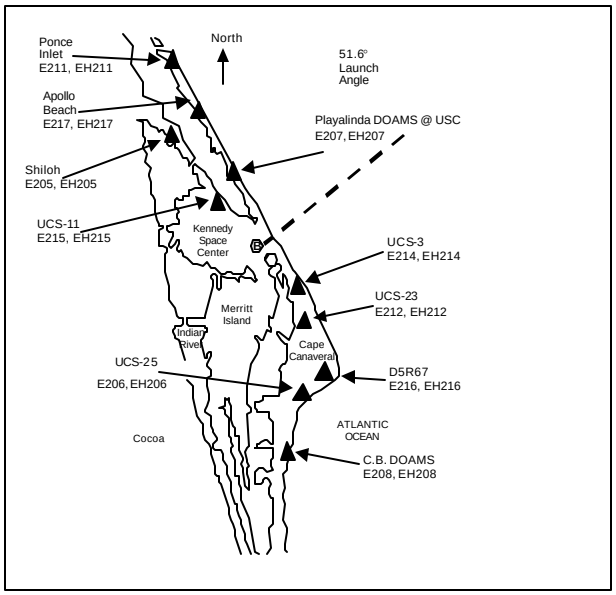


Figure 3.4-1-4. Long-range tracker sites.

NASA is procuring additional cameras to provide increased redundancy and refurbishing existing cameras. For instance, the U.S. Air Force-owned optics for the Cocoa Beach, Florida, camera (the "fuzzy camera" on STS-107) have been returned to the vendor for repair. We have completed an evaluation on current and additional camera locations, and refined the requirements for camera sites. Additional sites have been picked and are documented in the Launch and Landing Program Requirements Document 2000, sections 2800 and 3120. Additional operator training will be provided to improve tracking, especially in difficult weather conditions.

NASA has approved the development and implementation of an aircraft-based imaging system known as the WB-57 Ascent Video Experiment (WAVE) to provide both ascent and entry imagery. The use of an airborne imaging system will provide opportunities to observe the vehicle during days of heavier cloud cover and in areas obscured from ground cameras by the exhaust plume following launch.

The primary hardware for the WAVE consists of a 32-in. ball turret system, manufactured by Southern Research Institute, mounted on the nose of two WB-57 aircraft (figure 3.4-1-5). The use of two aircraft flying at an altitude of 60,000 ft will allow a wide range of coverage with each airplane providing imagery over a 400-mi path. The entry imaging program will involve the use of a Navy P3 aircraft to provide imagery during the later stages of entry.

Figure 3.4-1-5. WB-57 aircraft.

The WAVE ball turret houses an optical bench that provides a location for installation of multiple camera systems (high-definition television, infrared). The optics consist of a 5-m fixed focal length lens with an 11-in. diameter, and the system can be operated in both autotrack and manual modes.

WAVE will be used on an experimental basis during the first two Space Shuttle flights following return to flight. Based on an analysis of the system's performance and quality of the products obtained, following these two flights NASA will make the decision on whether to continue use of this system on future flights. The Critical Design Review for the WAVE was completed June 30-July 1, 2004.

NASA's plan for use of ground-based wideband radar and ship-based Doppler radar to track ascent debris is addressed in Part 2 of this document under item SSP-12, Radar Coverage Capabilities and Requirements.

FORWARD WORK

NASA is evaluating improving camera optics, upgrading tracking capabilities, and adjusting camera settings. Ship-based and airborne sensors are also under development.

The Space Shuttle Program (SSP) is addressing hardware upgrades, operator training, and quality assurance of ground-based cameras according to the integrated imagery requirements assessment.

NASA is developing 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 Space Shuttle Main Engines are starting.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03 (Completed)	Program Approval of Ground Camera Upgrade Plan
SSP	Sep 03 (Completed)	Program Approval of funding for Ground Camera Upgrade Plan
SSP	Feb 04 (Completed)	Baseline Program Requirements Document Requirements for additional camera locations
SSP	May 04 (Completed)	Begin refurbishment of 14 existing trackers. Will be ongoing until all refurbishment of all trackers is complete (expected 2006). Trackers and optics will be borrowed fromother ranges to support launch until the assets are delivered
SSP	Jul 04 (Completed)	Critical Design Review for WAVE airborne imaging system
SSP	Aug 04	Baseline revised Launch Commit Criteria
SSP	Feb 05	Acquire new optics and cameras
SSP	Mar 05	Acquire six additional trackers, optics, cameras, and spares for all systems. Trackers will be borrowed from other ranges to support launches until the vendor delivers the new KSC trackers

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

NASA agrees that it is critical to verify the performance of the External Tank (ET) modifications to eliminate ascent debris. Additionally, real-time downlink of this information may help in the early identification of some risks to flight. The Space Shuttle currently has two on-board high-resolution cameras that photograph the 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 for image analysis, NASA is replacing the 35mm film camera in the Orbiter umbilical well with a high-resolution digital camera and equipping the flight crew with a handheld digital still camera with a telephoto lens. Umbilical and handheld camera images will be downlinked after safe orbit operations are established.

NASA has defined the Enhanced Launch Vehicle Imaging System (ELVIS) as imaging equipment on the Orbiter, ET, and Solid Rocket Boosters. The ELVIS integration team is composed of members from across the Program to consolidate efforts to obtain additional data to view debris sources and impact locations as well as review design changes.

STATUS

NASA has completed its assessment and concluded that it is feasible to accommodate the new umbilical well camera before return to flight. Orbiter design engineering and modifications to provide this capability are under way on all three vehicles. We anticipate being able to provide imagery from this camera on STS-114. This capability will be supplemented by handheld still imagery to provide additional views of the separating ET.

FORWARD WORK

NASA will continue installation of the digital cameras and establish the capability to downlink the images from the Shuttle's umbilical well cameras to the ground during flight. NASA is also beginning to develop plans for effectively analyzing and integrating the real-time data to be of greatest benefit to mission decision-making. The Space Shuttle Program (SSP) will research options to improve functionality in reduced light conditions.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Sep 03 (Completed)	Initiate Orbiter umbilical well feasibility study
SSP	Apr 04	Complete preliminary design review/critical design review on approved hardware
SSP	Jul 04	Begin Orbiter umbilical well installations
SSP	Sep 04	Begin system functional testing

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 to detect and assess damage.

NASA IMPLEMENTATION

To meet the requirement to assess the health and status of the Orbiter's Thermal Protection System (TPS), NASA will use a combination of on-vehicle ascent cameras and on-orbit inspections. The on-orbit inspections will consist of information from an Orbiter Boom Sensor System (OBSS) and photographs from the International Space Station (ISS). On-orbit inspections will provide more detailed and higher resolution inspection coverage.

On flight day two of STS-114, the Shuttle crew will perform the first inspection of the wing leading edge (WLE) and nose cap Reinforced Carbon-Carbon (RCC) using the Shuttle Remote Manipulator System (SRMS), or robotic arm, and the OBSS. The OBSS, a 50-ft instrumented boom that will be carried in the Shuttle payload bay, will be grappled by the SRMS to facilitate viewing areas of the Shuttle that would not be accessible using just the SRMS. The OBSS will allow the crew to make an early assessment of the WLE and nose cap RCC areas.

The ISS crew will perform a subsequent inspection of Shuttle tile, including the Orbiter WLE and forward section of both wings' TPS, by taking digital photos of the Shuttle as it performs a rotation maneuver about 600 ft from the ISS. Both sets of high-resolution imagery will be downlinked to the ground for evaluation. On-orbit inspection techniques are discussed in detail in our response to R6.4-1.

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

STATUS

The advantages and disadvantages of externally mounted camera options on the ET and SRBs were presented to the Program Requirements Control Board on July 24, 2003. The approved minimum configuration for STS-114 (figure 3.4-3-1) includes cameras mounted on the (1) ET liquid oxygen (LO_2) feedline fairing location and (2) SRB forward skirt.

Furthermore, NASA has approved design and installation of additional cameras on the ET and SRBs for the earliest possible implementation (figures 3.4-3-2 and 3.4-3-3). These configurations widen the scope of the available imagery. This will improve coverage of the Orbiter WLE and forward section of both wings' TPS. In addition, the planned OBSS and ISS photographs will provide imagery of all RCC and all tiles on the underside of the Orbiter, which includes critical landing gear door and umbilical door areas.

FORWARD WORK

NASA will continue to research options to improve camera resolution, functionality in reduced lighting conditions, and alternate camera mounting configurations. In the meantime, work is proceeding on the new SRB camera designs and implementation of the approved ET and SRB cameras.

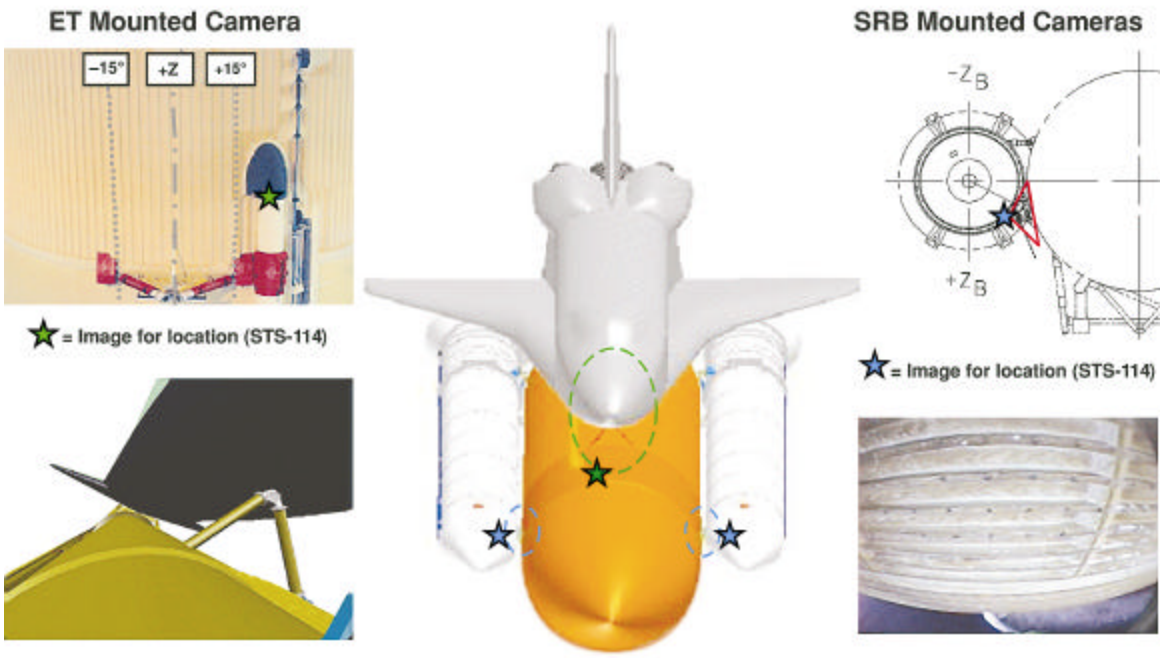


Figure 3.4-3-1. ET flight cameras (STS-114 configuration).

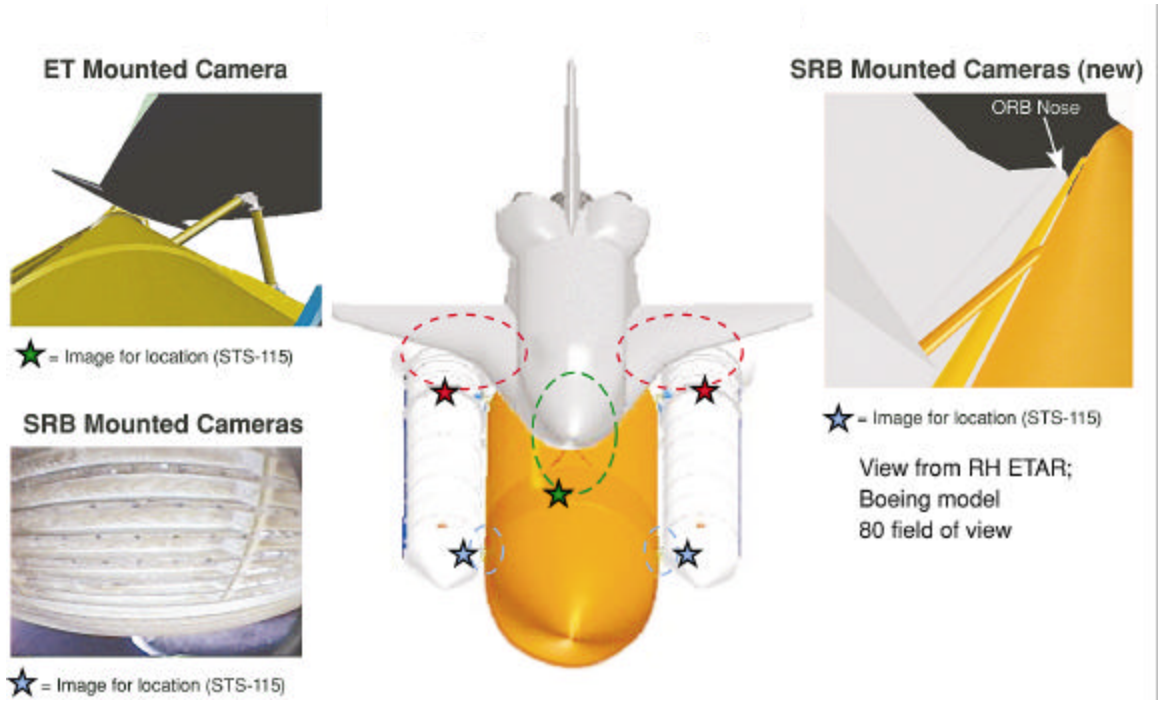


Figure 3.4-3-2. ET flight cameras (TBD configuration).

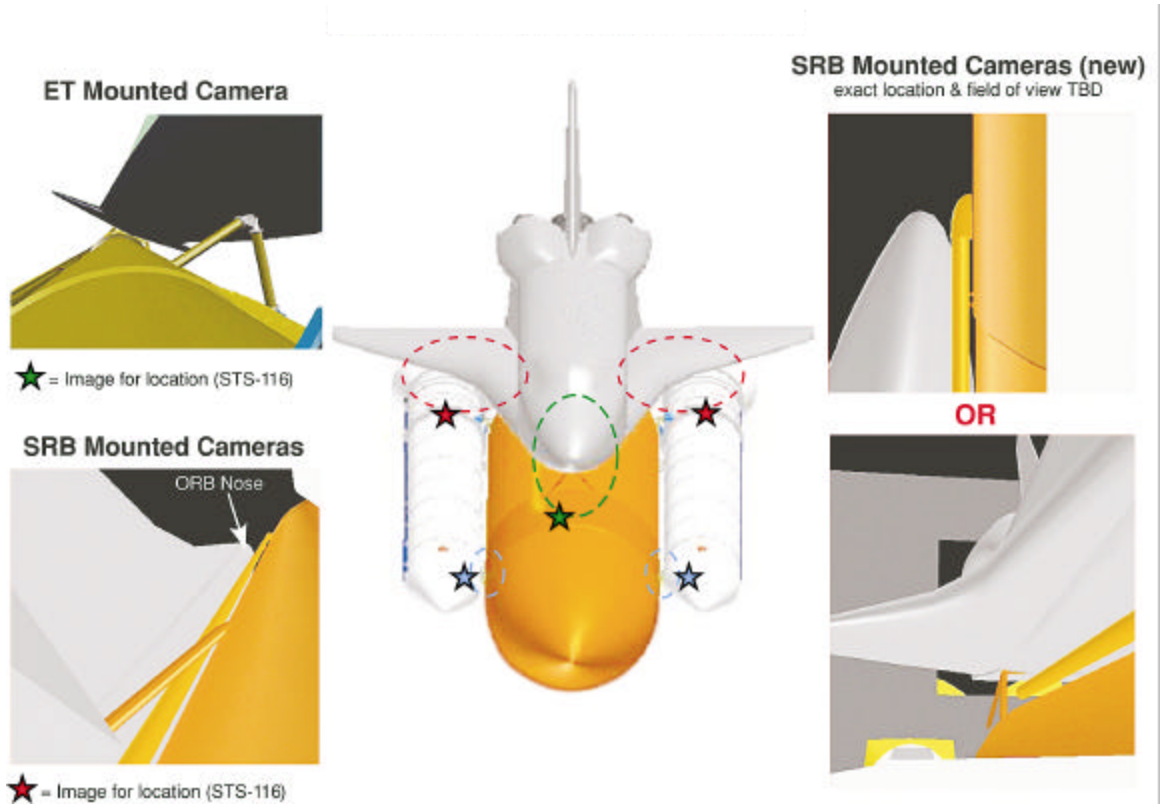


Figure 3.4-3-3. ET flight cameras (TBD configuration).

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	May 03 (Completed)	Start ET hardware modifications
SSP	Jul 03 (Completed)	Authority to proceed with ET LO_2 feedline and SRB forward skirt locations; implementation approval for ET camera
SSP	Apr 04	Systems Requirements Review
SSP	Apr 04	Begin ET camera installations
SSP	Aug 04	Review SRB camera enhancements for mission effectivity
SSP	Oct 04	Begin SRB forward skirt camera installation

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]

Note: The Stafford Covey Return to Flight Task Group held a plenary session on April 15, 2004, in Houston, Texas. NASA's progress toward answering this recommendation was reviewed, and the Task Group agreed that the actions taken were sufficient to conditionally close this recommendation.

BACKGROUND

The *Columbia* Accident Investigation 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 (subsequently renamed the National Geospatial-Intelligence Agency [NGA]) that provides for on-orbit assessment of the condition of each Orbiter vehicle as a standard requirement. In addition, NASA has initiated discussions with other agencies to explore the use of appropriate national assets to evaluate the condition of the Orbiter vehicle. Additional agreements have been developed and are in final review. The operational teams have developed standard operating procedures to implement agreements with the appropriate government agencies at the Headquarters level.

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. Over 70 percent of the requested clearances have been completed, and the remaining clearances are nearing completion.

Plans to demonstrate and train people per the new processes and procedures have been developed and will be exercised over the next few months, well before the launch of STS-114. Testing and validation of these new processes and procedures is under way and will be completed by end of the year (2004). Since this action may involve receipt and handling of classified information, the appropriate security safeguards will be observed during its implementation.

FORWARD WORK

None.

SCHEDULE

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

Columbia Accident Investigation Board

Recommendation 3.6-1

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

BACKGROUND

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

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

NASA IMPLEMENTATION

The SSP agrees that MADS needs to be maintained until a replacement system is developed and implemented (ref. R3.6-2). The Instrumentation Problem Resolution Team (PRT) will be reviewing sensor requirements for various Orbiter systems to determine appropriate action for sensors. The PRT will also ensure proper maintenance of the current MADS hardware.

STATUS

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

The SSP will maintain the current MADS, including flight hardware and ground support equipment and sensor and data acquisition components, until a replacement system is operational. Upgrades to the current system and additional sensor requirements are covered under the Vehicle Health Monitoring System project (ref. R3.6-2).

FORWARD WORK

Covered in CAIB Recommendation 3.6-2.

SCHEDULE

Covered in CAIB Recommendation 3.6-2.

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. 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 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 addition of sensors 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 or archived for download after landing. The VHMS will also allow the addition of other sensor data and instrumentation systems.

STATUS

The VHMS Project has successfully baselined the systems requirements for the Digital MADS (DMADS), which will replace the existing MADS.

The VHMS Project gained Program Requirements Control Board (PRCB) approval to evaluate the addition of payload bay accelerometers to Orbiter Vehicle (OV)-104 for STS-121. These accelerometers are currently installed on OV-103 and will be active for STS-114.

To improve data collection ability in the short term until the availability of the DMADS, the PRCB also approved an assessment of connecting the MADS Pulse Code Modulation Unit to the solid-state recorder to provide on-orbit downlink of additional low-rate MADS ascent data. If implemented, this will increase NASA's ability to access data during missions.

FORWARD WORK

The Space Shuttle Program (SSP) will continue VHMS Project requirements reviews and implementation plans, and will provide status updates to the PRCB.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03 (Completed)	VHMS Program Requirements Review
SSP	Oct 03 (Completed)	VHMS Program Requirements Document baselined at Space Shuttle Upgrades PRCB
SSP	Jan 04 (Completed)	Modular Memory Unit-Retrofit (MMU-R) Requirements Document baselined
SSP	Mar 04 (Completed)	MMU-R System Requirements Review

*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 polyimide film used as electrical insulation. Kapton-insulated wire has many advantages; however, several disadvantages have been identified. As a result, the 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 taking a broad approach to mitigate Orbiter wiring concerns by developing promising technologies and partnering with other government agencies. The SSP is continuing to improve its inspection and repair techniques. Additionally, the Program is evaluating other wire insulation types, identifying inaccessible wiring, and developing a wire replacement methodology.

At Ames Research Center, engineers are developing the proposed Hybrid Reflectometer, a TDR derivative. The goals of this development are to mature TDR technologies (including hardware and software) for more sensitive wire insulation defect detection, and to package the system into a device for operational use in the Orbiter.

At Langley Research Center (LaRC), engineers are developing a wire insulation age-life tester. Potential technologies for this application include ultrasonic and infrared spectroscopy. Additionally, LaRC engineers are developing an ultrasonic crimp joint tool to measure the integrity of wire crimps as they are made. At Johnson Space Center, engineers are developing a destructive age-life test capability.

The problem of aging wiring is not unique to NASA or the SSP. 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. NASA will partner with industry, academia, and other government agencies to find the most effective means to address these concerns. For example, NASA will continue to participate in the Joint Council for Aging Aircraft and collaborate with the Air Force Research Laboratory.

STATUS

NASA is developing promising technologies and collaborating with industry and other government agencies to find the most effective means to address these concerns. The Orbiter Project Office approved a project plan to address this recommendation and provided fiscal year 2004 funding.

FORWARD WORK

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

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Apr 04	Present project plan to the Program Requirements Control Board

Columbia Accident Investigation Board

Recommendation 4.2-1

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

BACKGROUND

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

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

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

NASA IMPLEMENTATION

The new bolt catcher assembly and related hardware will be designed and qualified by testing as a complete system to demonstrate compliance with factor-of-safety requirements. The bolt catcher housing will be fabricated from a single piece of aluminum forging (figure 4.2-1-3) that removes the weld from the original design (figure 4.2-1-4). Further, a new energy-absorbing material will 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.

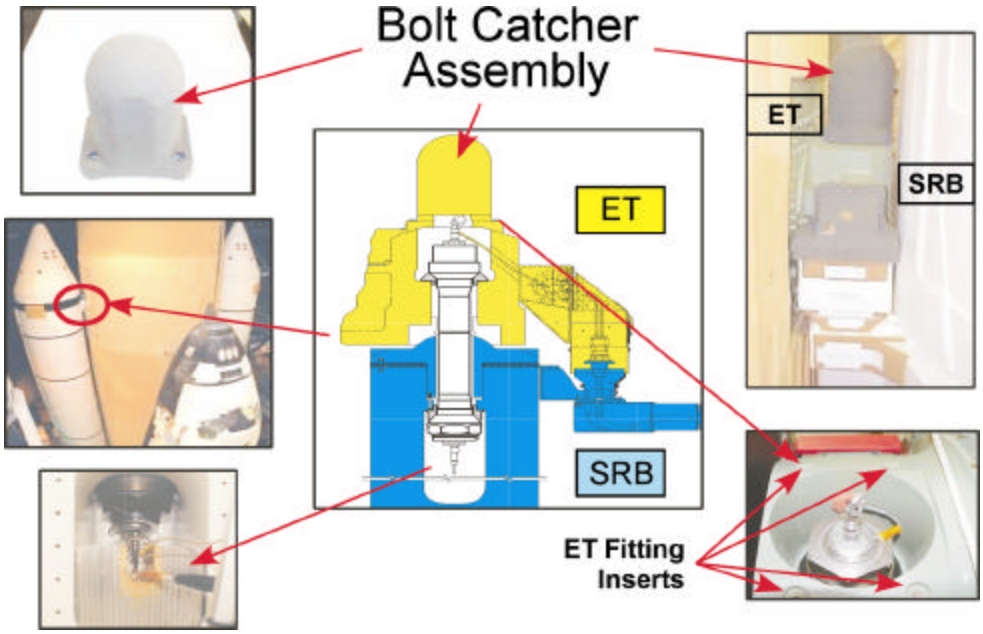
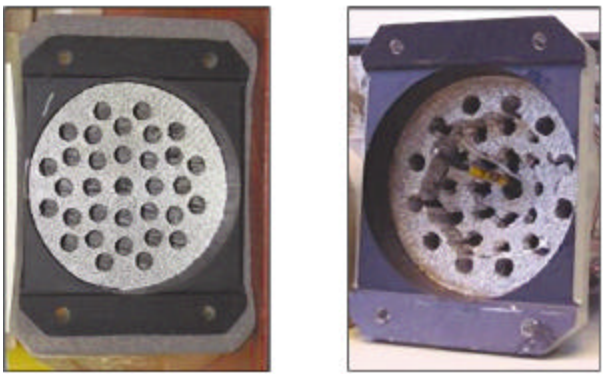


Figure 4.2-1-1. SRB/ET forward attach area.



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.

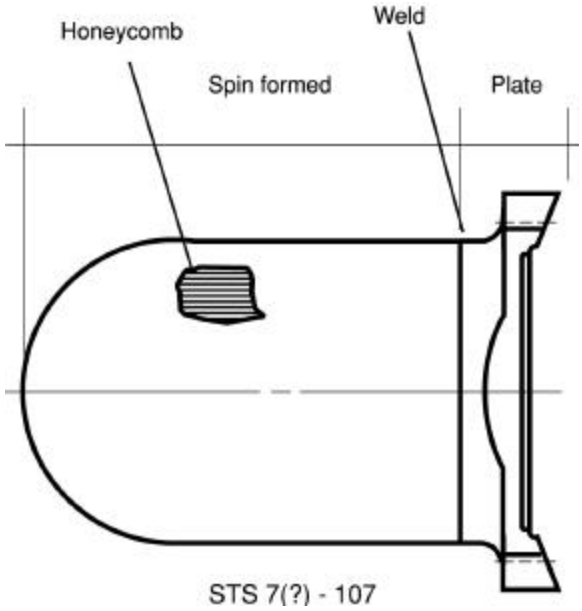


Figure 4.2-1-4. Original two-piece welded design.

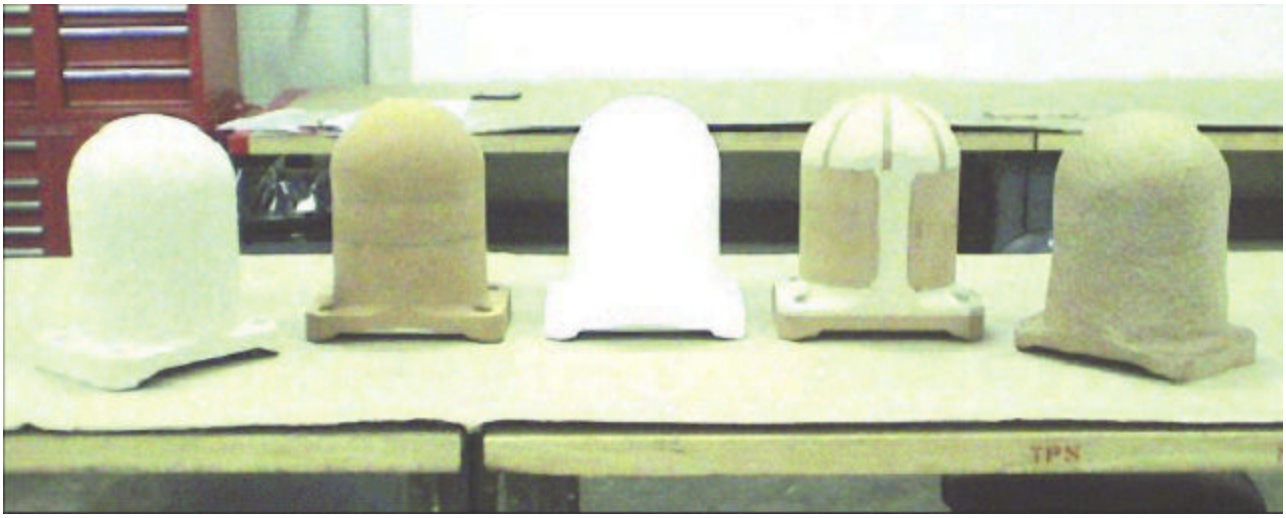


Figure 4.2-1-5. Thermal protection concepts.

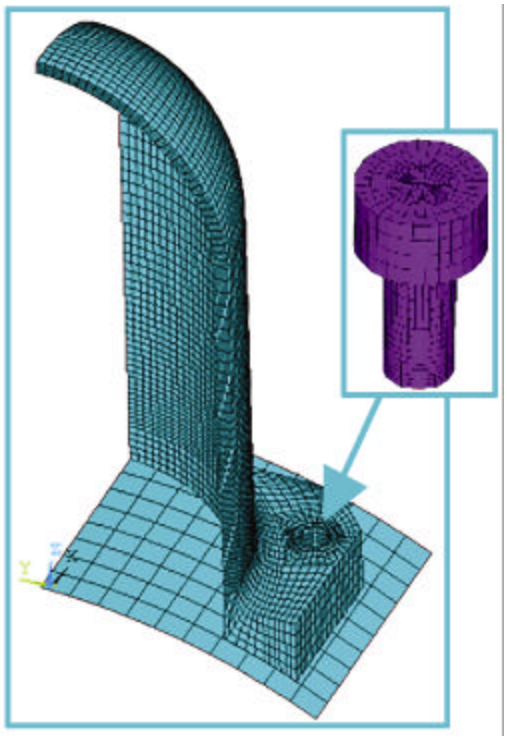


Figure 4.2-1-6. ET bolt/insert finite element model.

STATUS

NASA has completed the redesign of the bolt catcher assembly, the redesign and resizing of the ET attachment bolts and inserts, the testing to characterize the energy absorber material, and the testing to determine the design loads. Structural qualification to demonstrate that the assembly complies with the 1.4 factor-of-safety requirement is under way. Cork has been selected as the Thermal Protection System (TPS) material for the bolt catcher. TPS qualification testing is under way including weather exposure followed by combined environment testing, which includes vibration, acoustic, thermal, and pyrotechnic shock testing.

FORWARD WORK

NASA will complete structural and thermal protection material qualification testing. NASA will review our response to the *Columbia* Accident Investigation Board recommendation with the Stafford Covey Return to Flight Task Group.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	May 04 (Completed)	Complete Critical Design Review
SSP	Jul 04	Complete Qualification
SSP	Aug 04	Deliver First Flight Article

Columbia Accident Investigation Board

Recommendation 4.2-3

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

Note: The Stafford Covey Return to Flight Task Group held a plenary session on April 15, 2004, in Houston, Texas. NASA's progress toward answering this recommendation was reviewed and the Task Group agreed that the actions taken were sufficient to conditionally close this recommendation.

BACKGROUND

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

NASA IMPLEMENTATION

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

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

In addition to these specific corrective measures taken by the ET Project, in March 2004 the Space Shuttle Program (SSP) widened the scope of this corrective action in response to a recommendation from the Return to Flight Task Group (RTFTG). The scope was widened to include all flight hardware projects. An audit of all final closeouts will be performed to ensure compliance with the existing guidelines that a minimum of two persons witness final flight hardware closures for flight for both quality assurance and security purposes.

The audits included participation from Project engineers, technicians, and managers. The following were used to complete the audit: comprehensive processing and manufacturing reviews, which included detailed work authorization and manufacturing document appraisals, and on-scene checks.

STATUS

The SSP has approved the revised approach for ET TPS certification, and the Space Flight Leadership Council approved it for RTFTG review. TPS verification activities are under way, and specific applicable ET processing procedures are under review.

All major flight hardware elements (Orbiter, ET, Solid Rocket Booster, Solid Rocket Motor, extravehicular activity, vehicle processing, and main engine) have concluded their respective audits as directed by the March 2004 SSP initiative. The results of the audits were presented to the Program Manager on May 26, 2004. The two-person closeout guideline was previously well-established in the SSP and largely enforced by multiple overlapping quality assurance and safety requirements. A few projects have identified and are addressing some specific processing or manufacturing steps to extend this guideline beyond current implementation; or where rigorous satisfaction of this guideline can be better documented. Changes to Program-level requirements documents are under way,

and will include the requirement for the projects and elements to have a minimum of two people witness final closeouts of major flight hardware elements.

FORWARD WORK

Formally document Program-level requirement to include a minimum two-person attendance at major flight element closeouts, and incorporate changes or corrections identified by the audit process.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
ET	Dec 03 (Completed)	Review revised processes with RTFTG
All flight hardware elements	May 04 (Completed)	Audit results of all SSP elements due
ET	May 04 (Completed)	Assessment of Audit Results
SSP	May 04 (Completed)	SSP element audit findings presented to SSP Manager
SSP	Jun 04 (Completed)	Responses due; PRCB action closed
SSP	Jan 05	Revised requirements formally documented

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 damage as the degree of safety calculated for the International Space Station. Change the micrometeoroid and orbital debris safety criteria from guidelines to requirements.

BACKGROUND

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

The current Orbiter impact damage guidelines dictate that there will be no more than a 1 in 200 risk for loss of vehicle for any single mission. This recommendation suggests that the Orbiter meet the same degree of safety that the ISS meets in regards to MMOD risks. The ISS currently has a 0.5 percent catastrophic risk of MMOD debris impact per year. If we assume there will be five Space Shuttle flights per year, this would require that the Orbiter meet an annual average MMOD critical damage risk of 1 in 1000 for any single mission. This risk tolerance may vary from mission to mission, depending on whether the risk profile is determined annually or over the remaining life of the Shuttle Program. NASA continues to evaluate the appropriate means of determining the Shuttle MMOD risk profile.

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

NASA IMPLEMENTATION

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

- Orbiter vehicle design upgrades to decrease vulnerability to MMOD
- Operational changes
- Development of an inspection capability to detect and repair critical damage
- Addition of an on-board impact sensor system to detect critical damage that may occur to the Thermal Protection System (TPS) during ascent or while on orbit.

Once they are fully defined, NASA will change the MMOD safety criteria from guidelines to requirements.

STATUS

NASA's assessments indicate that a combination of operational and hardware changes may meet the *Columbia* Accident Investigation Board (CAIB) recommendation for less than a 1 in 1000 probability of critical impact from MMOD on each mission. Appropriate changes will be made over time according to prioritization based on a combination of the efficacy of the change and the relative difficulty of its implementation.

In the short term following return to flight (RTF), NASA is considering the following actions to achieve a 1 in 1000 to 1 in 1200 critical impact risk per mission:

1. Yawing the ISS-Shuttle stack postdock by 180 degrees
2. Implementing late mission (Flight Day 6) inspection of TPS followed by repair if necessary
3. Installing wing leading edge (WLE) damage detection sensors and implementing inspection, repair, and/or

contingency Shuttle Crew Support (CSCS) operations if damage is detected during flight.

A longer-term strategy is also under consideration that shows promise of achieving a reduction in MMOD risk well below CAIB recommendations to a 1 in 1500 to 1 in 1700 mission risk level. The steps to accomplish this level of protection include the following:

1. Either continuing the 180-degree yaw strategy post-ISS dock, or docking to a nadir port on Node 2 placing the Orbiter in a tail-forward/belly-to-Earth attitude, a low-risk orientation for MMOD damage
2. Selective hardening of TPS tiles and WLE to reduce impact hazards from both launch debris and on-orbit MMOD strikes
3. Extending the impact damage detection sensors to the wing and belly TPS areas of the vehicle. If damage is detected, closer inspection of the impacted area will be initiated followed by repair or resorting to CSCS procedures if necessary

NASA is continuing to evaluate the following:

- Orbiter vehicle design upgrades to decrease vulnerability to MMOD

  The NASA response to CAIB Recommendation 3.3-2 addresses Orbiter hardening options that may lower MMOD risks.

  Hypervelocity impact tests are being conducted on various toughened tile options to assess risk reduction. The first phase of testing on these options will be complete in April 2004; risk assessments and program reviews will be done by July 2004; and a second phase of testing will occur before March 2005.

- Operational changes

  The Shuttle Program Flight Operations and Integration Office is exploring alternative Orbiter orientations to reduce the MMOD impact risk after docking to the ISS. Three Shuttle/ISS orientation cases are being investigated by the Shuttle/Station joint technical working groups (JTWGs) to support the MMOD risk assessment. The first two postdocked cases include the baseline docking location in the nominal ISS/Shuttle attitude and in a 180-degree yaw orientation from the nominal attitude. The third option is to dock the Orbiter to a nadir port on Node 2, which puts the Orbiter in a tail-forward/belly-to-Earth attitude. The first two cases are being assessed for the short-term ISS assembly following RTF and before Node 2 installation to the Station. The JTWG feasibility findings are being coordinated with the Station vehicle integrated performance and resources (VIPER) working group to produce an integrated feasibility assessment with respect to power generation, flight control, loads and dynamics, thermal, and propellant impacts. Special emphasis is being placed on the Node 2 nadir docking option since this orientation reduces the critical risk to the Shuttle to the greatest extent. Preliminary feasibility results for joint Program review are expected from the VIPER working group in April 2004.

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

  The NASA response to CAIB Recommendation 6.4-1 covers development of inspection capability. Flight Day 6 inspection will provide the capability to view more of the Orbiter's potential MMOD impact areas and will provide a later inspection opportunity than previously available with only a Flight Day 2 inspection.

- Addition of an on-board impact sensor system to detect critical damage that may occur to the TPS during ascent or while on orbit

  The initial impact damage sensor system for RTF will be capable of detecting impacts to the WLE Reinforced Carbon-Carbon (RCC) panels during ascent and on orbit. Future implementation for other Orbiter impact critical areas will be the focus as the critical stages of the WLE system development are completed. A broad range of data is being taken from flight data and ground impact tests to develop the operability of the initial system and requirements for a follow-on, high-reliability, impact sensor system.

  Flight data history and ground test impact accelerometer responses are being correlated to derive models of expected readings for use as analysis tools during the mission. Impact tests involve both ascent and hypervelocity conditions, a variety of projectiles and locations, and both low- and high-fidelity test articles. Tap/response tests have been conducted on the Orbiter wing and leading edge spar itself to assist in model validation. TPS damage team assessments of the impact type and damage conditions that are flight critical or need on-orbit repair will be used to determine what levels of accelerometer response will warrant additional on-orbit inspection during the mission.

Additional ascent and hypervelocity tests are being performed on flight-like tiled skin panels and test articles to model the responses on the leading edge spar accelerometers to impacts.

FORWARD WORK

Investigations will continue on potential vehicle modifications, such as new impact debris sensors, next-generation tiles and toughened strain isolation pad materials, improved RCC, and improved crew module aft bulkhead protection. Additionally, a study is under way to assess the advantages of alternative docking locations on ISS, as well as other ISS modifications that reduce the Orbiter's exposure to MMOD while docked. Hypervelocity impact tests will continue to be performed, and the BUMPER code will be updated to support the risk reduction effort.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Dec 03	Assess adequacy of MMOD requirements
SSP	Dec 03	Update risk management practices
SSP	Apr 04	WLE Sensor System Critical Design Review
SSP	Oct 04	Certify and Deliver for Vehicle Installation

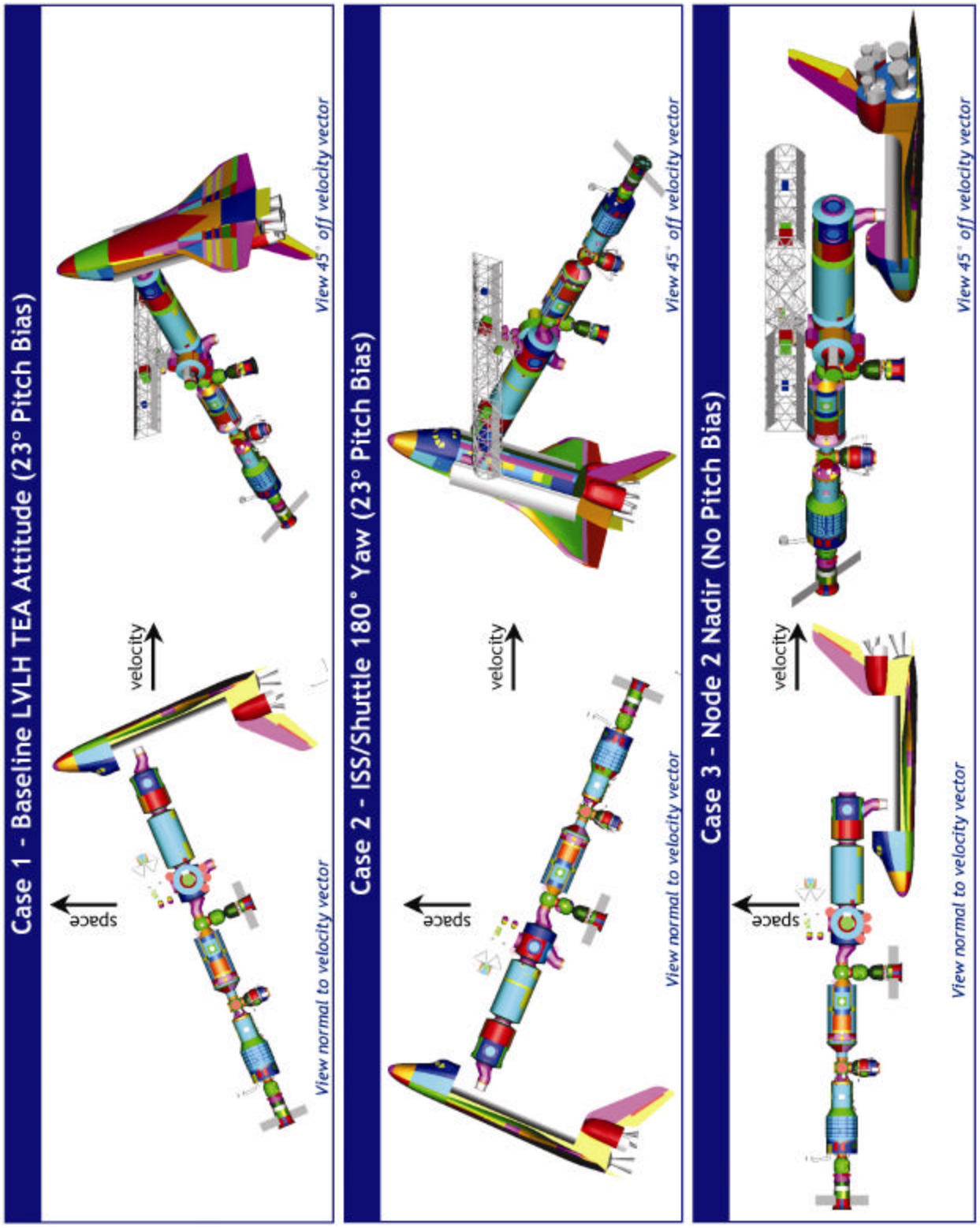


Figure 4.2-4-1. Post Dock Orientations.

Columbia Accident Investigation Board

Recommendation 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]

BACKGROUND

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

NASA IMPLEMENTATION

NASA and United Space Alliance (USA) have stopped using the term "processing debris" and changed work procedures to treat all debris with the same high level of preventative action. Rigorous definitions of FOD that are the industry standard have been adopted.

KSC chartered a multidiscipline NASA/USA team to respond to this recommendation. Team members were selected for their experience in important FOD-related disciplines including processing, quality, and corrective engineering; process analysis and integration; and operations management. The team began by fact-finding and benchmarking to better understand the industry standards and best practices for FOD prevention. They visited the Northrup Grumman facility at Lake Charles, La.; Boeing Aerospace at Kelly Air Force Base, Texas; Gulfstream Aerospace in Savannah, Ga.; and the Air Force's Air Logistics Center in Oklahoma City, Okla. At each site, the team studied the FOD prevention processes, documentation programs, and assurance practices. The team also collaborated with the aerospace industry leader in professional FOD prevention, National Aerospace FOD Prevention, Inc., and gathered industry-wide standards and best practices.

Armed with this information, the NASA/USA team developed a more robust FOD prevention program that not only fully answered the *Columbia* Accident Investigation Board (CAIB) recommendation, but also raised the bar by instituting a myriad of additional improvements.

The new FOD program is anchored in three fundamental areas of emphasis: First, it eliminates various categories of FOD, including "processing debris," and treats all FOD with equally aggressive reduction efforts. Second, it reemphasizes the responsibility and authority for FOD prevention at the operations level. Third, it elevates the importance of comprehensive independent monitoring by both contractors and the Government.

NASA and USA have adopted the rigorous definitions of FOD and foreign object damage that are the industry standards.

USA has also developed and implemented new work practices and strengthened existing practices. This new rigor will reduce the possibility for temporary worksite items or debris to migrate to an out-of-sight or inaccessible area, and it serves an important psychological purpose in eliminating visible breaches in FOD prevention discipline.

FOD "walkdowns" have been a standard industry and KSC procedure for many years. These are dedicated periods where all employees execute a prescribed search pattern throughout the work areas, picking up all debris. USA has increased the frequency and participation in walkdowns, and has also increased the number of areas that are regularly subject to them. USA has also improved walkdown effectiveness by segmenting FOD walkdown areas into zones. Red zones are all areas within three feet of flight hardware and all areas inside or immediately above or below flight hardware. Yellow zones are all areas within a designated flight hardware operational processing area. Blue zones are desk space and other administrative areas within designated flight hardware operational processing areas.

Additionally, both NASA and USA have increased their independent monitoring of the FOD prevention program. USA Process Assurance Engineers regularly audit work areas for compliance with such work rules as removal of potential FOD items before entering work areas and tethering of those items that cannot be removed (e.g., glasses), tool control protocol, parts protection, and Clean-As-You-Go housekeeping procedures. NASA

Quality personnel periodically participate in FOD walkdowns to assess their effectiveness and oversee contractor accomplishment of all FOD program requirements.

An important aspect of the FOD prevention program has been the planning and success of its rollout. USA assigned FOD Point of Contact duties to a senior employee who led the development of the training program from the very beginning of plan construction. This program included a rollout briefing followed by mandatory participation in a new FOD Prevention Program Course, distribution of an FOD awareness booklet, and hands-on training on a new FOD tracking database. Recurrent training will be required once a year and will be enforced by tying work area access renewals to completion of the training. Another important piece of the rollout strategy was the strong support of senior NASA and USA management for the new FOD program and their insistence upon its comprehensive implementation. Managers at all levels will take the FOD courses and will periodically participate in FOD walkdowns.

The new FOD program has a meaningful set of metrics to measure effectiveness and to guide improvements. FOD walkdown findings will be tracked in the Integrated Quality Support Database. This database will also track FOD found during closeouts, launch countdowns, postlaunch pad turnarounds, landing operations, and NASA quality assurance audits. "Stumble-on" FOD findings will also be tracked, as they offer an important metric of program effectiveness independent of planned FOD program activities. For all metrics, the types of FOD and their locations will be recorded and analyzed for trends to identify particular areas for improvement. Monthly metrics reporting to management will highlight the top five FOD types, locations, and observed workforce behaviors, along with the prior months' trends. Continual improvement will be a hallmark of the revitalized FOD program.

STATUS

NASA and USA have completed the initial benchmarking exercises, identified best practices, modified operating plans and database procedures, and begun the rollout orientation and initial employee training. Official, full-up implementation will begin on July 1, 2004, although many aspects of the plan existed in the previous FOD prevention program in place at KSC. The full intent of CAIB Recommendation 4.2-5 has been met, and NASA and USA have gone beyond the recommendation to implement a truly world-class FOD prevention program.

FORWARD WORK

Assessment audits by NASA will begin in October 2004 to ensure the ongoing effectiveness of the FOD prevention program. Continual improvement will be vigorously pursued for the remainder of the life of the Shuttle.

NASA will review our response to this CAIB recommendation with the Stafford Covey Return to Flight Task Group.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Ongoing	Review and trend metrics
SSP	Oct 03 (Completed)	Initiate NASA Management walkdowns
SSP	Dec 03 (Completed)	FOD Control Program benchmarking
SSP	Jan 04 (Completed)	Revised FOD definition
SSP	Apr 04 (Completed)	Draft USA Operating Procedure released for review
SSP	Jul 04	Implement FOD surveillance
SSP	Oct 04	Baseline audit of implementation of FOD definition, training, and surveillance
SSP	TBD	Periodic surveillance audit

Columbia Accident Investigation Board

Recommendation 6.2-1

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

BACKGROUND

Schedules are integral parts of program management and provide for the integration and optimization of resource investments across a wide range of connected systems. The Space Shuttle Program (SSP) needs to have a visible schedule with clear milestones to effectively achieve its mission. Schedules associated with all activities generate very specific milestones that must be completed for mission success. Nonetheless, schedules of milestone-driven activities will be extended when necessary to ensure safety. NASA will not compromise system safety in our effort to optimize schedules.

NASA IMPLEMENTATION

NASA's 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 building in launch margin, cargo and 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 and tools that are currently used by the International Space Station (ISS) where risk data are currently displayed on the One-NASA Management Information System. Senior managers of the Space Flight Enterprise can virtually review schedule performance indicators and risk assessments on a real-time basis.

Recent management changes in NASA's key human space flight programs will contribute to ensuring that Shuttle flight schedules are appropriately maintained and amended to be consistent with available resources. In 2002, the Office of Space Flight established the position of Deputy Associate Administrator for International Space Station and Space Shuttle Programs (DAA for ISS/SSP) to manage and direct both programs. This transferred the overall program management of the ISS and SSP from Johnson Space Center to Headquarters (figure 6.2-1-1). The DAA for ISS/SSP was given accountability for the execution of the ISS and SSP, and the authority to establish requirements, direct program milestones, and assign resources, contract awards, and contract fees.

As illustrated in figure 6.2-1-2, the Office of DAA for ISS/SSP employs an integrated resource evaluation process to ensure the effectiveness of both programs. Initial resource allocations are made through our annual budget formulation process. At any given time, there are three fiscal year budgets in work: the current fiscal year budget, the presentation of the next fiscal year Presidential budget to Congress, and preparation of budget guidelines and evaluation of budget proposals for the follow-on year. This overlapping budget process, illustrated in figure 6.2-1-3, provides the means for reviewing and adjusting resources to accomplish an ongoing schedule of activities with acceptable risk.

Defined mission requirements, policy direction, and resource allocations are provided to the ISS and SSP managers for execution. For major decisions affecting return to flight (RTF) efforts, the Space Flight Leadership Council is called upon to provide specific direction. The Office of DAA for ISS/SSP continually evaluates the execution of both programs as policy and mission requirements are implemented with the assigned resources. Resource and milestone concerns are identified through this evaluation process. Continued safe operation of the ISS and SSP is the primary objective of program execution; technical and safety issues are evaluated by the Headquarters DAA staff in preparation for each ISS and SSP mission and continuously as NASA prepares for RTF. As demonstrated in actions before the Columbia accident and continually during the RTF process, adjustments are made to program milestones, such as launch windows, to assure safe and successful operations. Mission anomalies, as well as overall mission performance, are fed back into each program and adjustments are made to benefit future flights.

The Office of DAA for ISS and SSP staff reviews and assesses the status of both programs daily. The cornerstone of the Office of DAA for ISS/SSP staff evaluation process is the NASA Management Information System (MIS) (figure 6.2-1-4). The One-NASA MIS provides NASA senior management with access to critical program data and offers a portal to a significant number of NASA center and program management information systems and Web sites. Among the extensive information on the One-NASA MIS are the Key Program Performance Indicators (KPPIs) (figure 6.2-1-5). The Office of DAA for ISS/SSP uses the KPPIs to present required information to the Space Flight Enterprise Program Management Council (PMC) and the Agency PMC on a quarterly basis.

Overall, the Office of DAA for ISS/SSP has implemented a comprehensive process for continually evaluating the effectiveness of the SSP. This process allows the Office of DAA for ISS/SSP staff to recognize and rapidly respond to changes in status, and to act transparently to elevate issues such as schedule changes that may require decisions from the appropriate leaderships. NASA, the Space Flight Leadership Council, and the Office of DAA for ISS/SSP have repeatedly demonstrated an understanding of acceptable risk, and have responded by changing milestones to assure continued safe operation.

STATUS

Currently, all the appropriate manifest owners have initiated work to identify their requirements. SSP now coordinates with the ISS Program to create an RTF integrated schedule. The SSP Systems Engineering and Integration Office reports the RTF Integrated Schedule every week to the SSP Program Requirements Control Board. Summary briefs are also provided at each Space Flight Leadership Council meeting. SSP Flight Operations has scheduling and manifesting responsibility for the Program, working both the short-term and long-term manifest options. The current proposed manifest launch dates are all "no earlier than" (NET) dates, and are contingent upon the establishment of an RTF date. A computerized manifesting capability is under development to more effectively manage the schedule margin, launch constraints, and manifest flexibility.

FORWARD WORK

The *Columbia* accident has resulted in new requirements that must be factored into the manifest. The ISS and SSP are working together to incorporate the RTF changes into the ISS assembly sequence. A periodic system review of the currently planned flights is being performed. After all the requirements have been analyzed and identified, a launch schedule and ISS manifest is established. NASA will continue to add margin that allows some changes while not causing downstream delays in the manifest.

Development will continue on the computer-aided tools to manage the manifest schedule margin, launch constraints, and manifest flexibility.

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

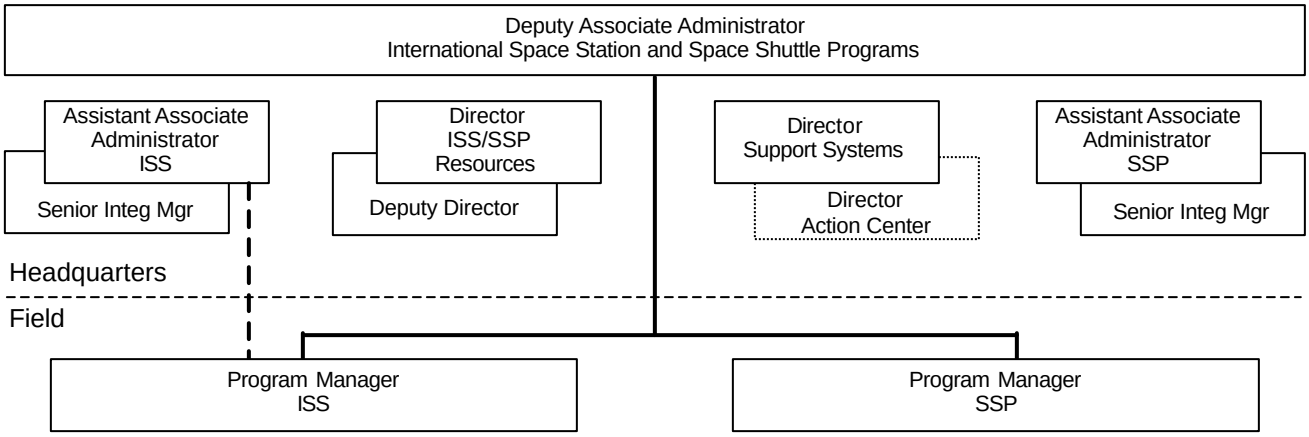


Figure 6.2-1-1. Office of Deputy Associate Administrator for International Space Station and Space Shuttle Programs (Code M-1) is Organized to Maximize Performance Oversight.

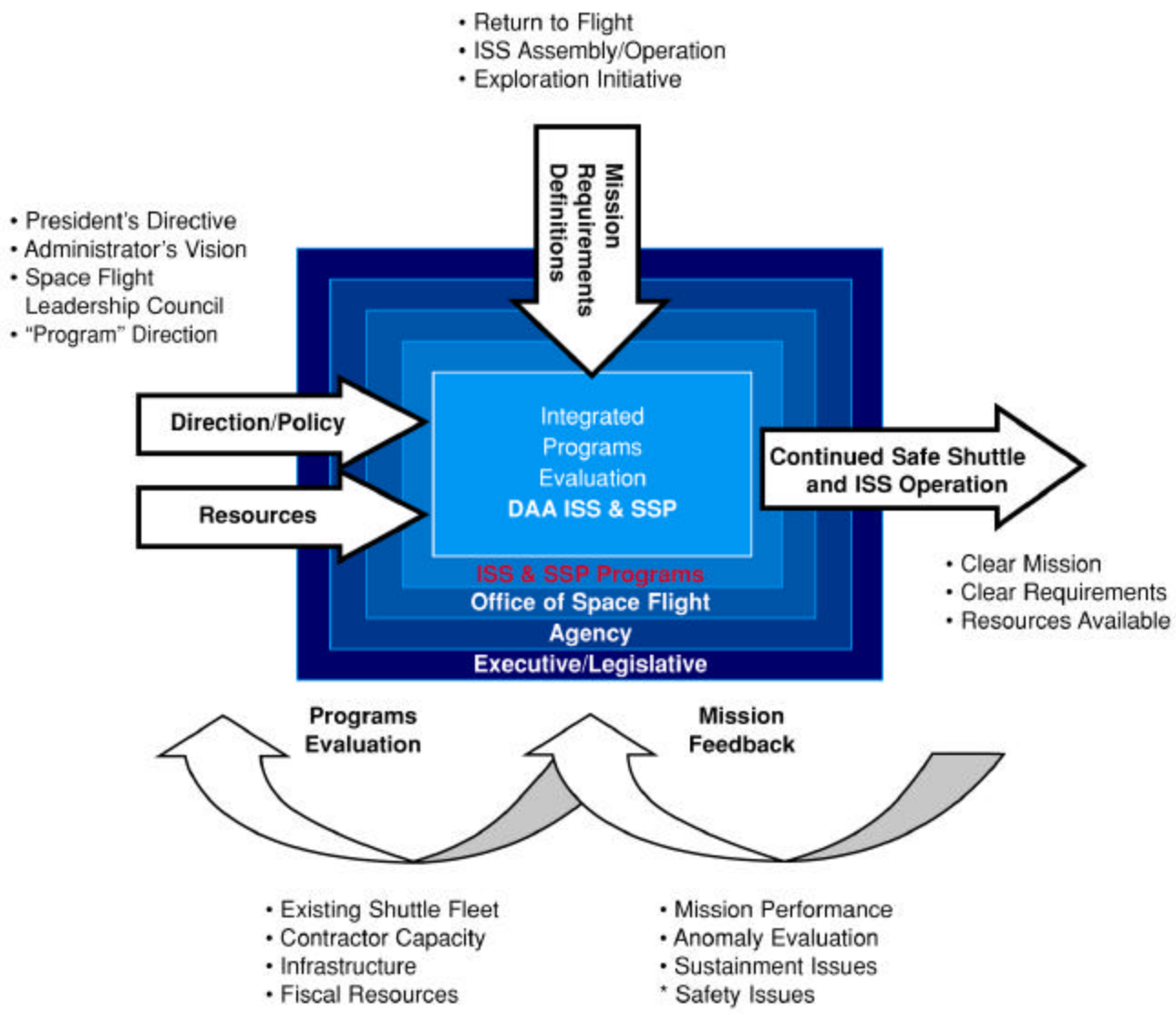


Figure 6.2-1-2. Integrated Resource Evaluation process is Employed by NASA Headquarters, Code M-1.

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

SCHEDULE

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

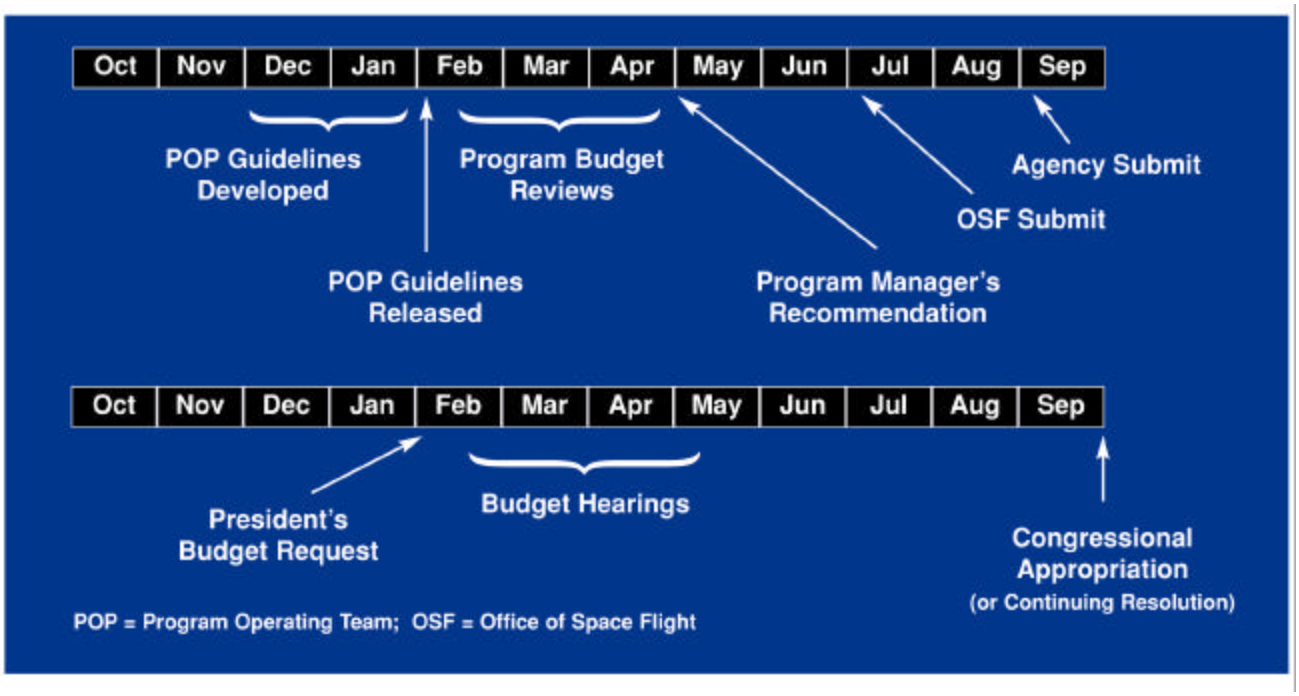


Figure 6.2-1-3. Office of Deputy Associate Administrator for ISS and SSP Annual Budget Formulation Process.

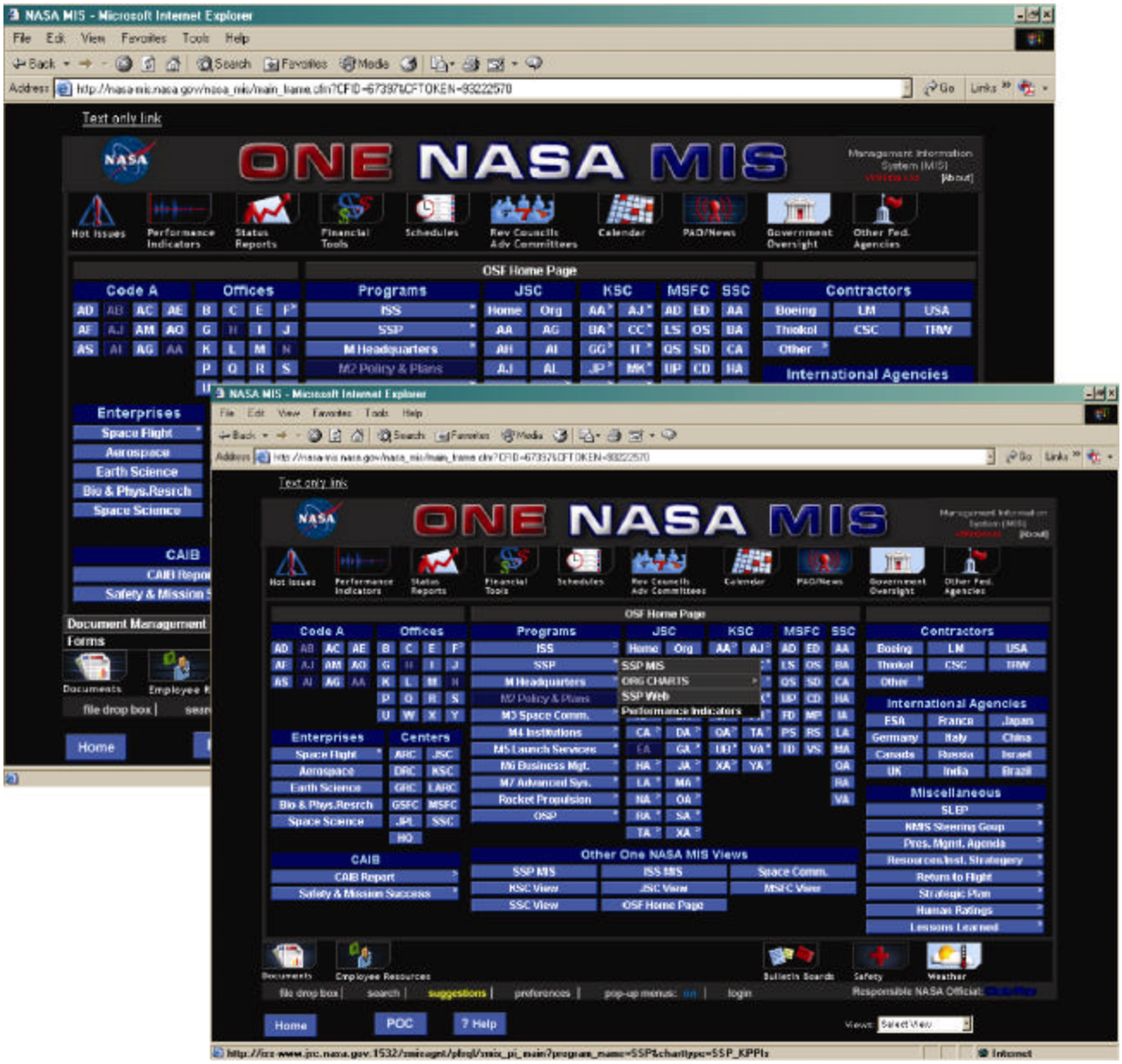


Figure 6.2-1-4. One NASA Management Information System (MIS) is a Tool used to Track Performance of the International Space Station and Space Shuttle Programs.

SHUTTLE
KEY PROGRAM PERFORMANCE INDICATORS (KPPIs)

SSP | SSP KPPIs

Sort --> | Orgs --> | POC --> | Reset

STATUS		PERFORMANCE INDICATOR		RESPONSIBLE ORGANIZATION	ACCOUNTABLE POC
R	SSP KPPI	Cost Summary	DETAILS	MM/Shuttle Business Office	YATES, LUCY
R	SSP KPPI	Development/ Production Summary	DETAILS	MT/Customer and Flight Integration	COGGESHALL, JOHN
Y	SSP KPPI	2020 SLEP	DETAILS	MA/SSP Development	NORBRATEN, LEE
Y	SSP KPPI	Near Term Improvement Integrated Scheudle approved by PRCB	DETAILS	MS/Systems Engineering and Integration	MURATORE, JOHN
Y	SSP KPPI	Processing Overview	DETAILS	KSC/Shuttle Processing	WETMORE, MIKE
Y	SSP KPPI	Program Stoplight Chart	DETAILS	MA/Space Shuttle Program Office	PARSONS, BILL
Y	SSP KPPI	Risk	DETAILS	MA/SSP S&MA	PARSONS, BILL
Y	SSP KPPI	SSP RTF Integrated Schedule and Inchstones	DETAILS	MA/Space Shuttle Program Office	MURATORE, JOHN
Y	SSP KPPI	Shuttle Manifest	DETAILS	MT/Customer and Flight Integration	COGGESHALL, JOHN
Y	SSP KPPI	Special Topic: AHMS	DETAILS	MA/SSP Development	NORBRATEN, LEE
G	KPPI	Infrastructure	DETAILS	Integration	WETMORE, MIKE
G	SSP KPPI	SSP Workforce	DETAILS	MM/Shuttle Business Office	YATES, LUCY
G	SSP KPPI	Special Topic: OV-105 OMM	DETAILS	MV/Orbiter	ALLISON, RON

Figure 6.2-1-5. Space Shuttle Key Program Performance Indicators (KPPIs).

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 contingences should involve potential loss of Shuttle or crew, contain numerous uncertainties and unknowns, and require the Mission Management Team to assemble and interact with support organizations across NASA/Contractor lines and in various locations. [RTF]

BACKGROUND

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

MMT training, including briefings and simulations, has previously concentrated on the prelaunch and launch phases, including launch aborts.

NASA IMPLEMENTATION

NASA's response will be implemented in two steps: (1) to review and revise MMT processes and procedures; and (2) to develop and implement a training program consistent with those process revisions.

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

NASA has established a formal MMT Training Program comprised of a variety of training activities and MMT simulations. MMT simulations will bring together the flight crew, flight control team, launch control team, engineering staff, outside agencies, and MMT members to improve communication and teach better problem-recognition and reaction skills. All MMT members, both primary and alternates, are required to complete a minimum set of training requirements to attain initial certification prior to performing MMT responsibilities, and participate in a sustained training program to maintain certification. Training records are being maintained to ensure compliance with the new requirements. NASA has employed independent external consultants to assist in developing these training activities and to evaluate overall training effectiveness.

STATUS

The SSP reviewed the MMT processes and revised the Program documentation (NSTS 07700, Volume VIII, Operations, Appendix D) accordingly to implement the following significant changes:

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.
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 at 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.

NASA has also completed a Mission Evaluation Room console handbook that includes MMT reporting requirements, a flight MMT reporting process for on-orbit vehicle inspection findings, and MMT meeting support procedures. Additionally, the SSP published a formal MMT training plan (NSTS 07700, Volume II, Program Structure and Responsibilities, Book 2 - Space Shuttle Program Directives, Space Shuttle Program Directive 150) that defines the generic training requirements for MMT certification. This plan is comprised of three basic types of training: courses and workshops, MMT simulations, and self-instruction. Courses, workshops, and self-instruction materials were selected to strengthen individual expertise in human factors, critical decision making, and risk management of high-reliability systems. Additionally, the SSP published a fiscal year (FY) 2004 training calendar that identifies the specific training activities to be conducted in FY 2004 and, for each activity, the associated date, objective, location, and point of contact. MMT training activities are well under way with several courses/workshops held at various NASA centers and three simulations completed.

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. A flight MMT reporting process for postlaunch pad debris assessment findings.

2. A flight MMT reporting process for launch imagery analysis findings and on-orbit vehicle inspection findings.

3. A flight MMT reporting process for Solid Rocket Booster/Reusable Solid Rocket Motor post-recovery hardware assessment findings.

4. MMT process revisions based on lessons learned during simulations.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Oct 03 (Completed)	MMT Interim training plan
SSP	Oct 03 (Completed)	MMT process changes to Program Requirements Change Board
SSP	Oct 03 (Completed)	Project/element process changes
SSP	Nov 03 – Return to Flight	MMT training
SSP		MMT Simulation Summary
	Nov 03 (Completed)	MMT On-Orbit simulation
	Dec 03 (Completed)	MMT SSP/International Space Station (ISS) Joint On-Orbit simulation
	Feb 04 (Completed)	MMT On-Orbit simulation
	Apr 04	MMT Prelaunch simulation
	May 04	MMT On-Orbit simulation involving Thermal Protection System (TPS) inspection
	Jul 04	MMT Prelaunch Contingency simulation. MMT SSP/ISS Joint On-Orbit simulation involving TPS inspection and national assets
SSP	Dec 03 (Completed)	Status to Space Flight Leadership Council and Stafford/Covey Task Group
SSP	Feb 04 (Completed)	MMT Final training plan
SSP	Apr 04	Status to Stafford/Covey Task Group
SSP	May 04	Miscellaneous MMT process revisions to address simulations lessons learned

Columbia Accident Investigation Board

Recommendation 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 sub-system, 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 [R9.2-1]

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

BACKGROUND

NASA has developed a draft plan for addressing recommendations 9.1-1 and 7.5-1, 7.5-2, and 7.5-3. This draft plan has been distributed for review and comment. NASA is in the process of addressing the comments received to this draft plan and revising it appropriately before releasing the plan officially. The following is a summary of the draft plan as it exists on April 19, 2004, and as it applies to R7.5-1.

INTRODUCTION

The *Columbia* Accident Investigation Board Report recommended establishment of an independent Technical Engineering Authority for the Space Shuttle Program (SSP). NASA chose to expand the concept NASA-wide to include technical organizations in addition to the Engineering Directorates (Mission and Ground Operations, Space and Life Sciences, Safety and Mission Assurance, etc.) as appropriate to the scope of the CAIB recommendation. Therefore, to avoid confusion, NASA dropped the word "engineering" from the title of the authority.

NASA's Independent Technical Authority (ITA) will provide independence and authority to institution-based technical personnel engaged in key program/project support activities critical to safety and mission success. Independence in this context means organizational independence, as well as independence from program and project funding decision authority. The purpose of the ITA is to provide technical checks and balances by assuring that the program/project manager does not have sole technical and resource authority over safety and mission success relevant technical standards and safety and reliability analysis products. The diagram in figure 7.5-1-1 shows an example of this organizational relationship for the Office of Space Flight Enterprise.

Under the leadership of the Associate Administrator (AA), Office of Safety and Mission Assurance (OSMA) and the NASA Chief Engineer, the Office of Space Flight (OSF) is in the process of initiating implementation of an ITA for the SSP and the International Space Station Program (ISSP).

NASA IMPLEMENTATION

The ITA is an institutional component of NASA, with elements both in the technical organizations at the field Centers and in the functional offices at NASA Headquarters. Agency ITA policy will be provided Agency organizational, program management, and safety

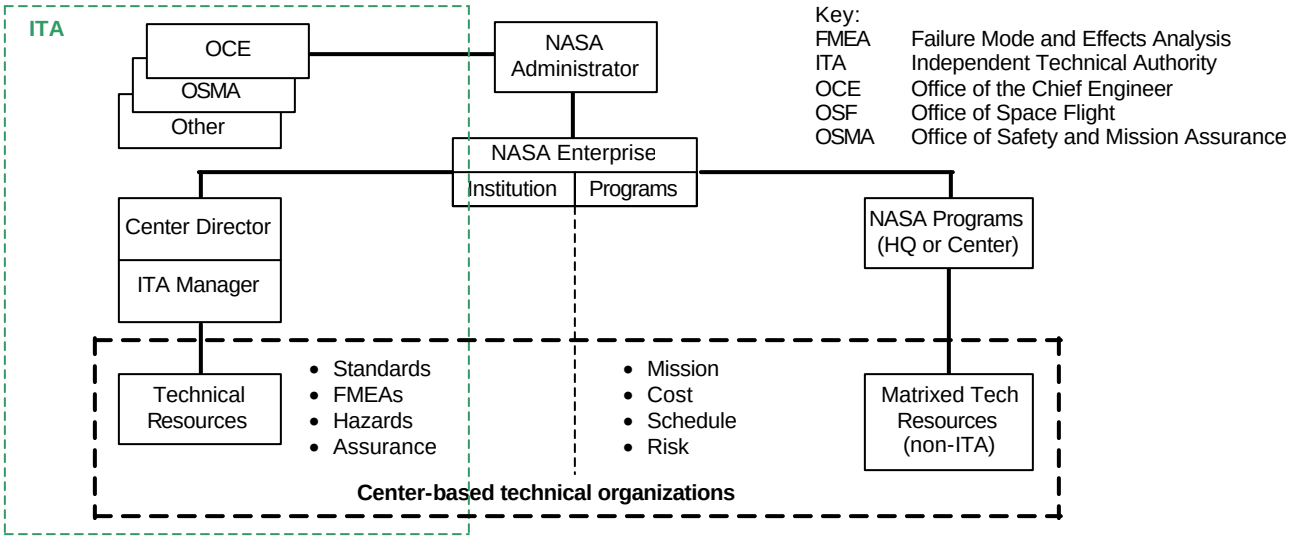


Figure 7.5-1-1. Example ITA Organization for the Office of Space Flight (OSF).

and mission assurance directives owned by the Chief Engineer, Chief Health and Medical Officer, and AA, OSMA. Each center element of the ITA will own and manage the use of technical standards as assigned by Headquarters. As part of establishing the ITA, each Center Director, with the concurrence of the AA for Safety and Mission Assurance and the NASA Chief Engineer, will select an ITA manager to lead ITA activities for their center. ITA functions will be carried out by the ITA manager's staff and designated technical personnel assigned to center line organizations. The ITA will be responsible for technical standards (including application, change (waiver, and deviation exception) authority); inter-center ITA collaboration; technical assessments and hazard analysis; Failure Mode Effects Analysis/Critical Item List (FMEA/CIL) reporting systems; and providing a reclama path for dissenting opinions that cannot be resolved within normal channels.

Table 7.5-1-1 presents the traceability of ITA functions to CAIB recommendations and a comparison of functions before *Columbia* and after the planned ITA implementation.

ITA Technical Standards

The ITA will be established throughout the Agency, with primary authority for technical standards residing at Headquarters and delegated as appropriate to technical experts throughout the NASA centers. All technical standards are being reviewed for applicability and appropriate change authority. In most cases, such standards already fall under the change authority of Engineering, SMA, or other technical organizations at Headquarters or the centers. Where they do not, the centers and programs/projects will affect an orderly transition of authority to the ITA once it is ready to take on the new responsibility. For NASA standards with Agencywide application, the Headquarters owner (Chief Engineer, OSMA, Chief Health and Medical Officer, or others) will have ultimate change authority.

To effectively and independently maintain control over the application of technical standards, and to ensure proposed deviations from those standards are appropriately considered, the Chief Engineer will establish a system in which "warrants" are assigned to experts in the ITA. These "warrants" are the delegation of authority for approving changes to technical standards to subject matter experts throughout the Agency. The Chief Engineer will also provide the policy for oversight of the warrant process.

In addition, each center element of the ITA will provide guidance to programs on the use of technical standards, and will review inclusion or elimination of standards in program requirements at existing program boards and panels .

ITA Collaboration

The OSF center ITA managers and Headquarters representatives as appropriate will participate in a forum for coordinating technical standard issues of mutual interest.

Table 7.5-1-1. Traceability of ITA Functions to CAIB Recommendations and Comparison of Functions Before *Columbia* and After ITA Implementation

ITA Function	CAIB Recommendation (R7.5-1)	Before *Columbia* Accident	After ITA Implementation
Technical Standards	Develop and maintain technical standards for all SSP projects and elements. Be the sole waiver-granting authority for all technical standards.	Program had authority for some of its technical standards.	ITA develops and maintains technical standards (through warrants).
		Program held waiver-granting authority for these technical standards	ITA approves initial application of standards to programs.
			ITA has sole change (including waiver) authority for technical standards.
Intercenter Collaboration	N/A	N/A	ITA Forum facilities Headquarters-center and intercenter collaboration; Safety and Reliability Panels handle relevant integration issues through long-established multicenter participation.
Technical Assessments, Analysis, and Integrated Hazard Assessment	Conduct trend and risk analysis at the subsystem system, and Enterprise levels. Decide what is and is not and anomalous event. Independently verify launch readiness.	Program performed risk assessment and limited trending.	ITA (with help from center line organizations, Independent Assessment, and NASA Engineering and Safety Center as required)conducts trending, integrated hazard, and risk analysis as a check and balance to similar program assessments.
		Program defined anomalous events and controlled Problem Resolution and Corrective Action (PRACA) process.	The ITA will examine the Program's new IFA system and independently evaluate and formally approve program recommendations as to what is and is not an IFA.
		Center Director concurs on CoFR.	Each Center Director will conduct an ITA review prior to major milestones and flights. • The review will include all ITA products and processes that are a part of the SSP CoFR. • The review will include results of relevant ITA assessments and analyses. • In addition to the ITA manager'' assessment, all appropriate center-based line organizations will present their state of readiness at the review. • The results of this ITA assessment will be a principle basis for the signature of the Center Director on the CoFR.
FMEA/CIL Reporting Systems	Own the failure mode, effects analysis, and hazard reporting systems.	Program owned review panels and process.	ITA will own the process used by safety and reliability review panels for FMEA/CIL and hazard analyses. The independent SMA organizations will chair these panels on an ITA function and have primary responsibility for approving FMEAs, CILs, and hazard reports as a prerequisite to program approval to the same.

Table 7.5-1-1. Concluded

ITA Function	CAIB Recommendation (R7.5-1)	Before *Columbia* Accident	After ITA Implementation
Providing Reclama Path for Dissenting Opinions	N/A	Reclama paths for dissenting opinions existed, but were not perceived as easy to use by dissenters.	ITA provides reclama path for dissenting opinions.
Space Shuttle Recertification	Approves the provisions of the recertification program called for in Recommendation 9.2-1	The Program and its authorized projects and elements have certified systems and processes with the advice and consent of the matrixed center technical line organizations per program requirements.	Reference Recommendation 9.2-1
Funding ITA Functions	Funded directly from NASA Headquarters and should have no connection to or responsibility for schedule or program cost.	The Program authorized levels of and provided direct funding for institutional technical support.	ITA resource levels will be decided by the institution (center, IPO, IEC) and will be funded through Headquarters managed directed service pools.

The AA, OSF will appoint the chairperson of this forum from among the center ITA managers. The ITA Forum will focus on facilitating collaboration among centers relevant to OSF matters on the following issues:

- Coordinating the intercenter use of technical standards.
- Coordinating the intercenter involvement in program integration related ITA activities.
- Coordinating intercenter involvement in ITA technical assessments and analysis.
- Coordinating intercenter reclama path for dissenting opinions.

Technical Assessments and Analysis

Center elements of the ITA will provide the Center Director and Headquarters proactive evaluations of problems, trends, and reporting systems, and will conduct assessments using engineering, safety, reliability, quality, trend, integrated hazard, and risk analysis techniques.

Technical leads from the various center line organizations will be matrixed to the center ITA organization so they can remain cognizant of ongoing technical issues, maintain a detailed knowledge of the ongoing position concerning technical matters, and provide a reclama path for dissenting opinion to the Center Director and Headquarters.

Each Center Director will conduct an ITA review prior to major milestones and flights.

- The review will include all ITA products and processes that are a part of the SSP Certificate of Flight Readiness (CoFR).
- The review will include the results of all independent assessments and analyses conducted by the ITA that are relevant to the milestone or flight.
- In addition to the ITA manager's assessment, all appropriate center-based line organizations will present their state of readiness at the review.
- The results of this ITA assessment will be a principle basis for the signature of the Center Director on the milestone review or CoFR.

The ITA will formally approve program recommendations as to what is and is not an In-Flight Anomaly (IFA) as a prerequisite for Program approval of the same.

Table 7.5-1-2. Shuttle Safety and Reliability panels Chaired by the ITA

Panel	Program	Responsible ITA	Description
Ground Safety Review Panel (GSRP)	ISSP/SSP	Kennedy Space Center ITA	This panel is established to review the ground safety aspects of Space Shuttle payloads and ISS flight hardware, experiments, and cargo. The panel is responsible for conducting safety reviews as defined in NSTS/ISS 13830C, "Payload Safety Review and Data Submittal Requirements for Payloads using the Space Shuttle and International Space Station," and SSP 30599, "Safety Review Process." The panel is responsible for assuring the implementation of KHB 1700.7, "Kennedy Space Center Payload Ground Safety Handbook." It will have the authority to provide ground safety approval of payloads as a prerequisite to Program approval of same.
ISS Safety Review Panel	ISSP/SSP	Johnson Space Center (JSC) ITA	This panel is established to review the safety aspects of ISS flight hardware during the launch, return, and on-orbit mission phases as well as the safety of any visiting vehicles. This panel is cochaired by representatives of the SSP and ISSP. The panel is responsible for conducting safety reviews as defined in SSP 30599, "Safety Review Process." The panel is responsible for assuring the implementation of SSP 50021, "Safety Requirements Document." This panel will have the authority to provide approval of all ISS hazard reports as a prerequisite to Program approval of same.
Payload Safety Review Panel (PSRP)	ISSP/SSP	JSC ITA	This panel is established by the Manager, SSP, and the Manager, ISSP, to review the flight safety aspects of Space Shuttle payloads and ISS experiments and cargo. The panel is responsible for conducting safety reviews as defined in NSTS/ISS 13830C, "Payload Safety Review and Data Submittal Requirements for Payloads using the Space Shuttle and International Space Station." The panel is responsible for assuring the implementation of NSTS 1700.7B, "Safety Policy and Requirements for Payloads Using the Space Transportation System," and NSTS 1700.7B Addendum, "Safety Policy and Requirements for Payloads Using the International Space Station." See JSC Policy Charter, JPC 1152.4K, "Space Shuttle Payload Safety Review Panel (PSRP)," for further details. The panel will have the authority to provide safety approval of payloads as a prerequisite to Program approval of same.
SSP Reliability and Maintainability (R&M) Panel	SSP	JSC ITA	The SSP R&M Panel is being formed for the purpose of reviewing SSP FMEA/CILs (formerly part of responsibility of SSRP). This Panel will provide formal ITA approval of all FMEA/CILs as a prerequisite to Program approval of same.
System Safety Review Panel (SSRP)	SSP	JSC ITA	The SSRP is a mechanism for enhancing the SSP system safety management and engineering through informational interchanges, development of concepts to improve the SSP safety program, review of safety documentation, review of SSP integration and cargo integration, review of SSP element-level hazard identification and resolution activities, and recommendations to Level 2 management for hazard report disposition. See JSC NSTSPM Directive No. 110, "Space Shuttle Program (SSP) System Safety Review Panel (SSRP) Charter," for further details. The authority of this panel will be increased to include formal ITA approval of hazard reports as a prerequisite to Program approval of same.

FMEA/CIL and Hazard Analysis Process

To ensure the FMEA/CIL and hazard analysis system is appropriately managed, the ITA will own the processes used by safety and reliability review panels for FMEA/CIL and hazard analysis. The independent SMA organizations will also provide chairs for these panels as an ITA function. These chairs will have formal approval authority for FMEAs, CILs, and hazard reports as a prerequisite for program approval of the same. Table 7.5-1-2 summarizes the plan for ownership of the various panels relevant to the Space Shuttle.

Reclama Path for Dissenting Opinions

The ITA will provide a reclama path for dissenting opinions that cannot be addressed appropriately through normal channels. The center elements of the ITA will evaluate dissenting opinions across the technical community and ensure that valid technical issues are not overlooked or overridden by cost and schedule pressures. They will also provide a means to elevate issues to center management, OSF management, OSMA, the Chief Health and Medical Office, and the Office of the Chief Engineer.

ITA Funding

To address the CAIB concern about independence, NASA is establishing a system that provides funding to safety and mission assurance and ITA resources outside the authority of the program and project managers. For Headquarters programs like Space Shuttle and International Space Station (ISS), the Enterprise Institutional Program Office (IPO) will be responsible for ITA funding decisions. In all cases, the newly chartered Headquarters Institutional Executive Committee (IEC) will approve resource requirements of the Enterprise IPOs for center institutions including the ITA. The Chief Engineer and OSMA are permanent voting members of the IEC. To assure the independence of resource decision-making for ITA work, the Agency is establishing a new funding mechanism called "directed" service pools. The center will determine the resources needed to perform ITA tasks for each project, and will budget for them in the SMA/ITA pool. The SMA/ITA service pool will have two independent subpools, one for all program support SMA activities and the other for all non-SMA ITA activities.

STATUS

Three NASA functional offices (OSMA, the Chief Health and Medical Office, and the Office of the Chief Engineer) are developing Agencywide ITA policy, including the use of standards, technical warrants, and the fundamentals of the ITA concept itself. OSF is drafting an ITA Implementation Plan and has begun implementation of basic elements of the ITA for Space Shuttle and Space Station.

FORWARD WORK

Policies for an Agencywide ITA are being drafted and NASA centers are developing plans to implement the ITA. Engineering and Safety Standards are being assessed to determine their applicability to the ITA. Implementation of the ITA at OSF centers is already under way. Key milestones in forward work are shown in Table 7.5-1-3.

Table 7.5-1-3. Schedule of Milestones

Responsibility	Due Date	Activity/Deliverable
OSF Center Director	May 04	Develop Implementation Plan for each OSF center
OSF Center Director	May 04	Assign center ITA manager and identify key ITA personnel
OSF Center Director, AA/OSF, AA/OSMA, NASA Chief Engineer	Jun 04	Determine required human capital resources for each center's ITA through the Program Operating Plan process
AA/SMA and NASA Chief Engineer	Jun 04	Provide necessary policy updates and warrants
OSF Center ITA Organizations	Jun 04	Dry run of key ITA functions prior to return to flight
AA OSF	Jun 04	Official "Standup" of OSF ITA
Center Directors, Enterprises, AA/OSMA, NASA Chief Engineer, Chief Financial Officer	Oct 04	Establishment of independently funded service pools complete

Columbia Accident Investigation Board

Recommendation 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.

BACKGROUND

NASA has developed a draft plan for addressing recommendations 9.1-1 and 7.5-1, 7.5-2, and 7.5-3. This draft plan has been distributed for review and comment. NASA is in the process of addressing the comments received to this draft plan and revising it appropriately before releasing the plan officially. The following is a summary of the draft plan as it exists on April 19, 2004, and as it applies to R7.5-2.

INTRODUCTION

The *Columbia* Accident Investigation Board (CAIB) Report expressed concern about the lack of adequate capability and independence for the Shuttle Safety and Mission Assurance (SMA) personnel. One critical aspect of their concern was the lack of funding independence of the center-based SMA workforce from the program they support. Under full cost management, this conflict of interest appeared to be intensified. Under the leadership of the Associate Administrator (AA), Office of Safety and Mission Assurance (OSMA), NASA has developed a plan to improve the independence and capability of SMA organizations within NASA.

NASA IMPLEMENTATION

Space Shuttle Program

Each Office of Space Flight (OSF) center provides civil service and support contractor resources to meet the SMA requirements of the Program and its projects and elements. With the exception of a small SMA management team working directly for the Program Manager, the civil servants are assigned to SMA organizations that report through the Center Directors to Headquarters rather than through the Program Managers and are thus organizationally independent of the Program. The plan for recommendation 7.5-2 increases their independence by creating a financial mechanism, a directed service pool, for SMA that allows the centers (not the Program) to determine resource levels to meet the program requirements. These resource levels will be approved and budgeted by the OSF Institutional Program Office (IPO) and Institutional Executive Council (IEC) at Headquarters. The result will be that all center SMA personnel will be both organizationally and financially independent of the program they oversee and support. The Independent Technical Authority (ITA) plan also moves the System Safety Review Panel, Ground Safety Review Panel, Payload Safety Review Panel, and Reliability Panel from the Program and program element offices, where they have been, into the center SMA Directorates. The chairs of these panels will report to their various SMA Directors as an ITA function, although their products and services will continue to be provided to the Program. The approval of the chairs of these panels of the safety and reliability plans and products (e.g., hazard reports, Failure Modes and Effects Analysis/Critical Items Lists, etc.) will be a prerequisite to program approval of same (ref. R7.5-1). These changes in center SMA support tasks and independence represent substantial improvements to program checks and balances.

The NASA SMA support for and oversight of the Space Shuttle Program (SSP) consists of three components, program, center SMA, and now ITA personnel. The Program SMA Manager reports directly to the SSP Manager, and is responsible for the safety, reliability, and quality assurance programs within the Program. The Program SMA Manager has a small staff of discipline experts, and through them directs the safety, reliability, and quality activities of the prime contractors as well as the matrixed support personnel from the Johnson Space Center. The Program SMA office also integrates the safety and mission assurance activities performed by the other OSF centers for the various projects and program elements located at the other Centers. The specific authorities given to the center SMA organizations under the auspices of the new ITA will limit the Program SMA Manager's authority over significant safety, reliability, and quality activities. An example is the System Safety Review Panel. The Shuttle SMA Manager enforces the Program requirement to perform hazard analysis on the prime contractor. The prime contractor delivers the hazard

analysis first to the center SMA organization, and approval of the hazard analysis by the center SMA organization will be a prerequisite to the Program's acceptance of the same. Another example is quality standards. In recent years, the SSP adopted the quality assurance standard as a program requirement when the institution (like much of government) backed away from prescriptive standards ownership. The Program Manager took over change authority for that standard through his change board. In the future, the Program SMA Manager will continue as in the past to direct the contractor to carry out quality inspections, but now they will be executing per a NASA quality standard that is "owned" by the ITA. If the Program SMA Manager wants to allow the contractor to deviate, the center ITA must first approve the deviation.

Headquarters Office of Safety and Mission Assurance

OSMA is responsible to the Administrator for policy and functional oversight of all safety, reliability, and quality assurance activities within the Agency. It provides independent assurance and audit of center and program SMA activities, owns Agency SMA standards, and serves as an independent appeal path for issues that cannot be resolved by the centers.

With the implementation of the Agency plan for recommendation 9.1-1 (and thus 7.5-2), appropriate center and program documentation will be changed to require that the AA, OSMA formally approves selection of new program SMA Managers for major programs like Shuttle. Further, the AA, OSMA will be required to approve selection of new center SMA Directors, the Independent Verification and Validation (IV&V) Facility Director, and the NASA Engineering and Safety Center (NESC) Director, and to have a formal "functional manager" assessment as part of their annual performance evaluations. Many of these activities were done informally in the past; this plan formalizes these line authority changes.

To address CAIB Finding F7.4-13, OSMA is also rewriting the policy and process governing the OSMA Prelaunch Assessment Review (PAR). The newly created Review and Assessment Division within OSMA is responsible for developing the process and for standardizing it with other similar reviews for International Space Station missions, expendable launch vehicle missions, and certain experimental aerospace vehicle test flights. The purpose of the PAR is to prepare the AA, OSMA for the Shuttle Flight Readiness Review and provide the technical basis for the AA, OSMA's Certification of Flight Readiness (CoFR) concurrence signature. The policy will clearly require participation by the Program SMA, Center SMA, Independent Assessment (IA), NESC, and IV&V organizations. The PAR agenda will include a summary of SMA activities performed for the mission, as well as a discussion of all outstanding technical issues. Waivers to safety, reliability, and quality standards and requirements, including rationale and risk posture, will be covered, as will any outstanding SMA-related work to be completed prior to the mission, open NASA Safety and Reporting System issues, and CoFR exceptions.

To address the CAIB F7.4-4 concern that system safety policy oversight needed to be elevated at NASA Headquarters, OSMA has hired a dedicated, experienced System Safety Engineer. The first task of the new manager is policy review in conjunction with the Agency policy update.

The NASA Engineering and Safety Centers

The NESC, which will have a continuous presence at each of the OSF centers, represents a substantial increase in the Agency's independent technical capability. Senior NESC engineers will track the progress of the Shuttle Program during return to flight (RTF) with the intent of looking for tough issues, process misses, model or analysis deficiencies, and minority opinions, to work independently. These personnel, although stationed at the OSF centers, are operationally assigned to the Langley Research Center-based NESC, which is in turn functionally overseen by the Headquarters Office of the Chief Engineer and OSMA, and funded by OSMA. The NESC Program Plan was approved in November 2003.

The NESC will have a presence in SSP major reviews and change boards as an advisor/overseer with the authority of the AA, OSMA to intervene as necessary to prevent an unsafe act or avoid unacceptably high risk. Further, the NESC and a member of the OSMA Headquarters staff will participate in Mission Management Team meetings. They will oversee the process and offer advice, technical support, and a link for the Program to the significant independent engineering capabilities resident in the NESC, IA, and IV&V resources if needed.

NESC is developing interfaces with all the centers and with other government, industry and academic institutions. The NESC recently completed the first of its

"prototype" assessments, and has received good reviews on its initial work with the SSP as well as other activities. It provided a needed second opinion recently to the SSP Manager on the subject of Rudder Speed Brake Actuators. As the NESC ramps up to full capability during this fiscal year (FY), it is proving to be a valuable Agency asset.

Other Safety and Mission Assurance Capability Improvements

As in the past, resident at each space flight center (except Stennis) will be a small group of Independent IA personnel. They are funded by OSMA and have access to various independent support contractors as needed to carry out their assessments. They will continue to provide technical and process assessments for a variety of Headquarters and center-based customers under the direct management of the AA, OSMA. However, with the introduction of the NESC, which is primarily responsible for technical assessments, the IA teams will shift their focus to process and functional reviews. They will work with the NESC and Headquarters OSMA as needed to audit and assess program processes against NASA policy and procedures. They will maintain their technical competence by participating in technical reviews and by using their independent contractor workforce as needed for those reviews that require special competencies.

Also new since the *Columbia* accident, the software IV&V personnel that support the SSP at the OSF centers and at the Fairmont, West Virginia, IV&V Facility are now organizationally independent of the Program, and are functionally aligned to and funded by the OSMA. This management system has been in place for approximately 12 months, and represents a change from the system that was in effect for many years, in which the SSP held funding authority over its software IV&V.

SMA Financial Independence

Finally, beginning in 2005, all center SMA support to the SSP will be through directed service pools under the control of the OSF IPO through its four centers. The SSP will give the center its requirements for SMA support, and the center will decide the staffing levels required to meet the requirements. The budget for the center SMA service pools will be presented each year by the IPO to the IEC for approval. The AA, OSMA will be a voting member of that committee.

Prior to these changes, the SSP had funding approval authority for about 99% (based on FY 03 estimates) of the total SMA funding level for Shuttle (includes all contractor and center SMA resources). The remaining 1% consisted of center SMA senior supervisor time and approximately $2M per year of OSMA-funded IA activity. Under the new system, which includes the provision of funding approval independence achieved through the directed service pool, the SSP now has funding approval for only about 70% of the total SMA funding level. Nearly all of this funding pays for Shuttle prime and subcontractor SMA. The remaining 30% funding approval is accomplished through the directed service pool approved by the Headquarters IEC and through Headquarters OSMA. This 30% accounts for all center SMA civil service, all SMA support contractors, and OSMA's NESC, IV&V, and IA that support Shuttle. Part of the reason for this relative shift in funding levels is attributed to OSMA's substantial budget increase. The OSMA budget for FY 04 is in excess of $100M compared to less than $30M for FY 03. The major difference is the transfer of IV&V ($28M) and creation of the NESC ($45M). IV&V and NESC support multiple programs and activities. The NESC funding is expected to increase over the next two years to approximately $95M per year, including civil servant salaries, contractor, and administrative costs.

Recruiting for SMA

One of the concerns expressed by the CAIB, the Aerospace Safety Advisory Panel, and other internal and external reviews over the years has been the difficulty in drawing good engineers to the SMA organizations. As part of the Agency's recent Human Resources initiatives, employees must expand their experience beyond their existing organization, such as working at another center, to be considered for career advancement to executive ranks. As part of the response to R7.5-2, the Agency will allow an engineer to move from his/her engineering/operations/project organization to the local SMA organization for at least two years as an alternative to relocation to another center. This approach will be beneficial to the employee, the SMA organization, and the Program, and it will ensure a steady flow of highly motivated technical people into and out of SMA organizations, with engineers returning to their original organizations with increased awareness of and appreciation for SMA disciplines and systems engineering as a whole.

Feedback

As part of NASA's response to the CAIB concerns about "safety culture," a respected safety consultant, BST, took an Agencywide survey in February. The survey asked

several questions relating to leadership, teamwork, safety climate, and, importantly, upward communications. For the next three years, the Agency will be taking steps to transform the organizational culture with special emphasis on improving the upward communication of safety-related concerns. The results of the first survey have recently been published on the NASA Web site. To supplement the CAIB organizational recommendations (7.5-1, 7.5-2, and 7.5-3), selected intervention techniques will be validated over the next six months to measure their effectiveness in addressing known deficiencies. As time goes on, further surveys will help inform the Agency of the effectiveness of its changes on the safety culture. The next set of surveys is scheduled for the summer of this year at selected NASA sites.

STATUS

OSMA staffing was increased in FY 04 to accommodate new functional oversight responsibilities (NESC, IV&V, NASA Parts Program, and Micrometeoroid Orbital Debris Program). Center SMA civil service staffing has also increased in an effort to meet the RTF workload and address prior weaknesses as a part of OSF RTF. These increases improve the capability and competencies of the SMA community in support of the SSP. A new SMA Office has been established within the SSP. The baseline safety culture survey has been accomplished and results disseminated to the workforce. The NESC has stood up and is providing value added on a daily basis across the Agency. The Agency continues to review all Headquarters policy and procedural requirements directives with the intent of clearing up ambiguities.

FORWARD WORK

Headquarters OSMA will complete its PAR process redefinition. Shuttle CoFR processes continue to evolve to clarify SMA and ITA CoFR signature statements. As we progress to RTF, the NESC will continue to conduct trending and assessments of critical SSP systems and processes. The Agency continues to assess its SMA policies, and to work with BST on culture initiatives and feedback.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
NESC/OSMA	Completed	Fully functional and capable NESC in place
OSMA	Completed	Hire new personnel in OSMA
OSMA	Jun 04	Updated PAR process in place
OSF, OSMA, and SSP	TBD	Redefine CoFR signature statements
ADA Institutions	Summer 04	Follow-on safety culture surveys
OSMA	Through 05	Clarified and consistent Agency SMA Policy

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 inconsistent division of responsibilities between the Space 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). A more robust integration function might have enhanced our ability to recognize the true increase in risk represented by the STS-112 External Tank (ET) bipod ramp foam 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 Space Shuttle Integration Office into a Space Shuttle Systems Engineering and Integration Office (SEIO). The SEIO Manager now reports directly to the SSP Manager, placing the SEIO at a level in the Shuttle organization that establishes its authority and accountability for integration of all Space Shuttle elements.

The new charter clearly establishes the SEIO's responsibility for systems engineering, integration, performance, and safety of the Space Shuttle vehicle in all of its ground and flight activities where multiple project elements are involved. To clarify responsibilities and to sharpen the focus of the SEIO, the Cargo Integration function (and personnel) from the old Shuttle Integration Office were relocated to the Flight Operations and Integration Office, while the Flight Software function was transferred to SEIO. 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

NASA has completed the organizational and functional changes to comply with *Columbia* Accident Investigation Board (CAIB) Recommendation 7.5-3, and is preparing to review the response with the Stafford Covey Return to Flight Task Group.

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

Integration Control Board (ICB): NASA reorganized and revitalized the ICB. This board reviews and approves element recommendations and actions to ensure the appropriate integration of activities in the SSP. The Orbiter Project Office is a mandatory member of the ICB. Orbiter changes that affect multiple elements must go through the ICB process prior to SSP approval.

Space Shuttle Flight Software Office: Functions with multielement integration were relocated from the Orbiter Project to the SEIO. The Space Shuttle Flight Software organization was moved from the Orbiter Project to the SEIO, since the Flight Software Office manages software for multiple flight hardware elements in addition to the Orbiter. Because many integrated Space Shuttle performance requirements are implemented through flight software, this change provides a more comprehensive view of the Space Shuttle as an integrated vehicle. Also, since almost any change to the Shuttle hardware has a corresponding flight software change, placing the flight software function inside SEIO improves the Program's ability to detect and control the integration of element design changes. Finally, this move also strengthens the SSP by placing the Shuttle Avionics Integration Laboratory within the SEIO.

Systems Integration at Other Centers: 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 Engineering Integration Office (PSEIO) has increased its contractor and civil service technical strength and its responsibilities within the Program. Agreements between the PSEIO Project Office and the appropriate MSFC Engineering organizations were expanded to enhance anomaly resolution within the SSP. MSFC Engineering personnel participate in appropriate Program-level integration boards and panels, such as Structures and Loads; Aerodynamics; Aerothermodynamics; and Guidance, Navigation, and Control. PSEIO also participates in MSFC Element-level boards (e.g., Configuration Control Board, Element Acceptance Review, and Preflight Review) and brings a focused systems perspective and enhanced visibility into changes and anomalies affecting multiple Program elements. A PSEIO Review Board has been established to address the systems issues and ensure that the items are evaluated, tracked, and worked with the program SEIO.

System Integration Plan (SIP) Design Change Tool and the Master Verification Plans (MVPs): The role of the SIP has been revitalized. The SIPs are being developed for all major return to flight (RTF) design changes that impact multiple Shuttle elements. The SEIO is now responsible for all SIPs. The SIP Design Change Tool will further energize SEIO to be a proactive function within the SSP for integration of design changes and verification. MVPs are being updated to reflect consistent definition and usage of verification, validation, and certification and to enable a Design Certification Review effort prior to RTF.

Debris Environments Analyses: The SEIO is responsible for generating 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 (TPS) 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.

Testing: SEIO is either leading or playing a major role in planning and executing the following tests in support of RTF:

- 3% Wind Tunnel test to save ET redesigned bipod ramp
- Mobile Launch Platform rollout loads fatigue environment test
- Full-scale Reinforced Carbon-Carbon impact testing
- Main Propulsion System prevalve filter effectiveness tests
- Main Propulsion System flowliner tests
- Debris radar cross-section tests
- Booster Separation Motor debris tests

Independent Assessments: A major challenge facing the SSP is to determine if the scope and quality of SEIO's work is sufficient to deliver high-quality systems engineering and integration. To assure this, the SSP formed a standing independent assessment team to evaluate the performance of the SEIO function. The team is composed of members with experience in integrating large, complex flight systems. The team's first review was held in January 2004. Also, the SSP has contracted with the Aerospace Corporation to provide daily consultations on systems engineering and integration methodologies and specific vehicle technical issues. Aerospace Corporation has completed an audit of the SEIO function according to the Carnegie Mellon System Engineering Capability Maturity Model. Additionally, a Debris Transport Independent Assessment Team composed of experts from NASA, industry, and academia conducted a special independent assessment of SEIO's debris transport methodology. Significant improvements to the model were made as a result of this review.

Integrated Planning: SEIO is involved in the following planning activities:

- RTF integrated schedule
- Instrumentation to accompany RTF
- RTF imagery, including both ground and flight
- System integration plans for RTF design changes, such as ET bipod, Solid Rocket Booster bolt catcher, debris generation, debris transport, and debris impact tolerance
- In-flight operations concept for integrating TPS impact and damage assessments

- Night launch operations concept
- Integrated test plans for component testing
- RTF Design Certification Review

Linkages to Other Program Functions: SEIO has increased its engineering civil service staff from 7 to 17 and added a Chief Engineer for Integration to ensure that SEIO takes full advantage of JSC engineering resources. MSFC Engineering now sits as a cochair on systems engineering and integration (SE&I) panels to assure a thorough technical review; NASA Aeronautics Centers (Ames Research Center, Dryden Flight Research Center, Langley Research Center, and Glenn Research Center) are now invited to SE&I panels. The ET Project and Safety and Mission Assurance Directorate now have team members colocated with SEIO until the RTF redesign is completed.

FORWARD WORK

The organizational changes and resource increases to SEIO fully answer the CAIB findings that NASA had diminished its systems engineering capability beyond an acceptable level. The revitalized SEIO provides an enhanced focus on engineering excellence and proactive identification and mitigation of multielement integrated risks. This office has provided critical integration and leadership on complex tasks that will enable us to return safely to flight. NASA will review its response to this CAIB recommendation with the Stafford Covey Return to Flight Task Group as a subset of the CAIB Recommendation R9.1-1.

SCHEDULE

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

Columbia Accident Investigation Board

Recommendation 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]

INTRODUCTION

NASA has developed a draft plan for addressing recommendations 9.1-1 and 7.5-1, 7.5-2, and 7.5-3. This draft plan has been distributed for review and comment. NASA is in the process of addressing the comments received to this draft plan and revising it appropriately before releasing the plan officially. The following is a summary of the draft plan as it exists on April 19, 2004, and as it applies to R7.5-1, R7.5-2, and R7.5-3. The R9.1-1 plan outlines the approach for addressing recommendations 7.5-1, 7.5-2, and 7.5-3 by outlining the policies and plans for establishing an independent technical authority (ITA), improved independent safety and mission assurance capability, and enhanced systems integration for all NASA programs and for Shuttle specifically. For further details, refer to the sections of this Plan addressing recommendations 7.5-1, 7.5-2, and 7.5-3 specifically.

NASA IMPLEMENTATION

NASA Headquarters is responsible for providing leadership, policy, oversight, and direction for the Agency in various functional and programmatic areas. The Enterprises, through their Field Centers, are responsible for executing their programs within the bounds of the policies, oversight, and direction by Headquarters. The R9.1-1 Plan outlines the roles and responsibilities of Headquarters functional offices, the Enterprises, and the Field Centers to meet the *Columbia* Accident Investigation Board (CAIB) recommendations 7.5-1, 7.5-2, and 7.5-3.

Additionally, the plan acknowledges that such far-reaching changes must be addressed from a systems perspective to understand and avoid the unintended negative consequences of change. To do this, the plan establishes clear lines of authority, provides capability to match its authority, and minimizes duplication of accountability. Further, it clarifies total program safety accountability and limits unnecessary layers to NASA assurance organizations.

STATUS

NASA's first interim report addressing CAIB Recommendation 9.1-1 is under review and will be forwarded to the Return to Flight Task Group for review and comment. Although the CAIB recommendation only requires preparation of a detailed plan prior to return to flight, NASA concludes that this important issue requires prompt implementation. Therefore, NASA has begun taking the first steps to establish the policies, procedures, and organizations required to implement these CAIB recommendations within the Office of Space Flight (OSF). For a more detailed status of progress, refer to the sections in this plan addressing recommendations 7.5-1, 7.5-2, and 7.5-3.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
OSF Center Director	May 04	Develop Implementation Plan for each OSF Center
Associate Administrator OSF	Jun 04	OSF ITA Standup
Office of Safety and Mission Assurance	Each year as part of budget submission	Annual Reports to Congress

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 the Space Shuttle Service Life Extension Program (SLEP) to extend the vehicle's useful life. When SLEP was initiated, evaluation of the vehicle's mid-life recertification needs was a foundational activity. On January 14, 2004, the Vision for Space Exploration was announced. The vision shortens the required service life of the Space Shuttle Orbiter and, as a result, the scope of vehicle mid-life certification was changed substantially. Under the vision, the Shuttle will be retired following assembly of the International Space Station planned for the end of this decade.

NASA IMPLEMENTATION

Despite the reduced time frame for the operation of the Shuttle, NASA continues to place a high priority on maintaining the safety and capability of the Orbiters. A key element of this is timely verification that hardware processing and operations are within qualification and certification limits. This activity will revalidate the operational environments (e.g., loads, vibration, acoustic, and thermal environments) used in the original certification. This action is addressed in SSP-13.

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 SLEP requirements. The identification of these requirements puts NASA on track for making appropriate choices for resource investments in the context of the Vision for Space Exploration.

STATUS

In May 2003, the Space Flight Leadership Council (SFLC) approved the first SLEP 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. In March 2004, the annual SLEP summit revisited some of the critical issues for life extension and began a review of how to appropriately refocus available resources for the greatest benefit to NASA.

FORWARD WORK

Following SLEP Summit II, the SFLC issued two key actions to develop options for refocusing the SLEP and revalidating specific projects. First, the Space Shuttle Program (SSP) was asked to provide a description of the current Space Shuttle certification status by April 2004. Second, the manager of the SSP Development Office was asked to define the criteria that will be used for Shuttle certification investments by July 2004. The results of these actions will be presented to the Program Requirements Control Board (PRCB) and then to the SFLC for review.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 04	Present defined Space Shuttle certification criteria to the PRCB
SSP	Aug 04	Present status of current Space Shuttle certification to the PRCB

Columbia Accident Investigation Board

Recommendation 10.3-1

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

BACKGROUND

Closeout photography is used, in part, to document differences between actual hardware configuration and the engineering drawing system. The *Columbia* Accident Investigation Board (CAIB) recognized the complexity of the Shuttle drawing system and the inherent potential for error and recommended an upgrade to it (ref. 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 now uses primarily digital photography. Photographs are taken for various reasons, such as to document major modifications, visual discrepancies in flight hardware or flight configuration, and vehicle areas that are closed for flight. SIMS can be accessed by NASA employees and support contractors. Previously, images were difficult to locate, since they were typically retrieved by a cross-reference to the work-authorizing document that specifies them.

NASA IMPLEMENTATION

NASA formed a Photo Closeout Team consisting of members from the engineering, quality, and technical communities to identify and implement necessary upgrades to the processes and equipment involved in vehicle closeout photography. KSC closeout photography includes the Orbiter, Space Shuttle Main Engine, Solid Rocket Boosters, and External Tank based on Element Project requirements. The Photo Closeout Team divided the CAIB action into two main elements: (1) increasing the quantity and quality of closeout photographs, and (2) improving the retrieval process through a user-friendly Web-based graphical interface system (figure 10.3-1-1).

Increasing the Quantity and Quality of Photographs

Led by the Photo Closeout Team, the Space Shuttle Program (SSP) completed an extensive review of existing closeout photo requirements. This multi-center, multi-element, NASA and contractor team systematically identified the deficiencies of the current system and assembled and prioritized improvements for all Program elements. These priorities were distilled into a set of revised requirements that has been incorporated into Program documentation. Newly identified requirements included improved closeout photography of extravehicular activity tool contingency configurations and middeck and payload bay configuration. NASA has also added a formal photography work step for KSC-generated documentation and mandated that photography of all Material Review Board (MRB) reports be archived in the SIMS. These MRB problem reports provide the formal documentation of known subsystem and component discrepancies, such as differences from engineering drawings.

To meet the new requirements and ensure a comprehensive and accurate database of photos, NASA established a baseline for photo equipment and quality standards, initiated a training and certification program to ensure that all operators understand and can meet these requirements, and improved the SIMS. Also NASA, to verify the quality of the photos being taken and archived, has developed an ongoing process that calls for SIMS administrators to continually audit the photos being submitted for archiving in the SIMS. Operators who fail to meet the photo requirements will be decertified pending further training. Additionally, to ensure the robustness of the archive, poor-quality photos will not be archived.

NASA determined that the minimum resolution for closeout photography should be 6.1 megapixels to provide the necessary clarity and detail. KSC has procured 36 Nikon 6.1 megapixel cameras and completed a test program in cooperation with Nikon to ensure that the cameras meet NASA's requirements.

Improving the Photograph Retrieval Process

To improve the accessibility of this rich database of Shuttle closeout images, NASA has enhanced SIMS by developing a Web-based graphical interface. Users will be able to easily view the desired Shuttle elements and systems

and quickly drill down to specific components, as well as select photos from specific Orbiters and missions. SIMS will also include hardware reference drawings to help users identify hardware locations by zones. These enhancements will enable the Mission Evaluation Room (MER) and Mission Management Team to quickly and intuitively access relevant photos without lengthy searches, improving their ability to respond to contingencies.

To support these equipment and database improvements, NASA and United Space Alliance (USA) have developed a training program for all operators to ensure consistent photo quality and to provide formal certification for all camera operators. Additional training programs have also been established to train and certify Quality Control Inspectors and Systems Engineering personnel; to train Johnson Space Center (JSC) SIMS end users, such as staff in the MER; and to provide a general SIMS familiarization course. An independent Web-based SIMS familiarization training course is also in development.

STATUS

NASA has revised the Operation and Maintenance Requirements System (OMRS) to mandate that general closeout photography be performed at the time of the normal closeout inspection process and that digital photographs be archived in SIMS. Overlapping photographs will be taken to capture large areas. NSTS 07700 Volume IV and the KSC MRB Operating Procedure have also been updated to mandate that photography of visible MRB conditions be entered into the SIMS closeout photography database. This requirement ensures that all known critical subsystem configurations that differ from Engineering Drawings are documented and available in SIMS to aid in engineering evaluation and on-orbit troubleshooting.

The revised Shuttle Program closeout photography requirements are documented in RCN KS16347R1 to OMRS File II, Volume I S00GEN.625 and S00GEN.620. Additionally, NASA Quality Planning Requirements Document

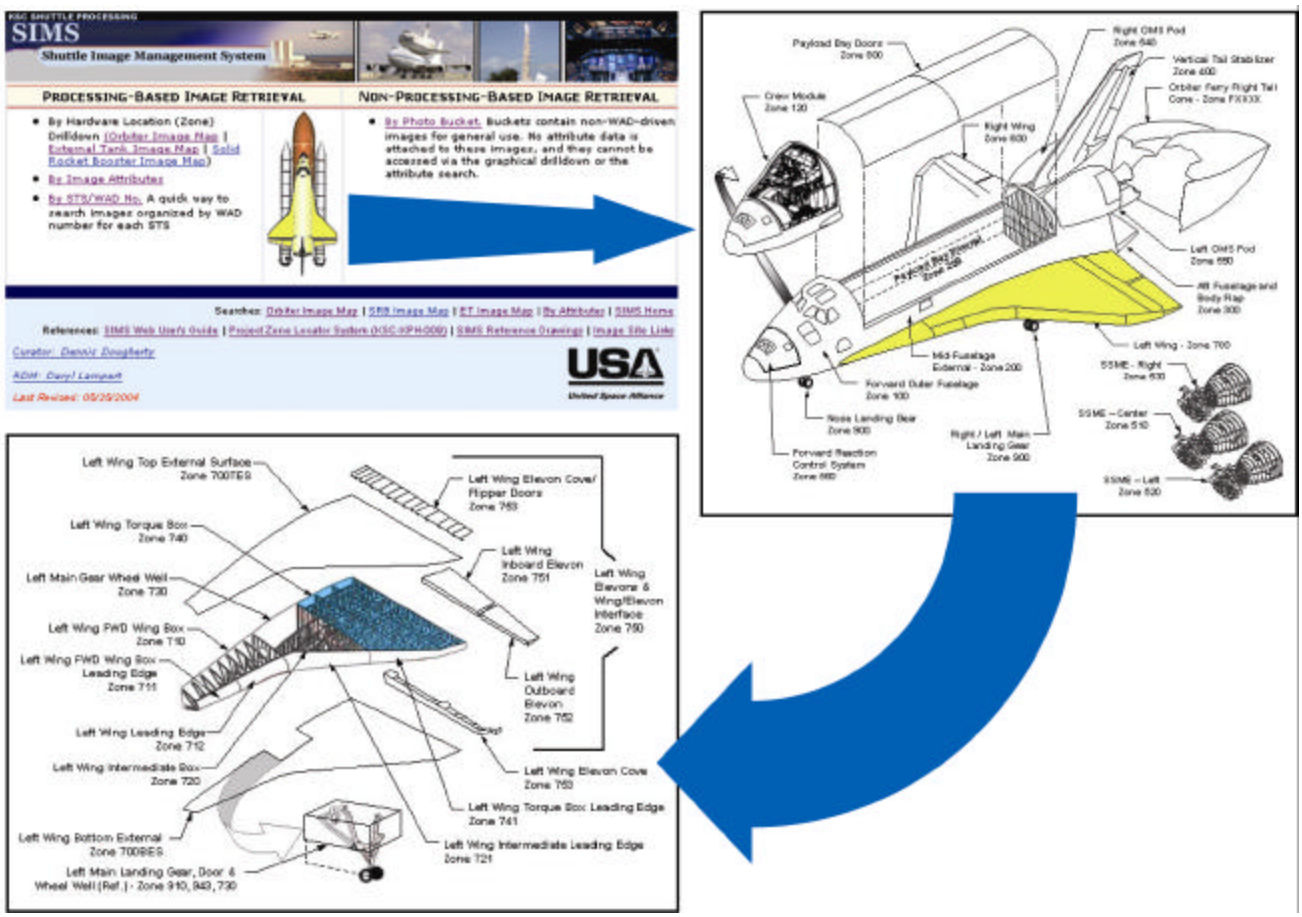


Figure 10.3-1-1. Enhanced SIMS graphic interface.

(QPRD) SFOC-GO0007 Revision L and USA Operation Procedure USA 004644, "Inspection Points and Personnel Traceability Codes," were updated to be consistent with the revised OMRS and QPRD documents.

The upgraded SIMS is operational and available for use by all SSP elements. Training is complete for critical personnel, and training will be ongoing to ensure the broadest possible dissemination within the user community.

FORWARD WORK

Training for Marshall Space Flight Center (MSFC) MER members will take place during the summer of 2004. NASA will review its response to this CAIB recommendation with the Stafford-Covey Return To Flight Task Group.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Feb 04 (Completed)	Develop SIMS drilldown and graphical require-ments
SSP	Apr 04 (Completed)	Projects transmit photo requirements to KSC Ground Operations
KSC	May 04 (Completed)	Complete graphical drilldown software implementation
KSC	Jun 04 (Completed)	Develop/complete SIMS training module
KSC	Jun 04 (JSC training completed)	Provide training to MER. Demonstrate SIMS interface to JSC/MSFC

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 (CAD) system.

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

NASA IMPLEMENTATION

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

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

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

STATUS

To date, the DSP 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 specifications to solid surfaces.
- Established a scanning capability at Kennedy Space Center to acquire as-built configuration information.
- Developed professional relationships with software vendors to evolve their standard products to meet SSP needs.
- Developed a prototype infrastructure to manage and share engineering data.
- Interviewed key SSP personnel to identify knowledge management issues.

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

FORWARD WORK

NASA will develop detailed plans and costs for upgrading the Shuttle engineering drawing system. Currently in the formulation phase, the work that remains to be completed includes assessing current design documentation and developing drawing conversion standards, a concept of operations, a system architecture, and procurement strategies. At the conclusion of this phase, the DSP will present detailed plans and costs for upgrading the Shuttle engineering drawing system and seek SSP authorization to proceed with implementation. SSP decisions on investments in digitization will be made bearing in mind the planned end of Shuttle operations following the completion of International Space Station assembly.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	May 04	Begin engineering order incorporation
SSP	Jun 04	Present drawing conversion concept to the Program Requirements Control Board

2 Raising the Bar – Other Corrective Actions

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

Space Shuttle Program Actions

NASA continues to receive and evaluate inputs from a variety of sources, including those that have been generated from within the Space Shuttle Program. It is systematically assessing all corrective actions and has incorporated many of these actions in this Implementation Plan. This section contains self-imposed actions and directives of the Space Shuttle Program that are being worked in addition to the constraints to flight recommended by the Columbia *Accident Investigation Board.*

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 1

NASA will commission an assessment, independent of the Space Shuttle Program (SSP), of the Quality Planning and Requirements Document (QPRD) to determine the effectiveness of government mandatory inspection point (GMIP) criteria in assuring verification of critical functions before each Shuttle mission. The assessment will determine the adequacy of existing GMIPs to meet the QPRD criteria. Over the long term, NASA will periodically review the effectiveness of the QPRD inspection criteria against ground processing and flight experience to verify that GMIPs are effectively assuring safe flight operations. This action also encompasses an independently led bottom-up review of the Kennedy Space Center Quality Planning Requirements Document (CAIB Observation 10.4-1).

BACKGROUND

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

NASA IMPLEMENTATION

The Space Flight Leadership Council (SFLC) and the Associate Administrator for Safety and Mission Assurance, with concurrence from the Safety and Mission Assurance (SMA) Directors at KSC, Johnson Space Center (JSC), and MSFC, chartered an independent assessment of the Space Shuttle Program (SSP) GMIPs for KSC Orbiter Processing and MAF External Tank manufacturing. The SFLC also approved the establishment of an assessment team consisting of members from various NASA centers, the Federal Aviation Administration, the U.S. Army, and the U.S. Air Force. This Independent Assessment Team (IAT) assessed the KSC QPRD and the MAF Mandatory Inspection Document criteria, their associated quality assurance processes, and the organizations that perform them. The team issued a final report in January 2004, and the report recommendations have become formal SSP actions. The report is also being used as a basis for the SSP to evaluate similar GMIP activity at other Space Shuttle manufacturing and processing locations. The IAT report concluded that the NASA quality assurance programs in place today are relatively good, based on the ground rules that were in effect when the programs were formulated; however, these rules have changed since the programs' formulation. The IAT recommended that NASA reassess its quality assurance requirements based on the modified ground rules established as a result of the *Columbia* accident. The modified ground rules for the Space Shuttle include an acknowledgement that the Shuttle is an aging, relatively high-risk development vehicle. As a result, the NASA Safety and Mission Assurance Quality Assurance Program must help to ensure both safe hardware and an effective contractor quality program.

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

- Strengthen the Agency-level policy and guidance to specify the key components of a comprehensive Quality Assurance Program that includes the appropriate application of GMIPs
- Establish a formal process for periodically reviewing QPRD and GMIP requirements at KSC and the Mandatory Inspection Documents and GMIPs at MAF against updates to risk management documentation (hazard analyses, failure modes and effects analyses/critical item list) and other system changes
- Continue to define and implement formal, flexible processes for changing the QPRD and adding, changing, or deleting GMIPs
- Document and implement a comprehensive Quality Assurance Program at KSC in support of the SSP activities

- Develop and implement a well-defined, systematically deployed Quality Assurance Program at MAF

In parallel with the IAT's review, a new process to make changes to GMIP requirements was developed, approved, and baselined at KSC. This process ensures that anyone can submit a proposed GMIP change, and that the initiator who requests a change receives notification of the disposition of the request and the associated rationale. That effort was completed in September 2003. Since then, several change requests have been processed, and the lessons learned from those requests have been captured in a formal revision A of the change process document, KDP-P-1822, Rev. A. This process will use a database for tracking the change proposal, the review team's recommendations, and the Change Board's decisions. The database automatically notifies the requester of the decision, and the process establishes a means to appeal decisions.

STATUS

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

- A formal process was implemented to revise GMIPs
- A change review board comprised of the Shuttle Processing Chief Engineer, SMA, and, as applicable, contractor engineering representatives has been designated to disposition proposed changes
- A new process is under development to document and to implement temporary GMIPs while permanent GMIP changes are pending, or as deemed necessary for one-time or infrequent activities. The new process will also cover supplemental inspection points
- A pilot project was initiated to trend GMIP accept/reject data to enhance first-time quality determination and identify paths for root cause correction
- Surveillance has been increased through additional random inspections for hardware and compliance audits for processes
- Enhanced Quality Inspector training, based on benchmarking similar processes, is under development
- A QPRD Baseline Review began March 22, 2004. This review will cover all systems and be complete in approximately one year

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

- Applying CAIB observations and the IAT recommendations to all MSFC propulsion elements
- Formalizing and documenting processes that have been in place for Quality Assurance program planning and execution at each manufacturing location
- Increasing the number of inspection points for External Tank assembly
- Increasing the level and scope of vendor audits (process, system, and supplier audits)
- Improving training across the entire MSFC SMA community, with concentration on the staff stationed at manufacturer and vendor resident management offices
- Further strengthening the overall Space Shuttle Quality Assurance Program by establishing a new management position and filling it on the Shuttle SMA Manager's staff with a specific focus on Quality

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC Shuttle Processing	Sep 03 (Completed)	Develop and implement GMIP change process
Headquarters	Oct 03 (Completed)	Report out from IAT
Headquarters	Jan 04 (Completed)	Publish the IAT report
KSC Shuttle Processing	Mar 04 (Completed)	Develop process for review of QPRD and kick off the baseline review
KSC Shuttle Processing	Apr 04	Develop and implement temporary GMIP process
KSC Shuttle Processing	Mar 05	Complete baseline review of QPRD

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 (CAIB) observed that NASA should take steps to mitigate the risk to the public from Orbiter entries. Before returning to flight, NASA is dedicated to understanding and diminishing potential risks associated with entry overflight, a topic that is also covered in CAIB Observations 10.1-2 and 10.1-3.

NASA IMPLEMENTATION

The overflight risk from impacting debris is a function of three fundamental factors: (1) the probability of vehicle loss of control (LOC) and subsequent breakup, (2) surviving debris, and (3) the population living under the entry flight path. NASA is identifying phases of entry that present a greater probability of LOC based on elements such as increased load factors, aerodynamic pressures, and 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. The measures undertaken to improve crew safety and vehicle health will result in a lower probability of LOC, thereby improving the public safety during entry overflight.

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

The results of these analyses will determine if some ground tracks must be removed from consideration as normal, preplanned, end-of-mission landing opportunities. In addition, NASA will incorporate population overflight, as well as crew considerations, into the entry flight rules that guide the flight control team's selection from the remaining landing opportunities. NASA will work with the U.S. Department of State, if any coordination with other countries is necessary to evaluate and mitigate public risk.

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 previously used Shuttle orbit inclinations: 28.5° (Hubble Space Telescope), 39.0° (STS-107), and 51.6° (International Space Station). The full range of entry crossrange[1] possibilities to each site was studied in increments of 25 nautical miles for all ascending (south to north) and descending (north to south) approaches. Figure SSP 2-1 displays the ground tracks simulated for the 51.6° inclination orbit. Although these preliminary results indicate that some landing opportunities have an increased public risk compared to others, the uncertainty of the input factors must be further reduced in order to make reliable decisions regarding public risk.

NASA Headquarters released a draft policy on ensuring public safety during all phases of space flight missions. The policy is currently under review by all stakeholders.

FORWARD WORK

The Space Shuttle Program (SSP) has generated preliminary data to compare public risk among various landing opportunities. This 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 analyses, research, and data obtained as part of this RTF effort. This shared work is being applied to the development of an Agency public safety policy for all phases of space flight missions.

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

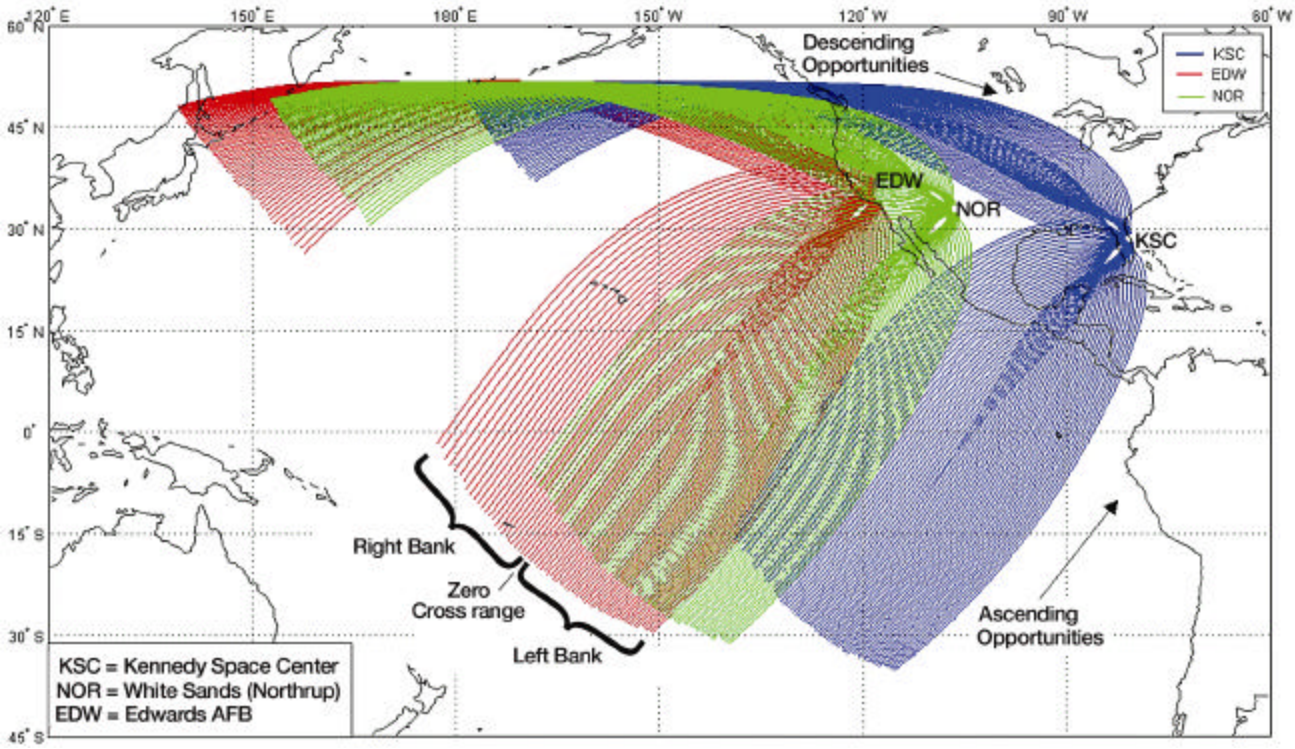


Figure SSP 2-1. Possible entry ground tracks from 51.6° orbit inclination. Blue lines are landing at KSC, green at NOR, red at EDW.

SCHEDULE

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

It is prudent for NASA to examine options for providing an emergency capability to sustain Shuttle crews on the International Space Station (ISS), should the Orbiter become unfit for entry. This Contingency Shuttle Crew Support (CSCS) capability could, in an emergency, sustain a Shuttle crew on board the ISS for a limited time to enable a repair to the Orbiter or allow the crew to be returned to Earth via a rescue mission. CSCS is not intended to mitigate known but unacceptable risks; rather, it is a contingency plan of last resort with limited capability to sustain the crew on the ISS. CSCS is not a certified capability with redundancy.

NASA IMPLEMENTATION

The fundamental rationale for return to flight is the elimination of critical debris from the External Tank (ET). NASA will resume Shuttle missions only when we have sufficient confidence in the ET to allow us to fly. While CSCS will offer a viable emergency capability for crew rescue, it will not be used to justify flying a Shuttle that is otherwise deemed unsafe.

After the ET is made safe, CSCS will provide an additional level of mitigation from residual risk. This is particularly desirable during the first few flights when we will be validating the improvements made to the Shuttle system. It is highly unlikely that the combination of failures necessary to lead NASA to invoke the CSCS capability will occur. It is secondary risk control and will be accomplished with zero fault tolerance in areas where ISS resources are taxed by an increased crew size. This approach is consistent with how NASA addresses other emergency measures, such as contingency launch aborts, to reduce residual risk to the crew.

STATUS

At the Space Flight Leadership Council (SFLC) on June 9, 2004, NASA approved the joint Space Shuttle Program (SSP)/ISS proposal to pursue CSCS as a contingency capability for STS-114 and STS-121. NASA will revisit the feasibility and need for continued CSCS capability following STS-121. CSCS capability will not be fault tolerant and is built on the presumption that, if necessary, all ISS consumables in addition to all Shuttle reserves will be depleted to support it. In the most extreme CSCS scenarios, it is possible that ISS will be decrewed following Shuttle crew rescue until consumables margins can be reestablished and a favorable safety review is completed. For the first two flights, NASA will ensure that the SSP has the capability to launch a rescue Shuttle mission within the time period that the ISS Program can reasonably predict that the Shuttle crew can be sustained on the ISS. This time period, which is referred to as the ISS "engineering estimate" of supportable CSCS duration, represents a point between worst- and best-case operational scenarios for the ISS based on engineering judgment and operational experience.

For planning purposes, NASA is assuming that the failures preventing the entry of the stranded Orbiter can be resolved before launching the rescue Shuttle. In an actual CSCS situation, it may not be possible to protect the rescue Shuttle from the hazards that resulted in the damage that precipitated the need for a rescue, and a difficult risk-risk trade analysis will be performed at the Agency level or above before proceeding to launch.

Contingency Capability for CSCS

CSCS is a contingency capability that will be employed only under the direst emergency situations. In NASA's formal risk management system, CSCS does not improve an otherwise "unacceptable" risk into the "accepted" category. The implementation of risk mitigation efforts such as CSCS will be accomplished to the greatest degree practicable, but are not formal controls to the SSP Integrated Hazards of "Degraded Functioning of Orbiter Thermal Protection System" and "Damage to the Windows Caused by the Natural or Induced Debris Environment." Since the acceptance rationale is not a formal control of the hazard, verification standards for this rationale are based on informed decisions by the Program management.

The use of CSCS as a contingency capability is analogous to some of our other abort modes. The ability to perform emergency deorbits provides some protection against

cabin leaks and multiple system failures. Contingency ascent aborts offer the ability to abort launches to contingency landing sites as protection against two or three Space Shuttle Main Engine failures. In both of these examples, as in many others, the capability is not certified for all, or even most, scenarios. Nevertheless, they do offer mitigation against residual risk and uncertainty. Another analogy can be drawn between CSCS and the ejection seats that were installed in the Orbiter for the first four flights of the Shuttle Program. They offered some crew escape capability during the first part of ascent and the last part of descent and landing, but they by no means represented comprehensive protection. However, they were an appropriate and valuable additional risk mitigation during the conduct of the initial test flights that validated the performance of the Shuttle system.

CSCS Requirements

The SSP and ISS Program have been working to define CSCS requirements using our established Joint Program Requirements Control Board (JPRCB) process. CSCS capability is not premised on the use of any International Partner resources other than those that are an integral part of joint ISS operations, such as common environmental health and monitoring systems. The additional capabilities that could be brought to bear by the International Partners to support CSCS could provide added performance margin.

The ISS Program, working with the Space and Life Sciences Directorate, has analyzed the impacts of maintaining up to seven additional people on the ISS in the event of CSCS. Their analyses indicate that at current operating levels, CSCS is feasible for long enough to allow the launch of a rescue mission: with current assumptions for a March 2005 launch, the ISS engineering estimate for STS-114 is approximately 59 days. The systems status will be updated continually as we approach a mission that calls for CSCS capability, and the ISS engineering estimate of CSCS duration will be revised accordingly.

The ISS Program is pursuing additional logistics to enable a more robust CSCS capability. NASA has begun coordination with the ISS International Partners to discuss the concept. NASA will evaluate current Shuttle and ISS support capabilities for crew rescue during CSCS and explore ways of using all available resources to extend CSCS to its maximum duration. This will involve making recommendations on operational techniques, such as undocking the Orbiter after depletion of usable consumables and having another Shuttle available for launch to rescue the crew within the projected CSCS duration. These actions are outside of the current flight rules and Orbiter performance capabilities and will need to be fully assessed. Currently NASA is assuming that STS-114 will require no newly developed Shuttle or ISS performance capabilities to enable CSCS. NASA will also evaluate CSCS options to maximize Shuttle/ISS docked capabilities. These options, such as power-downs and resource-saving measures, will be used to extend the time available for contingency operations including Thermal Protection System inspection and repair.

In addition to CSCS capability, NASA is evaluating the capability to launch on need to provide crew rescue. Using this capability, NASA could have a second Shuttle, designated STS-300, ready for launch on short notice during all missions. The ability to launch a rescue mission within the predicted CSCS duration will be held as a constraint to launch. The SSP, working with Safety and Mission Assurance and the ISS Program, is developing detailed criteria for the constraint. These criteria will be reported to the JPRCB.

NASA's designated rescue missions will be subject to the same development requirements as any other Shuttle mission; however, they will be processed on an accelerated schedule. Current estimates are that STS-300, the rescue mission for our first flight, can be processed for launch in approximately 45 days following the launch of STS-114. Processing time for STS-301 will be approximately 58 days following STS-121. These assessments assume a work acceleration to three shifts per day, seven days a week, but no deletion of requirements or alteration of protocols. Preplanning such extraordinary additional acceleration is not necessary, but provides another source of potential CSCS performance margin.

Stranded Orbiter Undocking, Separation, and Disposal

The Mission Operations Directorate has developed procedures for undocking a stranded Orbiter from the ISS, separating to a safe distance, then conducting a deorbit burn to disposal into an uninhabited oceanic area. These procedures have been worked in detail at the ISS Safe Haven Joint Operations Panel (JOP), and have been simulated in a joint integrated simulation involving flight controllers and flight crews from both the ISS Program and the SSP. Additional details will be refined, but the requirements and procedures for safely conducting a disposal of a stranded Orbiter are well understood.

Current plans call for the Orbiter crew to conduct a rewiring in-flight maintenance procedure on the day prior to disposal that would "hot wire" the docking system hook motors to an unpowered main electrical bus. Before abandoning the Orbiter

and closing the hatches, the crew would set up the cockpit switches to enable all necessary attitude control, orbital maneuvering, and ground uplink control systems. On the day of disposal, after the hatches are closed, Mission Control would uplink a ground command to re-power the bus, immediately driving the hooks to the open position. The rewiring procedure is well understood and within the SSP's experience base of successful on-orbit maintenance work.

The Orbiter will separate vertically upward and away from the ISS. Orbital mechanics effects will increase the relative opening rate and ensure a safe separation. The Mission Control Center will continue to control the attitude of the Orbiter within safe parameters. Once the Orbiter is farther than 1000 ft from the ISS, the attitude control motors will be used to increase the separation rate and to set up for the disposal burn for steep entry into Earth's atmosphere. The primary targeted impact zone would be near the western (beginning) end of an extremely long range of remote ocean. Planning a steep entry reduces the debris footprint; targeting the western end protects against eastward footprint migration due to underburn. This disposal plan has been developed with the benefit of lessons learned from the deorbit, ballistic entry, and ocean disposal of the Compton Gamma Ray Observatory in June 2000 and the Russian *Mir* Space Station in 2001.

FORWARD WORK

NASA will pursue the CSCS capability to a contingency level in support of the full joint crew.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
ISS Program	Aug 03 (Completed)	Status International Partners at Multilateral Mission Control Boards
ISS Program	Nov 03 (Completed)	Assess ISS systems capabilities and spares plan and provide recommendations to ISS and SSP
ISS Program	Jun 04 (Completed)	Develop CSCS Integrated Logistics Plan
ISS Program and SSP	Jun 04 (Completed)	Develop waste management and water balance plans
ISS Program and SSP	Jun 04 (Completed)	Develop ISS Prelaunch Assessment Criteria
ISS Program	Jun 04 (Completed)	Develop food management plan
SSP/ISS Program	Jun 04 (Completed)	Develop crew health and exercise protocols
ISS Program	Jun 04 (Completed)	Assess and report ISS ability to support CSCS
SSP/ISS Program	Aug 04	Safe Haven JOP report to JPRCB on requirements to implement CSCS

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 4

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

BACKGROUND

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

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

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

NASA IMPLEMENTATION

Each Space Shuttle Program (SSP) project will perform the following assessment for each accepted risk hazard report and any additional hazard reports indicated 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 as 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 SSP documentation.
6. Identify any additional feasible controls that can be implemented that were not originally identified and verified.
7. Assure that all causes have been identified and controls documented.

The System Safety Review Panel (SSRP) will serve as the forum to review the project's assessment of the validity and applicability of controls. The SSRP will assess the existence and effectiveness of controls documented in the hazard reports. In accordance with SSP requirements, the SSRP will review, process, and disposition updates to baselined hazard reports.

Although the scope of the 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. The Reusable Solid Rocket Motor and Extravehicular Activity Projects have completed their reviews. Their results have been presented to the Program Requirements Control Board and accepted by the Program. All Program elements have plans to complete accepted risk reviews by late summer 2004. Additionally, all elements intend to complete reviews of controlled hazard reports by the end of 2004.

NASA is undertaking an extensive rewrite of the External Tank (ET) and integration hazards for the Shuttle. As a result of this more rigorous hazard documentation process, risk will be more fully understood and mitigated before RTF. A special RTF panel of the SSRP is participating in the review and design process of those items requiring redesign or new hardware for flight; this includes ET bipod and Solid Rocket Booster bolt catcher among other items. NASA is committed to continuous, thorough reviews and updates of all hazards for the remaining life of the Shuttle Program.

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
SSRP	Oct 03 (Completed)	SSRP review element hazards and critical items list review processes Kennedy Space Center Sep 9, 11 Reusable Solid Rocket Motor Sep 24, 25 Integration Oct Solid Rocket Booster Sep 8 Space Shuttle Main Engine Oct 7, 8
SSP	Aug 04 (Ongoing)	Identify and review “Accepted Risk” hazard report causes and process impacts
SSP	Sep 04 (Ongoing)	Analyze implementation data
SSP	Sep 04	Validate and verify controls and verification methods
SSP	Oct 04	Develop, coordinate, and present results and recommendation
SSP	Dec 04	Review all hazard reports

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. It 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 Shuttle Program 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 two hundred million debris transport cases. These will include debris type, location, size, and release conditions (freestream Mach number, initial velocity of debris piece, etc.).

STATUS

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

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

The tools, along with their underlying limitations, were reviewed by an independent peer review team in September 2003 and February 2004. In addition, comprehensive "Debris Summits" were held in November 2003 and February 2004 to review all Space Shuttle Program (SSP)-wide activities related to debris generation, debris transport, and impact analyses.

Interim results of these analyses have already helped the Shuttle Program to respond to the *Columbia* Accident Investigation Board recommendations such as those on External Tank modifications (R3.2-1), Orbiter hardening modification (R3.3-2), and ascent and on-orbit imagery requirements (R3.4-1 and R3.4-3).

FORWARD WORK

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

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

SCHEDULE

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

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	Elements provide debris history/sources
SSP	Nov 03 (Completed)	Begin RTF [Return to Flight] Debris Transport analyses
SSP	Apr 04	Summary Report/Recommendation to PRCB-RTF cases only
SSP	Jun 04	Begin next set of Debris Transport analyses (approximately 30–40 cases)
SSP	Oct 04	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 proof 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 and deviations to SSP requirements and exceptions to the Operations and Maintenance Requirements and Specification 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 the Space Shuttle Service Life Extension Program.

The following instructions were provided to each project and element:

1. Any item that has 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.

In addition to reviewing all SSP waivers, deviations, and exceptions, each element is reviewing all NASA Accident Investigation Team working group observations and findings and Critical Item List (CIL) waivers associated with ascent debris.

STATUS

Each project and element presented a plan and schedule for completion to the daily Program Requirements Change Board (PRCB) on June 25, 2003. Each project and element is identifying and reviewing the CIL waivers associated with ascent debris generation.

FORWARD WORK

The SSP continues to review the waivers, deviations, and exceptions at the daily PRCB.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Oct 04	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 (CAIB), 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 SSP Program Requirements Control Board (PRCB). Each project and element will disposition recommendations within its 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: the Space Shuttle Main Engine Project Office, the Reusable Solid Rocket Motor Project Office, the Mishap Investigation Team, the External Tank Project, the Solid Rocket Booster Project Office, Space Shuttle Systems Integration, the Early Sightings Assessment Team, the Certification of Flight Readiness Process Team, the Unexplained Anomaly Closure Team, the Previous Debris Assessment Team, the Hardware Forensics Team, and the Materials Processes and Failure Analysis Team.

Project and PRCB recommendations currently being implemented include revision of the SSP contingency action plan, modifications to the External Tank, and evaluation of hardware qualification and certification concerns. Numerous changes to Orbiter engineering, vehicle maintenance and inspection processes, and analytical models are also being made as a result of the recommendations of the various accident investigation working groups. In addition, extensive changes are being made to the integrated effort to gather, review, and disposition prelaunch, ascent, on-orbit, and entry imagery of the vehicle, and to evaluate and repair any potential vehicle damage observed. All of this work complements and builds upon the extensive recommendations, findings, and observations contained in the CAIB Report.

FORWARD WORK

The Orbiter Project Office will report the findings and recommendations of the following working groups to upcoming SSP PRCBs: Starfire Team, Integrated Entry Environment Team, Image Analysis Team, Palmdale Orbiter Maintenance Down Period Team, Space/Atmospheric Scientist Panel, *Columbia* Accident Investigation Fault Tree Team, *Columbia* Reconstruction Team, Hazard Controls Analysis Team, and the *Columbia* Early Sighting Team.

SCHEDULE

Following PRCB approval of recommendations, the responsible project office will develop implementation schedules.

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.

Note: NASA has closed this Space Shuttle Program Action through the formal Program Requirements Control Board (PRCB) process. The following summary details NASA's response to the Space Shuttle Program action and any additional work NASA intends to perform beyond the Space Shuttle Program action.

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 for Space Flight, approximately two weeks before 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 Shuttle PRCB has assigned an action to each organization to review NSTS 08117, Certification of Flight Readiness, to ensure that its internal documentation complies and responsibilities are properly described. This 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 reviewed the CoFR process in place during STS-112, STS-113, and STS-107 to identify any weaknesses or deficiencies in its organizational plan.

STATUS

NASA has revised NSTS 08117, Certification of Flight Readiness, including providing updates to applicable documents lists as well as the roles and responsibilities within project and Program elements, and has increased the rigor of previous mission data review during the project-level reviews. The revised document was approved by the PRCB in January 2004 and released in February 2004.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP Element reviews	Aug 03 (Completed)	Report results of CoFR reviews to PRCB
SSP Program Office	Feb 04 (Completed)	Revise 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 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 acceptance rationale, are documented in a CIL that accepts the design.

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 SSP 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 SSP 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 SSP 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 SSP requirements, such as the Thermal Protection System, select pressure and thermal seals, and certain primary structures.

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. The SSRP will review any updates to baselined CILs.

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. Several projects have made status reports to the PRCB as a step toward formal completion of their reviews.

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	Oct 04	Projects status reports to PRCB
SSP	Oct 04	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 of its 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* accident. 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. These areas are

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), Environmental Protection Agency).
3. FEMA provided immediate and indispensable access to communication, computer, and field equipment for the *Columbia* accident response and recovery effort. They also provided transportation, search assets, people, and money for goods and services. NASA should plan on providing these assets for any future incidents that are not of a magnitude significant enough to trigger FEMA participation.
4. NASA will consider developing or acquiring a generic database to document vehicle debris and handling.
5. NASA and the Department of Defense manager for Shuttle contingency support will review their agreement to ensure understanding of relative roles and responsibilities in accident response.
6. NASA will ensure that a geographic information system (GIS) is available and ready to provide support in the event of a contingency. The GIS capabilities provided during the *Columbia* recovery were of great importance.
7. The Mishap Investigation Team (MIT) is a small group of people from various disciplines. NASA will review MIT membership and supplemental support, and include procedures in its contingency plan for quickly supplementing MIT activities with administrative, computer, and database support and debris management.
8. Since replacing initial responders with volunteers is important, NASA will consider developing a volunteer management plan. For the *Columbia* recovery, an impromptu system was implemented that worked well.
9. NASA will review the frequency and content of contingency simulations for adequacy. The SSP holds useful contingency simulations that include senior NASA managers. An on-orbit contingency simulation will be considered, and attendance by Accident Investigation Board standing members will be strongly encouraged.
10. NASA will include additional contingency scenarios in the contingency action plan. The current plan, which is primarily oriented toward ascent accidents, will be revised to include more orbit and entry scenarios with appropriate responses.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Apr 04	Review and baseline revisions to the SSP Contingency Action Plan, NSTS 07700, Vol. VIII, App. R.

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 11

Based on corrosion recently found internal to body flap actuators, NASA will inspect the fleet leader vehicle actuators to determine the condition of similar body flap and rudder speed brake actuators.

BACKGROUND

Internal corrosion was found in Orbiter Vehicle (OV)-104 body flap (BF) actuators in Fall 2002, and subsequently in the OV-103 BF actuators. In addition, corrosion pits were discovered on critical working surfaces of two BF actuators (e.g., planetary gears and housing ring gears), and general surface corrosion was found inside other BF actuators.

Since the rudder speed brake (RSB) actuator design and materials are similar to BF actuators, similar internal corrosion in RSB actuators could adversely affect performance of Criticality 1/1 hardware. Any existing corrosion will continue to degrade the actuators. The loss of RSB functionality due to "freezing up" of the bearing or jamming caused by broken gear teeth would cause Orbiter loss of control during entry. The operational life of the installed RSB actuators is outside of Orbiter and industry experience. The Space Shuttle Program (SSP) and the Space Flight Leadership Council (SFLC) approved removal of all RSB actuators to investigate corrosion, wear, and hardware configuration.

NASA IMPLEMENTATION

The SSP directed the removal and refurbishment of all four OV-103 RSB actuators. The SSP spares inventory included four RSB actuators. All spare RSB actuators were returned to the vendor for acceptance test procedure (ATP) revalidation. All passed ATP and were returned to logistics. The removed (original) OV-103 RSB actuators were disassembled, and one of the actuators, actuator 4, was found to have the planetary gear set installed in reverse. Analysis showed that this condition presented negative margins of safety for the most severe load cases. In addition to the reversed planetary gears and corrosion, fretting and wear were documented on some of the gears from OV-103 RSB actuators. Surface pits resulting from the fretting have led to microcracks in some of the gears.

As a result of the reversed planetary gear set discovery, the spare actuators, installed in OV-103, were X-rayed, and actuator 2 was also found to have the planetary gear set installed in reverse. Spare actuator 2 has been returned to the vendor to have the discrepancy corrected.

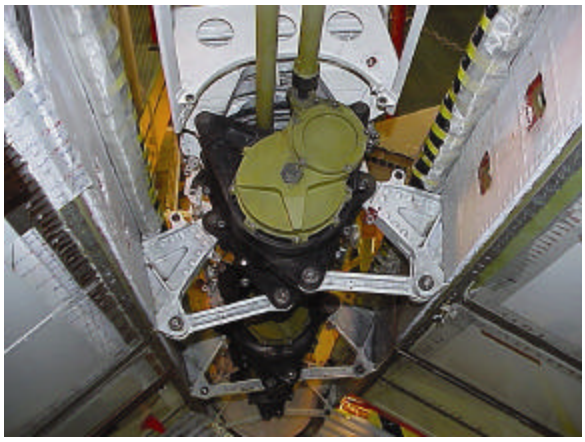


Figure SSP 11-1. OV-103 RSB actuator.

Once spare actuator 2 is repaired, the spare actuators will be reinstalled on OV-103. The plan for OV-104 and OV-105 is to remove the current RSB actuators and return them to the vendor for disassembly and inspection. OV-104 will have new or refurbished actuators installed before its next flight. OV-105 will receive new actuators before its next flight.

STATUS

The ground support equipment needed for the removal and refurbishment of the RSB actuators has been procured and made ready for use at the Kennedy Space Center. The RSB actuators were removed from OV-103 and shipped to the vendor, where they are being disassembled and inspected. The spare actuators will be reinstalled on OV-103. RSB actuators will be removed from OV-105 and OV-104 beginning in April 2004 and shipped to the vendor for disassembly and inspection.

FORWARD WORK

For OV-104, the vendor will provide new actuators for positions 1 and 3. Actuators for positions 2 and 4 will be assembled from existing new parts and refurbished parts, all within specification. All actuators for OV-104 will be made available by late Summer 2004. A new ship-set of actuators is being procured for OV-105.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	Initial plan reported to SFLC
SSP	Aug 03 (Completed)	ATP Spare RSB actuators at vendor and returned to Logistics
SSP	Sep 03 (Completed)	OV-103 RSB actuators removed and replaced with spares
SSP	Mar 04 (Completed)	RSB findings and analysis completed
SSP	May 04	New actuator 3 for OV-104 delivered
SSP	Aug 04	New actuator 1 for OV-104 delivered
SSP	Aug 04	Actuators 2 and 4 for OV-104 delivered
SSP	TBD	New ship-set of RSB actuators for OV-105 delivered

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 12

NASA will review flight radar coverage capabilities and requirements for critical flight phases.

Note: NASA has closed this Space Shuttle Program Action through the formal Program Requirements Control Board process. The following summary details NASA's response to the Space Shuttle Program Action and any additional work NASA intends to perform beyond the Space Shuttle Program Action.

BACKGROUND

In addition to Shuttle vehicle ascent imaging by photo and visual means, NASA uses radar systems of the Air Force Eastern Range to monitor Space Shuttle launches. There are several C-Band radars and a Multiple Object Tracking Radar (MOTR) used to monitor the ascent trajectory. Although not specifically designed to track debris, these radars have some limited ability to resolve debris separating from the ascending vehicle, particularly between T+30 to T+250 seconds.

During the STS-107 launch, the MOTR, which is specifically intended for the purpose of tracking several objects simultaneously, was unavailable.

NASA IMPLEMENTATION

The Space Shuttle Systems Engineering and Integration Office commissioned the Ascent Debris Radar Working Group (ADRWG) to characterize the debris environment during a Space Shuttle launch and to identify/define the return signals seen by the radars. Once the capabilities and limitations of the existing radars for debris tracking were understood, this team researched proposed upgrades to the location, characteristics, and post-processing techniques needed to provide improved radar imaging of Shuttle debris.

The specific technical goal of the ADRWG was to improve the radars' ability to resolve, identify, and track potential debris sources. Another goal was to decrease the postlaunch data processing time such that a preliminary radar assessment is available more rapidly, and to more easily correlate the timing of the ascent radar data to optical tracking systems. Successful implementation of a radar debris tracking system will have an advantage over optical systems as it is not constrained by ambient lighting or cloud interference. It further has the potential to maintain insight into the debris shedding environment beyond the effective range of optical tracking systems.

STATUS

The ADRWG was initiated in August 2003. After a review of existing debris documentation and consultation with radar experts within and outside of NASA, a planning presentation outlining the approach and process to be used was provided to the Space Shuttle Program (SSP) office in September 2003. A number of workshops were held at NASA centers and at Wright-Patterson Air Force Base to characterize the debris sources and how they appeared on radar, and to analyze the potential debris threat to the Shuttle represented by the radar data.

The ADRWG constructed a composite list of potential debris sources. This list was coordinated with all of the Shuttle elements and will be the basis for analysis of radar identification capabilities such as radar cross section (RCS) signatures. A series of critical radar system attributes was compiled, and a number of existing radar systems has been evaluated against these criteria. Data analysis included comparisons of radar data with known RCS signatures and ballistic trajectories.

On January 13, 2004, the ADRWG provided its initial findings and draft recommendations to the SSP. The team found that the existing range radars were not well suited to perform the Shuttle debris assessment task because of their sitting and configuration. Only a properly sited and configured radar system can be expected to provide the insight needed to assess the debris threat during a Shuttle launch. A candidate architecture, using several elements of the Navy Mobile Instrumentation System (NMIS), formed the basis of the radar system for return to flight (RTF). A long-term, highly capable architecture was also proposed for an on-board debris radar detection capability. Development of this potential capability will continue. However, this capability will not be available for RTF.

Radar field testing included a series of six Booster Separation Motor firings to characterize how the plume contributed to the existing radar data. These tests were completed at the U.S. Navy's China Lake facility in

February 2004. A comprehensive set of RCS measurements of candidate Shuttle debris material has been completed at Wright-Patterson Air Force Base and was correlated to dynamic field results at the Naval Air Station at Patuxent River in June 2004.

The final SSP presentation, including field results, prior mission analysis, and final recommendations, was completed in April 2004. To provide adequate threat assessment, a ground-based radar system must include both wideband capabilities to provide the precise position of debris as well as Doppler capabilities for differential motion discrimination. Also necessary are near-real-time data reduction and display in remote facilities, ballistic coefficient traceability, and the highest calibration to meet Range Certification Standard STD 804-01. To meet these requirements, NASA, in cooperation with the U.S. Navy and the U.S. Air Force, is developing a radar plan that involves relocation of the U.S. Navy midcourse radar from Puerto Rico to Cape Canaveral. This radar provides wideband, coherent C-band radar coverage, which will be supplemented with continuous pulse Doppler X-band ship-based radar mounted on the Solid Rocket Booster recovery ships.

A Memorandum of Understanding between NASA and the U.S. Navy is in work for implementation of flight radar coverage. A proof of concept using debris radar for a Delta 2 launch using the U.S. Navy's NMIS is planned for July 2004.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
ADRWG	Nov 03 (Completed)	Complete Radar Study
ADRWG	Nov 03 (Completed)	Finalize finding and recommendations
ADRWG	Apr 04 (Completed)	Provide final list of debris sources
SSP	Apr 04 (Completed)	Baseline requirements and initiate implementation – Present to SSP Program Requirements Control Board

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 13

NASA will verify that hardware processing and operations are within the hard qualification and certification limits.

BACKGROUND

An Orbiter Project Office investigation into several Orbiter hardware failures identified certification environments that were not anticipated or defined during original qualifications. Some examples of these include drag chute door pin failure, main propulsion system flow liner cracks, and environmental control and life support system secondary O_2/N_2 flex hose bellows failure.

Because of these findings by the Orbiter Project Office, all projects and elements are assessing all Space Shuttle hardware operations according to requirements for certification/qualifications. If a finding is determined to be a constraint to flight, the project or element will immediately report the finding to the Program Requirements Control Board (PRCB) for disposition.

NASA IMPLEMENTATION

On December 17, 2002, prior to the *Columbia* accident, the Space Shuttle Program (SSP) Council levied an action to all SSP projects and elements to review their hardware qualification and verification requirements and to verify that processing and operating conditions are consistent with the original hardware certification (memorandum MA-02-086). At the SSP Council meeting April 10-11, 2003, each Program project and element identified that its plan for validating that hardware operating and processing conditions, along with environments or combined environments, is consistent with the original certification (memorandum MA-03-024). The PRCB has reissued this action as a return to flight action.

STATUS

Interim status reports from the SSP project and element organizations have been presented to the SSP PRCB and will continue throughout the year 2004. As a result of this proactive review, NASA has identified some areas for additional scrutiny, such as the Solid Rocket Booster Separation Motor debris generation and Orbiter nose-wheel steering failure modes. This attitude of critical review, even of systems that have consistently functioned within normal specifications, has significantly improved the safety and reliability of the Shuttles and reduced the risk of future problems.

FORWARD WORK

The SSP projects and elements will continue assessing the hardware qualification and verification with concentration on the Criticality 1 hardware. Some SSP projects and elements have completed work, and other SSP projects and elements have work that is ongoing. In all cases qualification and verification assessment commitments for return to flight will be completed by January 2005. A preliminary assessment has been completed and shows no constraints to the hardware certification limits. Actions to mitigate any certification findings are being directed by the PRCB. Certification assessments for certain lower criticality hardware will continue through 2006.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
All SSP project and element organizations	Jan 04	Present certification assessment results to SSP PRCB for return to flight commitments
All SSP project and element organizations	Dec 06	Present certification assessment results to SSP PRCB for any remaining post-return to flight commitments

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 14

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

BACKGROUND

The Shuttle Thermal Protection System (TPS) consists of various materials applied externally to the outer structural skin of the Orbiter. These materials allow the skin temperatures to remain within acceptable limits during the extreme temperatures encountered during entry. As in the case of the *Columbia* accident, failure of the TPS can result in the catastrophic loss of the crew and vehicle. The TPS is composed of an assortment of materials that includes Reinforced Carbon-Carbon (RCC), ceramic tiles, Nomex-coated blankets, thermal panes, metals, silica cloths, and vulcanizing material.

Failure of the TPS can be caused by debris impact. The debris impact location, energy, impact angle, material, density, and shape are all critical factors in determining the effects of the debris impact on the TPS.

NASA IMPLEMENTATION

NASA is developing models to accurately predict the damage resulting from a debris impact, and a damage-tolerance test plan is in work. NASA is also developing more mature models to determine if damage is survivable or must be repaired before safe entry.

The Space Shuttle Program Requirements Control Board (PRCB) issued an action that encompasses all efforts related to the testing and analysis necessary to determine the thresholds between damage and no-damage cases, and between damage that is safe for entry verses damage that must be repaired. This action also addresses the development of models to improve tile and RCC damage prediction, and to determine the maximum possible repair capability while in flight. To fulfill this PRCB action, the Orbiter Debris Impact Assessment Team (ODIAT) was created to integrate all NASA, United Space Alliance, Boeing, and Lockheed-Martin efforts necessary to determine the different debris damage thresholds for both tile and RCC and to develop predictive debris damage models. Figure SSP 14-1 shows the interfaces between the ODIAT and various new or existing teams that are working return to flight (RTF) activities.

The ODIAT effort is comprised of four main activities:

- Impact testing on tile, RCC flat plates, and full RCC panels;
- Material property testing of RCC coupons and potential debris types;
- Analysis and integration of test results into predictive models; and
- Damage tolerance testing and analysis to determine the threshold for damage that must be repaired.

STATUS

Efforts are under way for each of the major focus areas. Foam impact tile testing is ongoing at Southwest Research Institute (SwRI) in San Antonio, Texas. Ice impact tests at the White Sands Test Facility and ablator impact tests at Kennedy Space Center will begin shortly. The first set of full-scale RCC panel impact tests is complete. RCC panel 9L from OV-103 was shot three times. The first test used a 0.1-lb. foam projectile at a velocity of 701 ft/sec; no damage resulted from the impact. A second foam impact of 0.2 lb. at 688 ft/sec also produced no damage. The final test used a 0.167-lb. piece of foam shot at 1167 ft/sec, and caused severe cracking of the panel, but did not actually create a hole in the panel.

Coupon testing for RCC material properties is under way at Southern Research Institute in Birmingham, Alabama. Data from testing thus far indicate that flown material (panel 8L from OV-104 with 26 flights) has material properties slightly degraded from new material, but significantly higher than the allowables used in the mission life models for RCC. Data from these tests are being used to verify and modify new models. The production of additional RCC coupon material for testing is under way at Lockheed-Martin in Dallas.

Analysis and modeling work is continuing for both the RCC and the tile. The data collected will be used to develop and verify two types of RCC and tile models. One model will be

used in real-time situations where a timely answer is needed. This model will provide a conservative answer to possible damage assessments. The second model will provide very accurate predictions of possible damage. This model may take several days to code and run and will be used for situations where time is available and detailed results are necessary. The analysis and modeling tasks are being worked in conjunction with Boeing, Langley Research Center, Glenn Research Center, and SwRI.

Damage tolerance testing is under way at Langley Research Center and Johnson Space Center. Through structural and thermal testing of damaged RCC and tile samples, we can determine exactly how much damage can be allowed while still ensuring a safe return for the crew and vehicle. Testing thus far has shown that RCC cannot tolerate a loss of coating from both the front and back surfaces, and that a hole in a panel on the order of 0.02 in^2 may be survivable, depending on the amount of associated coating damage and cracking.

FORWARD WORK

NASA will continue to conduct tests that provide insights into the material and physical properties of the TPS. NASA is also developing minor and critical damage criteria for the TPS by performing RCC foam impact tests, arc jet tests, and wind tunnel tests. Results from these tests will also help to determine the location dependencies of the impacting debris. Techniques for repairing tile and RCC are under development. The ability of the International Space Station crew to provide support to an Orbiter crew during a Shuttle TPS repair scenario or during a crew rescue operation is under investigation. The combination of these capabilities will help to ensure a lower probability that critical damage will be sustained, while increasing the probability that any damage that does occur can be detected and the consequences mitigated during flight.

Additional information related to this action can be found in other sections of this Implementation Plan. Information on the damage that the TPS can sustain, and still allow for successful entry of the Orbiter into Earth's atmosphere, is further explained in NASA's response to Recommendation R3.3-3. Information regarding the TPS inspection and repair capabilities being investigated is further explained in NASA's answer to Recommendations R6.4-1 and R3.3-2.

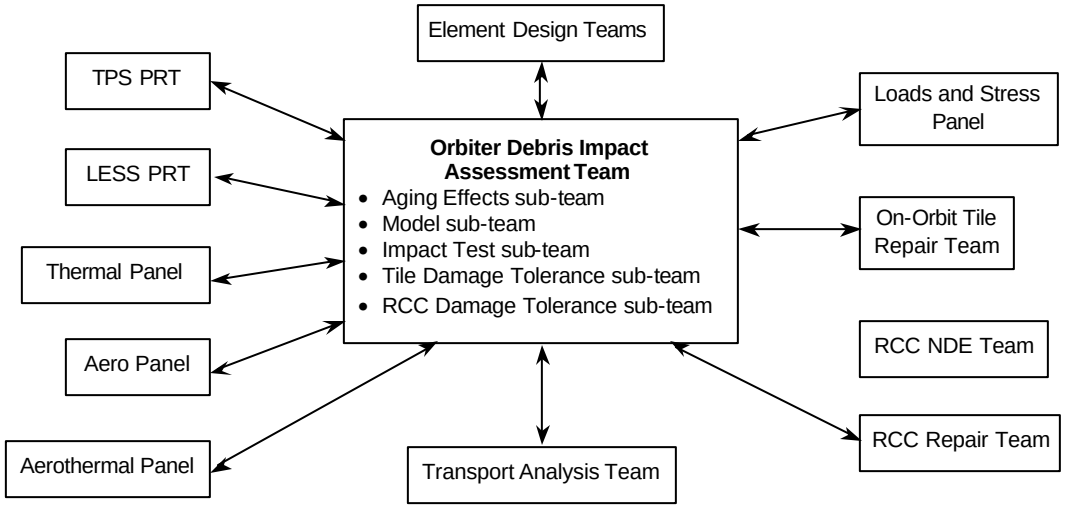


Figure SSP 14-1. Orbiter Debris Impact Assessment Team integrates efforts from other teams.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
ODIAT	Oct 03 (Completed)	Panel 9 Testing
ODIAT	May 04	RCC Materials Testing Complete
ODIAT	Dec 04	Tile Impact Testing Complete; RCC Model Correlation Complete; Tile Model Verification Complete
ODIAT	Feb 05	Final RCC Model Verification (Contingency RTF)
ODIAT	TBD	Damage Tolerance Test and Analysis Complete

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 15

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

BACKGROUND

Bipod ramp foam was released during the launch of STS-112 in October 2002. After the mission, the Space Shuttle Program (SSP) considered this anomaly and directed the External Tank Project to conduct the testing and analysis necessary to understand the cause of bipod foam release and present options to the SSP for resolution. The Program did not hold completion of these activities as a constraint to subsequent Shuttle launches because the interim risk was not judged significant. The *Columbia* accident investigation results clearly disclose the errors in that engineering judgment.

NASA IMPLEMENTATION

NASA will conduct a full review of its anomaly resolution processes with the goal of ensuring appropriate disposition of precursor events in the future.

In support of the return to flight activity, the SSP, supported by all projects and elements, began to identify and implement improvements to the problem tracking, in-flight anomaly disposition, and anomaly resolution processes. A team is reviewing SSP and other documentation and processes, as well as audited performance for the past three Shuttle missions. The conclusion is that, while clarification of the requirements identified in NSTS 08126, Problem Reporting and Corrective Action (PRACA) System Requirements, is needed, the implementation of those requirements appears to be the area that has the largest opportunity for improvement. Issues identified indicate misinterpretations of definitions, resulting in misidentification of problems, and noncompliance with tracking and reporting requirements.

The recommended actions are to

1. Train all SSP elements and support organizations on PRACA requirements and processes. The SSP community is not as aware of the PRACA requirements and processes as they should be to avoid repeating past mistakes.

2. Update NSTS 08126 to clarify the in-flight anomaly (IFA) definition, delete “program” IFA terminology, and add payload IFAs and Mission Operations Directorate (MOD) anomalies to the scope of the document.

3. Update the PRACA nonconformance system (Web PCASS) to include flight software, payload IFAs, and MOD anomalies. These changes will be incorporated in a phased approach. The goal is to have a single nonconformance tracking system.

STATUS

A Change Request (CR) is in work to update NSTS 08126, PRACA System Requirements. In addition, United Space Alliance (USA) is consolidating its PRACA databases and updating the cause codes. After this effort is completed for the USA databases, it will be expanded to include Lockheed-Martin and ATK Thiokol. NASA and its contractors will provide training as part of this activity to ensure that all SSP elements and support organizations understand the PRACA system and are trained in entering data into PRACA.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Johnson Space Center (JSC)	Apr 04	Approve CR to update NSTS 08126, PRACA Systems Requirements.
Kennedy Space Center (KSC)-USA	Jun 05	Consolidate the USA PRACA databases and update the cause codes.
KSC	Jun 05	Train USA/KSC/JSC personnel on PRACA database changes and cause code usage.
Marshall Space Flight Center (MSFC)/Michoud Assembly Facility (MAF)	Dec 05	Consolidate changes into the non-USA PRACA databases from the USA PRACA databases.
MSFC/MAF	Jan 06	Train Lockheed-Martin/ATK Thiokol/MSFC/MAF personnel on PRACA database changes and cause code usage.

CAIB Observations

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

Columbia Accident Investigation Board

Observation 10.1-1

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

BACKGROUND

NASA has a more general risk management requirement, codified in NASA Policy Directive (NPD) 8700.1A. However, it does not currently have an Agency risk policy that specifically addresses range flight operations, such as launch and entry of space vehicles and operation of uncrewed aircraft. NPD 8700.1A calls for NASA to implement structured risk management processes using qualitative and quantitative risk-assessment techniques to make optimal decisions regarding safety and the likelihood of mission success. The NPD also requires program managers to implement risk management policies, guidelines, and standards and establish safety requirements within their programs. These and other related policies are designed to protect the public as well as NASA personnel and property.

Individual NASA range safety organizations, such as those at Wallops Flight Facility (WFF) and Dryden Flight Research Center (DFRC), have established public and workforce risk management requirements and processes at the local level. These NASA organizations often work in collaboration with the Air Force and other government range safety organizations. They have extensive experience applying risk assessment to the operation of Expendable Launch Vehicles and uncrewed aircraft and are currently developing range safety approaches for the operation of future Reusable Launch Vehicles, which include launch and entry risk assessment.

NASA IMPLEMENTATION

Development of any Agency policy requires significant coordination with the NASA Centers and programs that will be responsible for its implementation. The NASA Headquarters Office of Safety and Mission Assurance has established a risk policy working group to perform the initial development and coordination on the risk acceptability policy for launch and entry of space vehicles and uncrewed aircraft. This working group hosted a range safety risk management workshop July 24 - 25, 2003, at NASA Headquarters. Working group members in attendance included NASA personnel from Kennedy Space Center (KSC), DFRC, WFF, Johnson Space Center (JSC), and Headquarters. Also in attendance were representatives from the *Columbia* Accident Investigation Board (CAIB).

Thus far, the working group has received a comprehensive technical briefing on the CAIB-initiated entry risk study that was performed by ACTA Inc., and obtained perspective on the CAIB investigation and recommendations related to assessing public risk from a CAIB Staff Investigator. They have also obtained Agencywide perspective on application of risk assessment to range operations for all current and planned programs (e.g., Shuttle, Expendable Launch Vehicles, Reusable Launch Vehicles, Unmanned Aerial Vehicles, and high-altitude balloons). Building on this information, they have coordinated plans for addressing risk to the public for return to flight (RTF) and for development of NASA range safety risk policy and have begun to draft a proposed NASA risk policy.

The draft policy will be applicable to all range flight operations, including launch and entry of space vehicles and operation of uncrewed aircraft and will include requirements for risk assessment, mitigation, and acceptance/disposition of residual risk to the public and operational personnel. It will incorporate performance standards that provide for safety while allowing appropriate flexibility needed to accomplish mission objectives and include acceptable risk criteria that are consistent with those used throughout the government, the commercial range community, and with other industries whose activities are potentially hazardous to the public. Finally, the policy will provide a risk management process within which the required level of management approval increases as the level of assessed risk to public and the workforce increases and will be flexible enough to allow the fidelity of Program risk assessments to improve over time as knowledge of the vehicle's operational characteristics increases and models used to calculate risk are refined.

The policy document being developed will be a part of a NASA Procedural Requirement (NPR) 8715.XX, NASA

Range Safety Program, which will describe NASA's range safety policy, roles and responsibilities, requirements, and procedures for protecting the safety and health of the public, the workforce, and property during range operations. Chapter 3 of this NPR will contain the NASA risk management policy for all range operations including launch and entry of space vehicles and operation of uncrewed vehicles.

STATUS

The draft NPR, including the risk policy, is nearing completion. The NASA Safety and Mission Assurance (SMA) Directors were briefed on the draft NPR on October 15, 2003, with particular focus on the range safety risk policy. The SMA Directors and other members of the NASA SMA community completed a review of the draft NPR in November 2003. The resulting draft was entered into the Agency's formal approval process at the end of January 2004 using the NASA Online Directives Information System (NODIS). Due to issues raised during the Agency comment period, the NASA Executive Council will conduct a special review of the proposed policy before completion of the approval process.

FORWARD WORK

The draft risk policy requires that each program documents its safety risk management process in a written plan approved by the responsible NASA official(s). Before RTF, the Space Shuttle Program (SSP) will draft its plan and obtain the required Agency approvals. The SSP will also perform launch and entry risk assessments for the initial and subsequent planned Shuttle missions. Launch risk assessment will continue to be performed by the 45th Space Wing in coordination with the Shuttle Program and KSC. SSP efforts to assess entry risk are addressed by Space Shuttle Program Action 2.

In accordance with the risk policy and the Space Shuttle safety risk management plan, the appropriate level of NASA management will review and address the assessed risk to the public and the workforce before RTF.

SCHEDULE

Brief the NASA Executive Council, resolve any concerns, and complete the approval process. The dates of the NODIS review cycle and expected final signature are dependent on the results of the Executive Council review.

Action	January NODIS Review Cycle
Begin SMA Discipline Review	Oct 03 (Completed)
SMA Review Comments Due	Nov 03 (Completed)
Disposition SMA Comments	Nov/Dec 03 (Completed)
Final Proofread, prepare NODIS Package, route for OSMA Management Signature, provide feedback to SMA Directors	Dec 03 / Jan 04 (Completed)
Published Deadline for Submission to NODIS	Jan 04 (Completed)
Briefing to the NASA Executive Council	Apr 04
NODIS Review and Final Signature	(Pending)

Columbia Accident Investigation Board

Observations 10.1-2 and 10.1-3

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

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

BACKGROUND

The *Columbia* accident raised important questions about public safety, since *Columbia*'s debris was scattered over a ground impact footprint approximately 275 miles long and 30 miles wide. Although there were no injuries to the public due to the falling debris, the accident demonstrates that Orbiter breakup during entry may pose a risk to the general public.

NASA IMPLEMENTATION

NASA is currently studying the relative risks to persons and property associated with entry to the three primary Shuttle landing sites, and is developing plans and policies to mitigate the public risk. The results of these analyses will also determine if some ground tracks must be removed from consideration as normal, preplanned, end-of-mission landing opportunities. For a complete discussion of this topic and Observation 10.1-2, see the related actions in Space Shuttle Program Action 2.

NASA is also leading efforts to study the debris recovered from *Columbia* to address Observation 10.1-3. This is a multiyear project involving experts from NASA, the Federal Aviation Administration, and the U.S. Air Force. Due to the large number of pieces to be studied and the desire to get the best engineering data possible, the results of this effort are not expected until 2006. Therefore, integrating results of this effort into the public risk assessments will not be possible until that time. However, this will not impede NASA's ability to develop and implement a plan that mitigates the risk that Shuttle flights may pose to the general public prior to return to flight.

STATUS

The Space Shuttle Program (SSP) issued a Program Requirements Control Board Directive to the Johnson Space Center Mission Operations Directorate to develop and implement a plan to mitigate the risk to the general public, thus addressing Observation 10.1-2. See Space Shuttle Program Action 2 for a status of this effort.

NASA is currently leading efforts to study the debris recovered from *Columbia*, to address Observation 10.1-3. The interagency team is in the final stages of defining requirements for data collection, and has performed a measurement-taking trial run to refine those requirements. The schedule for this activity is described below.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	May 04	Finalize Responsibilities and Requirements for Data Collection
SSP	Jun 04	Begin Data Collection Phase
SSP	Dec 05	End Data Collection Phase (depending on requirements)
SSP	Mar 06	Refined public risk assessments and mitigation plans

For the schedule to develop and implement a plan to mitigate the risk to the general public, see Space Shuttle Program Action 2.

Columbia Accident Investigation Board

Observation 10.2-1

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

NASA IMPLEMENTATION

In July 2003, NASA published a Human-Rating Requirements and Guidelines for Space Flight Systems policy document, NASA Procedural Requirement (NPR) 8705.2. This document includes a requirement for flight crew survivability achieved through a combination of abort and crew escape capabilities. The requirements in NPR 8705.2 evolved from NASA lessons learned from the Space Shuttle, Space Station, and other human space flight programs, including the lessons from the *Challenger* and *Columbia* accidents. This will be the guiding document for the development of the planned Crew Exploration Vehicle (CEV).

A multidisciplinary team at the NASA Johnson Space Center (JSC), called the Crew Survival Working Group (CSWG), has been formed to develop a report incorporating lessons learned from both the *Challenger* and *Columbia* accidents. The CSWG has participation from the Flight Crew Operations, Engineering, and Space and Life Sciences Directorates. In recent months, the CSWG has developed a plan to complete a comprehensive, crew-centric analysis of the two Shuttle accidents, as well as of previous human space flight accidents. After completion of the analysis, the CSWG will issue a formal report documenting lessons learned for enhancing crew survivability in future human space flight vehicles, such as the CEV. This information will be even more critical as NASA prepares to implement the Vision for Space Exploration.

STATUS

Phase one of the CSWG work, an analysis of the *Columbia* accident, has begun. The JSC Space and Life Sciences Directorate has contracted with the University Space Research Association and the Biodynamics Research Corporation to perform additional assessments.

FORWARD WORK

The Vision for Space Exploration includes a redefinition of the requirements for space transportation vehicles to support human space flight. The NASA Headquarters Office of Exploration Systems (Code T) will be the lead organization for this requirements definition. NPR 8705.2, Human-Rating Requirements and Guidelines for Space Flight Systems, and the work of the CSWG will form principle inputs into that process.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
CSWG	Nov 03 (Completed)	Draft report and recommendations
CSWG	Apr 04 (Completed)	Plan of work for detailed analysis of human space flight vehicle accidents and lessons learned
CSWG	Apr 05	Final report on STS-107 accident with recommendations and lessons learned for future vehicle design to improve crew survivability
CSWG	Apr 06	Final report on STS-51L accident
CSWG	Apr 07	Integrated report on human space flight accidents with engineering syllabus

Columbia Accident Investigation Board

Observation 10.4-1

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

This Observation is addressed in Section 2.1, Space Shuttle Program Action 1.

Columbia Accident Investigation Board

Observation 10.4-2

Kennedy Space Center's Quality Assurance programs should be consolidated under one Mission Assurance office, which reports to the Center Director.

Note: NASA has closed this observation through the formal Program Requirements Control Board process. The following summary details NASA's response to the observation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board (CAIB) observation.

BACKGROUND

Prior to the *Challenger* accident, Quality Assurance functions were distributed among the programs at Kennedy Space Center (KSC). In response to the findings of the Rogers Commission Report, KSC consolidated its Safety and Mission Assurance (SMA) functions into a single organizational entity. In May 2000, KSC once again dispersed the SMA function into each program and appropriate operational directorate. This was done to provide direct SMA support to each of the directorates, to ensure that the programs had the resources to be held accountable for safety. and to enhance acceptance of the SMA role. Although this improved the relationships between SMA and the programs, the dependence of SMA personnel on program support limited their ability to effectively perform their role.

NASA IMPLEMENTATION

In close coordination with the effort led by the Associate Administrator for Safety and Mission Assurance (AA for SMA) in responding to CAIB Recommendation 7.5-2, KSC has established a center-level team to assess the KSC SMA organizational structure. This team was chartered in October 2003 to determine plans for implementing a consolidated SMA organization. The team developed several different candidate organizational structures. To maintain the benefits of the existing organization, which had SMA functions distributed to the appropriate programs and operational directorates, and to limit disruption to ongoing processes, the KSC Center Director chose a consolidated structure organized internally by program (see figure 10.4-2-1).

On January 13, 2004, KSC formed a Return to Flight Reorganization Team, which included an SMA Reorganization Team. The first task of this team was to perform a bottom-up review of the entire SMA organization. This bottom-up review revealed the need for additional SMA resources to fully perform the required functions. The proportion of SMA personnel to the total center population was deliberately decreased from a period shortly before the creation of the Space Flight Operations Contract (SFOC) based on the tasks transitioned to the contractor workforce; however, the bottom-up review demonstrated the need for expansion of the oversight/insight function and the associated collection of SMA data independent of the contractor-derived SMA data. As a result, additional SMA positions (Full-Time Equivalents (FTEs)) are being provided. These additional FTEs will reduce the amount of overtime currently required of the SMA professionals. They will also bring the percentage of SMA personnel to the entire KSC population back to the level that existed prior to the SFOC (see figure 10.4-2-2, chart 1). The additional positions will also decrease the dependence on the contractor for SMA data.

The bottom-up review also revealed unnecessary duplication of independent assessment resources. It was determined that if the entire KSC SMA workforce became centralized and once again independent of the programs, there would be no need for a large independent assessment organization.

When developing the single consolidated SMA organization at KSC, the SMA Reorganization Team identified the need for an Integration Division. Depicted as SA-G in figure 10.4-2-1, this Division will be responsible for ensuring consistency across the programs and for developing and implementing technical training for the SMA disciplines. The Integration Division will include discipline experts in Safety Engineering, Quality Engineering, Quality Assurance, Software Assurance, Reliability, Human Factors, and Risk Management, and it will be responsible for policy creation and review and procurement assurance.

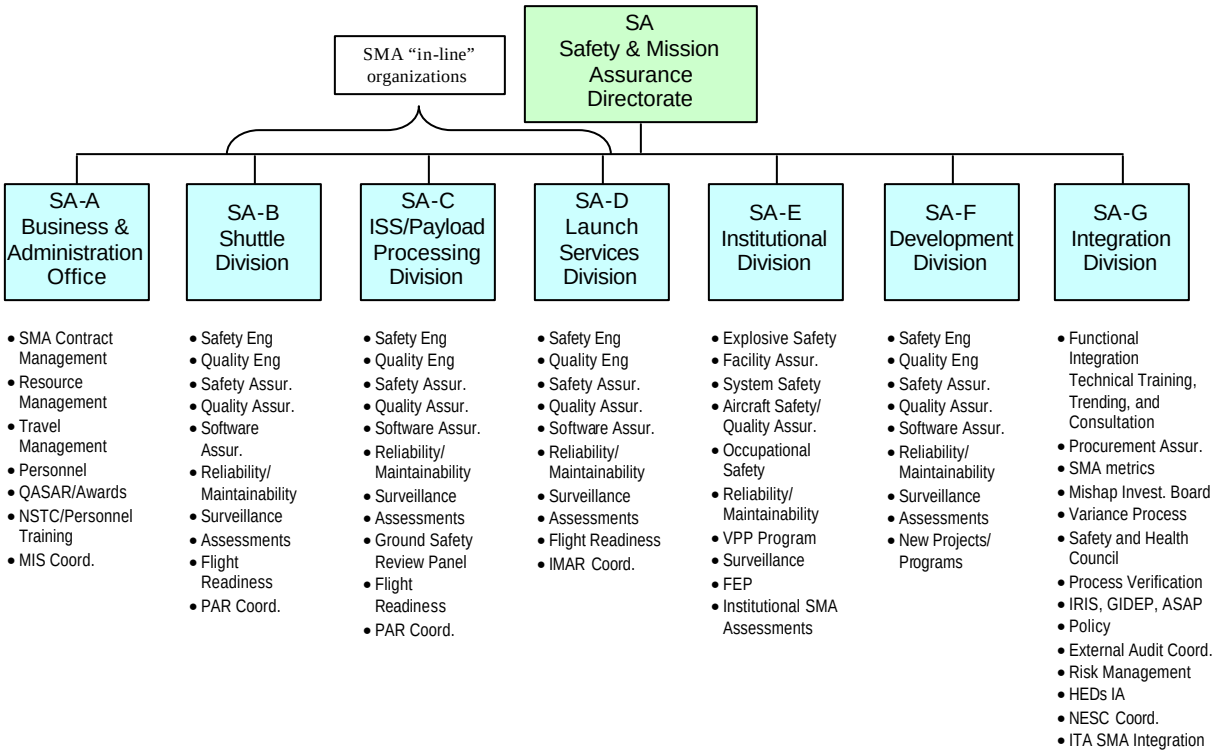


Figure 10.4-2-1. Consolidated SMA.

The SMA Reorganization Team also evaluated the work required by the planned Independent Technical Authority (ITA) to incorporate its requirements into the centralized SMA organization. To fulfill these requirements, KSC has requested three FTEs for SMA/ITA within the total 58 being requested. These three FTEs will be responsible for SMA trending and integration.

In addition to the managerial independence established by consolidation, the SMA Reorganization Team worked with the KSC financial organization and NASA Headquarters to create a new "directed service pool" funding process. The directed service pool gives the SMA Directorate the authority to determine, in consultation with the programs, the level of support it will provide to each program. The SMA Reorganization Team also developed an avenue to use the Johnson Space Center SMA contract to provide for immediate resource needs while allowing SMA to have an independent contract at the end of this fiscal year.

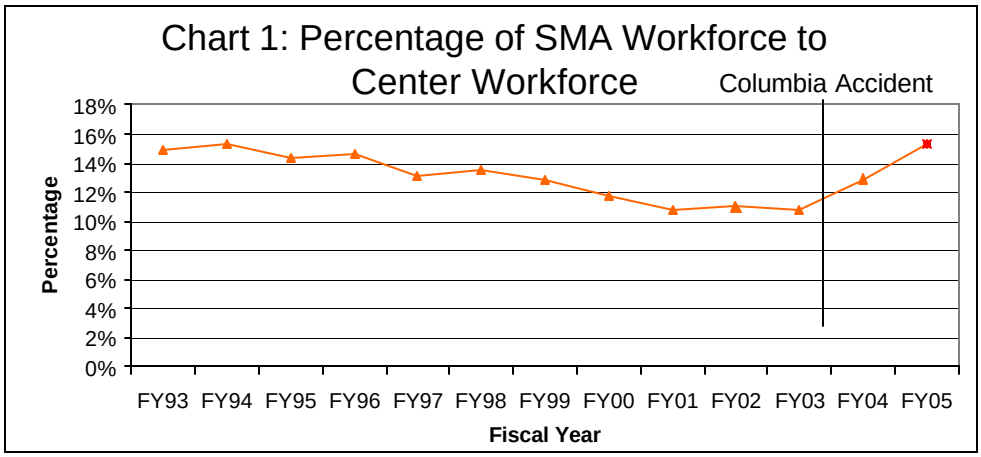
Finally, KSC has several ongoing initiatives to address the culture within SMA and throughout the center. Specifically, Behavioral Science Technologies Inc. has identified the need for the KSC SMA organization to work on improving its organizational culture. This process will continue after the SMA reorganization is complete.

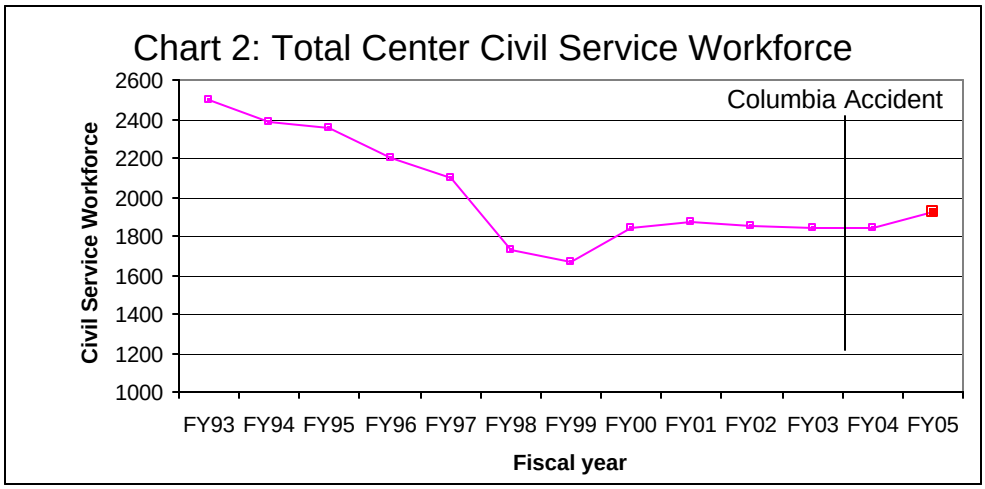
STATUS

Complete.

FORWARD WORK

None.





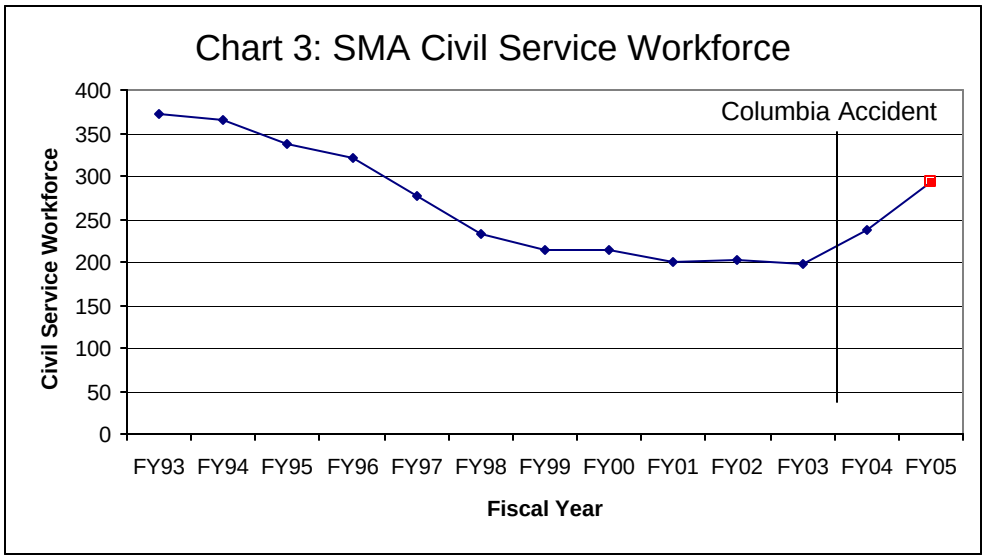


Figure 10.4-2-2. SMA workforce.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Completed	Recommendations to KSC Center Director
KSC	Apr 04 (Completed)	Reorganization definition complete
KSC	May 04 (Completed)	Implementation complete

Columbia Accident Investigation Board

Observation 10.4-3

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

BACKGROUND

The *Columbia* Accident Investigation Board reported most of the training for quality engineers, process analysts, and quality assurance specialists was on-the-job training rather than formal training. In general, Kennedy Space Center (KSC) training is extensive for the specific hardware tasks (e.g., crimping, wire bonding, etc.), and includes approximately 160 hours of formal, on-the-job, and safety/area access training for each quality assurance specialist. However, there are deficiencies in basic quality assurance philosophy and skills.

NASA IMPLEMENTATION

NASA is benchmarking quality assurance training programs as implemented by the Department of Defense (DoD) and Defense Contract Management Agency (DCMA). NASA's goal is to develop a comparable training program for the quality engineers, process analysts, and quality assurance specialists. The training requirements will be documented within the training records template.

STATUS

KSC is working with DCMA to benchmark its training program and to determine where we can directly use its training. A team recently completed a DCMA quality assurance skills course.

FORWARD WORK

KSC will benchmark with DoD and the companies used to provide their quality assurance training. Then, KSC will document a comparable training program and update the training templates. Personnel will be given a reasonable timeframe to complete the training.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Apr 04	Benchmark DoD and DCMA training programs
KSC	Aug 04	Develop and document improved training requirements
KSC	Aug 05	Complete personnel training

Columbia Accident Investigation Board

Observation 10.4-4

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

BACKGROUND

The *Columbia* Accident Investigation Board Report highlighted Kennedy Space Center's (KSC's) reliance on the International Organization for Standardization (ISO) 9000/9001 certification. The report stated, "While ISO 9000/9001 expresses strong principles, they are more applicable to manufacturing and repetitive-procedure industries, such as running a major airline, than to a research-and-development, flight test environment like that of the Space Shuttle. Indeed, many perceive International Standardization as emphasizing process over product." ISO 9000/9001 is currently a contract requirement for United Space Alliance (USA).

NASA IMPLEMENTATION

NASA has assembled a team of Agency and industry experts to examine the ISO 9000/9001 standard and its applicability to the Space Shuttle Program. Specifically, this examination will address the following: 1) ISO 9000/9001 applicability to USA KSC operations; 2) how NASA should use USA's ISO 9000/9001 applicable elements in evaluating USA performance; 3) how NASA currently uses USA's ISO certification in evaluating its performance; and 4) how NASA will use the ISO certification in the future and the resultant changes.

STATUS

NASA has assembled an ISO 9000/9001 review team. The team has established a review methodology and has partially completed the first step, determining the applicability of the standard to USA KSC operations.

FORWARD WORK

The team is working to the schedule listed below. The KSC surveillance plan will be updated after completion of all planned activities.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Apr 04	Identify applicability to USA KSC Operations
KSC	Jul 04	Proper usage of standard in evaluating contractor performance
KSC	Jul 04	Current usage of standard in evaluating contractor performance
KSC	Aug 04	Future usage of standard and changes to surveillance or evaluation of contractor
KSC	Aug 04	Presentation of Review

Columbia Accident Investigation Board

Observation 10.5-1

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

BACKGROUND

The Kennedy Space Center (KSC) Processing Review Team conducted a review of the ground processing activities and work documents from all systems for STS-107 and STS-109, and from some systems for Orbiter Major Modification. This review examined approximately 3.9 million work steps and identified 9672 processing and documentation discrepancies resulting in a work step accuracy rate of 99.75%. While this is comparable to our performance in recent years, our goal is to further reduce processing discrepancies; therefore, we initiated a review of STS-114 documentation.

NASA IMPLEMENTATION

NASA has performed a review and systemic analysis of STS-114 work documents from the time of Orbiter Processing Facility roll-in through system integration test of the flight elements in the Vehicle Assembly Building. Pareto analysis of the discrepancies revealed areas where root cause analysis is required.

STATUS

The STS-114 Problem Resolution Team systemic analysis revealed six Corrective Action recommendations consistent with the technical observations noted in the STS-107/109 review. Teams were formed to determine the root cause and long-term corrective actions. These recommendations were assigned Corrective Action Requests that will be used to track the implementation and effectiveness of the corrective actions. In addition to the remedial actions from the previous review, there were nine new system-specific remedial recommendations. These remedial actions primarily addressed documentation errors, and have been implemented. Quality and Engineering will continue to statistically sample and analyze work documents for all future flows.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Feb 04 (Completed)	Program Requirements Control Board

Columbia Accident Investigation Board

Observation 10.5-2

NASA should implement United Space Alliance's suggestions for process improvement, which recommend including a statistical sampling of all future paperwork to identify recurring problems and implement corrective actions.

BACKGROUND

The Kennedy Space Center (KSC) Processing Review Team (PRT) conducted a review of the ground processing activities and work documents from all systems for STS-107 and STS-109, and from some systems for the Orbiter Major Modifications. This review examined approximately 3.9 million work steps and identified 9672 processing and documentation discrepancies resulting in a work step accuracy rate of 99.75%. These results were validated with the review of STS-114 work documents (ref. Observation 10.5-1). Pareto analysis of the discrepancies revealed areas where corrective action is required and where NASA Shuttle Processing surveillance needs augmentation.

NASA IMPLEMENTATION

NASA will refocus the KSC Shuttle Processing Engineering and Safety and Mission Assurance (SMA) surveillance efforts and enhance the communication of surveillance results between the two organizations. KSC Shuttle Processing Engineering will increase surveillance of processing tasks and of the design process for government-supplied equipment and ground systems. This will include expanding the list of contractor products requiring NASA engineering approval. SMA surveillance will be expanded to include sampling of closed paper and hardware surveillance (ref. Observation 10.5-3). The initial focus for sampling of closed paper will be to determine the effectiveness of corrective action taken by the contractor as a result of the PRT's work.

NASA will improve communication between the Engineering Office and SMA through the activation of a Web-based log and the use of a new Quality Planning and Requirements Document change process for government inspection requirements.

STATUS

Engineering and SMA organizations are evaluating and revising their surveillance plans. Required changes to the Ground Operations Operating Procedures are being identified.

FORWARD WORK

NASA will implement periodic reviews of surveillance plans and adjust the tasks as necessary to target problem areas identified by data trends and audits.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Nov 03 (Completed)	Surveillance task identification
KSC-Engineering	Aug 04	Surveillance plan documentation update
KSC-SMA	Jul 04	Surveillance plan documentation update

Columbia Accident Investigation Board

Observation 10.5-3

NASA needs an oversight process to statistically sample the work performed and documented by Alliance technicians to ensure process control, compliance, and consistency.

BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a statistically valid sampling program to evaluate contractor operations. Kennedy Space Center (KSC) currently samples contractor operations within the Space Shuttle Main Engine Processing Facility; however, the sample size is not statistically significant and does not represent all processing activities.

NASA IMPLEMENTATION

NASA will assess the implementation, required resources, and potential benefits of developing a statistical sampling program to provide oversight to the work performed and documented by United Space Alliance (USA) technicians. The USA In-Process Sampling Group is developing a sampling program. NASA Process Analysts will assess the USA sampling program by collecting additional data to independently evaluate USA's statistics. Initially, NASA will use USA's Web-based data maintenance and metric capabilities for tracking active work authorization documents (WADs). However, NASA has already begun initial development of an independent statistical sampling program for both active and closed WADs. This will provide additional verification of the quality of USA's work.

STATUS

NASA and USA have worked together over the past several months to collect data on work in process and closed vehicle problem report sample data. We have begun to compare data with overall favorable results. We will continue to gather and compare data to ensure continued consistency in results and to refine sampling techniques to achieve the required level of quality assurance.

FORWARD WORK

NASA will continue improving its ability to assure the quality of USA work. NASA will enhance our insight through sampling of the Problem Reporting and Corrective Action system, Test Preparation Sheets (TPS), and completed Orbiter Maintenance Instructions (OMIs) for accuracy in preparation and completeness in execution. NASA will determine the resources required to provide a statistically significant sampling program along with developing metrics for further trending that will include goals.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Nov 03 (Completed)	Provide resource estimate
KSC	Nov 03 (Completed)	Implement in-process sampling program
KSC	Nov 03 (Completed)	Implement Closed WAD sampling program – vehicle problem reports only
KSC	Mar 04 (Completed)	Define/develop in-process metrics
KSC	Apr 04	Closed WAD sampling program – addition of Space Shuttle Main Engine and ground support equipment problem reports
KSC	May 04	Define/develop closed WAD sampling standard metrics
KSC	Jun 04	Closed WAD sampling program – addition of discrepancy reports
KSC	Nov 04	Closed WAD sampling program – addition of TPSs and OMIs

Columbia Accident Investigation Board

Observation 10.6-1

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

BACKGROUND

NASA agrees that greater stability in Orbiter Maintenance Down Period (OMDP) processes will reduce risk.

NASA IMPLEMENTATION AND STATUS

The next OMDP, for OV-105, began in December 2003 and is ongoing. In planning for this OMDP, NASA emphasized stability in the work plan to ensure that quality and safety are maintained at the highest possible levels.

FORWARD WORK

The Space Shuttle Program (SSP) will continue to assess and periodically review the status of all required modifications.

NASA will continue to integrate lessons learned from each OMDP and will emphasize factors that could destabilize plans and schedules. NASA will also conduct delta OMDP Flow Reviews for each Orbiter on an ongoing basis.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Oct 03 (Completed)	OV-105 OMDP Modification Site Flow Review
SSP	Ongoing	Delta OMDP Flow Reviews

Columbia Accident Investigation Board

Observation 10.6-2

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

BACKGROUND

The transfer of Orbiter Maintenance Down Periods (OMDPs) from Palmdale to Kennedy Space Center placed additional demands on the existing infrastructure, ground support equipment, and personnel. NASA made significant efforts to anticipate these demands, to transfer the needed equipment from Palmdale, and to hire additional personnel required to accomplish the OMDP-related tasks independent of normal Orbiter flow processing. Because of the fluctuating demands on the Orbiters supporting the flight manifest, some workers with unique critical skills were frequently shared among the Orbiter in OMDP and the Orbiters being processed for flight. Additional inspection and modification requirements, and unanticipated rework for structural corrosion and Thermal Protection Systems, created demands on limited critical skill sets not previously anticipated.

NASA IMPLEMENTATION

NASA has applied the lessons learned from the just completed Orbiter Vehicle (OV)-103 OMDP to the OV-105 OMDP. These lessons have allowed NASA and United Space Alliance managers to better integrate infrastructure, equipment, and personnel from a more complete set of work tasks, unlike the piecemeal approach used during OV-103's OMDP. The requirements for the second OV-105 OMDP were approved, with the exception of two modifications. The Program Requirements Control Board approved 72 modifications at the Modification Site Requirements Review in early July 2003, and reviewed the overall modification plan again in mid-October 2003 at the Modification Site Flow Review. The OV-105 OMDP began in December 2003.

Many "out of family" discrepancies identified as the result of scheduled structural and wiring inspections require design center coordination and disposition. The incorporation of new Orbiter modifications also requires close coordination for design issue resolution. Timely design response can reduce the degree of rescheduling and critical skill rebalancing required. During the OV-103 OMDP, design center engineers were available on the floor in the Orbiter Processing Facility where the work was being accomplished to efficiently and effectively disposition discrepancies when identified. This approach reduced the need to reschedule work until a disposition was made, thus reducing the need for workload or resource rebalancing.

STATUS

- Lessons Learned from the third OV-103 OMDP have been incorporated into the current OV-105 OMDP. More accurate estimates of structural inspection and wiring discrepancies are anticipated as the review of OV-103 discrepancy data continues.
- Additional personnel hiring focusing on critical skill sets has been coordinated with the NASA Shuttle Processing Directorate and the NASA Orbiter Project Office.
- The additional emphasis on "on floor" design response, which helped to reduce rescheduling and resource rebalancing during OV-103's third OMDP, is being expanded for OV-105's first OMDP.

FORWARD WORK

The Space Shuttle Program (SSP) will follow the practice of approving most or all of the known modifications for incorporation at the beginning of an Orbiter Vehicle's OMDP, typically at the Modification Site Requirements Review. Lessons learned will be captured for each ensuing OMDP and will be used to improve future OMDP processing.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Oct 03 (Completed)	Mod Site Flow Review
SSP	Dec 03 (Completed)	Complete OV-103 Lessons Learned
SSP	Ongoing	Incorporated lessons learned for OMDP processing

Columbia Accident Investigation Board

Observation 10.6-3

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

BACKGROUND

In June 2003, NASA requested that the U.S. Air Force conduct an assessment of the Orbiter Maintenance Down Period/Orbiter Major Modification (OMDP/OMM) being performed at Kennedy Space Center (KSC). The U.S. Air Force team provided similarities, compared best practices, identified differences between NASA and the U.S. Air Force practices, identified potential deficiencies, and provided recommendations and areas for potential improvements. NASA is using this information to improve our practices and processes in evaluating the Orbiter fleet, and to formulate our approach for continued benchmarking.

NASA has also initiated a number of aging vehicle assessment activities as part of the integrated Space Shuttle Service Life Extension Program (SLEP) activities. Each of the Space Shuttle element organizations is pursuing appropriate vehicle assessments to ensure that Shuttle Program operations remain safe and viable throughout the Shuttle's operational life.

NASA IMPLEMENTATION

Personnel fromWright-Patterson Air Force Base have provided direct support to SLEP and have contributed to management decisions on needed investments through membership on SLEP panels. NASA will continue to work with the U.S. Air Force in its development of aging vehicle assessment plans. Planned assessments for the Space Shuttle Orbiters, for example, include expanded fleet leader hardware programs and corrosion control programs.

In addition to working with the U.S. Air Force on these assessments, NASA is actively drawing upon resources external to the Space Shuttle Program that have valuable experience in managing the operations of aging aircraft and defense systems. NASA is identifying contacts across government agencies and within the aerospace and defense industries to bring relevant expertise from outside the Shuttle Program to assist the team. The Orbiter Project has already augmented its aging Orbiter assessment team with systems experts from Boeing Integrated Defense Systems.

In 1999, NASA began a partnership with the U.S. Air Force Research Laboratory, Materials and Manufacturing Directorate, at Wright-Patterson Air Force Base to characterize and investigate wire anomalies. The Joint NASA/Federal Aviation Administration/Department of Defense Conference on Aging Aircraft focused on studies and technology to identify and characterize these aging systems. NASA will continue this partnership with constant communication, research collaboration, and technical interchange.

Following the June 2003 Air Force assessment of the OMDP/OMM being performed at KSC, a group of engineers went on a fact-finding trip in July 2003 to Warner-Robins Air Force Base to learn more about Air Force maintenance on C-130s, C-141s, and C-5s. They met with Air Force personnel who had performed the previous assessment. All agreed that a joint working group, including United Space Alliance, needed to be formed. The next targeted visit will most likely be to Tinker Air Force Base to review maintenance on KC-135 aircraft and possibly to Hill Air Force Base to review B-2 aircraft maintenance.

STATUS

NASA will continue to solicit participation of government and industry aging system experts from across the aerospace and defense sectors in the Space Shuttle aging vehicle assessment activities. NASA is particularly interested in benchmarking the aging system management practices of relevant programs within the U.S. Air Force and other agencies and will work to establish opportunities for meetings and ongoing interchange on this subject.

FORWARD WORK

NASA will continue to work with the U.S. Air Force to benefit from its knowledge of operating and maintaining long-life aircraft systems.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC/U.S. Air Force	TBD	Establish Joint U.S. Air Force/NASA Working Group
KSC	TBD	Benchmark additional U.S. Air Force Logistics Centers

Columbia Accident Investigation Board

Observation 10.6-4

The Space Shuttle Program Office must determine how it will effectively meet the challenge of inspecting and maintaining an aging Orbiter fleet before lengthening Orbiter Major Maintenance intervals.

BACKGROUND

An aging Orbiter fleet presents inspections and maintenance challenges that must be incorporated in the planning of the Orbiter Maintenance Down Periods (OMDPs). Prior to the *Columbia* accident, the Space Shuttle Program Office had begun an activity to lengthen the interval between OMDPs from the current requirement of every 3 years or 8 flights to a maximum of 6 years or 12 flights. Initially the Structures Problem Resolution Team (PRT) was assigned the action to examine all structural inspection requirements for effects to extending the OMDP interval. No specific extension period was identified. The Structures PRT examined every requirement dealing with structural inspections in the Orbiter Maintenance Requirements and Specifications Document and compared findings from previous OMDP and in-flow inspections to determine whether new inspection intervals were warranted. The findings from this effort resulted in updated intervals for structures inspections. Structural inspections can support an OMDP interval of 6 years or 12 flights. Part of this new set of inspections is the inclusion of numerous interval inspections that would be conducted between OMDPs. Adverse findings from the sampling inspections could lead to a call for an early OMDP.

In the wake of the *Columbia* accident, there is no longer a desire to extend the OMDP interval. The requirement for OMDP intervals will remain every 3 years or 8 flights.

NASA IMPLEMENTATION

Orbiter aging vehicle assessments, initiated as part of the Shuttle Service Life Extension Program, will ensure that inspection requirements are evaluated for any needed requirements updates to address aging vehicle concerns. An explicit review of all hardware inspection requirements will be conducted during the Orbiter life certification assessment to determine if aging hardware considerations or certification issues warrant the addition of new inspection requirements or modification to existing requirements. Subsequent to completion of the life certification assessment, inspection requirement adequacy will continue to be evaluated through ongoing aging vehicle assessment activities, including the Orbiter fleet leader program and corrosion control program.

STATUS

NASA has initiated an assessment to ensure that Space Shuttle operations remain safe and viable throughout the Shuttle's service life.

FORWARD WORK

Orbiter life certification assessments are currently under way for the highest criticality hardware components in support of STS-114 return to flight. Completion of certification verification for the remaining Orbiter hardware will be conducted in a prioritized manner through 2006. Planning for the expanded Orbiter fleet leader hardware assessment and corrosion control programs is under way with an anticipated start date in mid 2004.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	2004	Orbiter life certification assessment for highest criticality hardware
SSP	2006	Orbiter life certification assessment for remaining hardware

Columbia Accident Investigation Board

Observation 10.7-1

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

BACKGROUND

The Space Shuttle Program has initiated an action to assess the *Columbia* Accident Investigation Board observations related to corrosion damage in the Shuttle Orbiters. This action has been assigned to the Orbiter Project Office.

NASA IMPLEMENTATION

The Orbiter element is in full compliance with this observation. Before the disposition of any observed corrosion on Orbiter hardware, a full review is conducted via the Orbiter Corrosion Control Board. Nondestructive analysis is typically used to determine the mechanism, depth, and breadth of the existing corrosion. Inspection intervals are reviewed on a case-by-case basis as new corrosion is discovered. Disposition of corroded components requires evaluation and/or analysis by appropriate subsystem, stress, and materials engineers. Positive margins must be retained, or the affected component is replaced or supplementary load paths are applied. Any course of action must be agreed upon by all technical communities and coordinated through the Obiter Corrosion Control Board.

STATUS

The Orbiter Program is in compliance with this observation.

FORWARD WORK

None.

SCHEDULE

None.

Columbia Accident Investigation Board

Observation 10.7-2

Long-term corrosion detection should be a funding priority.

BACKGROUND

Both Orbiter engineering and management concur that ongoing corrosion of the Space Shuttle fleet should be addressed as a safety issue. As the Orbiters continue to age, NASA must direct the appropriate level of resources to sustain the expanding scope of corrosion and its impact to Orbiter hardware.

NASA IMPLEMENTATION, STATUS, AND FORWARD WORK

Recently, the Aging Vehicle Assessment Committee approved a proposal to expand the scope and authority of the Orbiter Corrosion Control Board. Funding authorization has been received, and NASA, United Space Alliance, and Boeing are working to develop and implement an expanded corrosion control program.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Orbiter Project Office	Completed	Direct appropriate long-term funding (sustained)
Orbiter Project Office	Jun 04	Develop an advanced Orbiter Corrosion Control Program to detect, trend, analyze, and predict future corrosion issues

Columbia Accident Investigation Board

Observation 10.7-3

Develop non-destructive evaluation inspections to find hidden corrosion.

BACKGROUND

An integral part of an effective corrosion control program is the continual development and use of nondestructive evaluation (NDE) tools. The development of such tools to explore hidden corrosion is a complex problem.

NASA IMPLEMENTATION

NASA is investigating a wide range of advanced NDE techniques, and has several activities ongoing to use NDE to find hidden corrosion.

- Chartered by NASA, the NASA NDE Working Group (NNWG) has representatives from each of the NASA field centers and affiliated contractors. This group meets periodically to address both short- and long-term Space Shuttle Program needs. In the past, the NNWG has executed efforts to develop NDE techniques directly in support of this subject, such as corrosion under tile and corrosion under paint. To date, these efforts have experienced only limited success.
- Before the *Columbia* accident, the NASA Johnson Space Center (JSC) initiated a partnership with the NASA Langley Research Center to specifically address hidden corrosion. This work is ongoing.
- Recently, United Space Alliance (USA) initiated efforts to investigate advanced techniques such as the Honeywell Structural Anomaly Mapping System to support both structural assessments as well as hidden corrosion. This technology is currently under assessment for potential certification by the Federal Aviation Administration.
- JSC is developing a set of hidden corrosion test standards. These standards will be used for future evaluation of potential NDE techniques.

These efforts will be expanded. A review of current activities will be completed, and compared with long-term Program needs. Both the current NNWG and the future advanced Orbiter Corrosion Control Panel will work together to establish the scope of the effort and, subsequently, to present recommendations to Orbiter Program management.

Appropriate Program resources should be committed in several areas to sustain ongoing development activities well into the future.

STATUS AND FORWARD WORK

The chair of the NNWG is leading NASA's efforts to enhance our NDE capabilities to detect hidden corrosion. As a result of these efforts, the Aging Vehicle Assessment Committee approved a proposal to expand the scope and authority of the Orbiter Corrosion Control Board. Funding authorization has been received, and NASA, USA, and Boeing are working to develop and implement an expanded corrosion control program. The assessment will include a review of NASA efforts to develop NDE tools.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Orbiter Project Office	Jun 04	Develop an advanced Orbiter Corrosion Control Program, chartered to detect, trend, analyze, and predict future corrosion issues. Development of NDE techniques for corrosion detection shall be included in the Program.
NNWG	Jun 04	Coordinate the support of the NNWG in support of advanced NDE development to address hidden corrosion
Orbiter Project Office	TBD	Direct appropriate funding to support the Orbiter Corrosion Control Program.
Orbiter Project Office	TBD	Direct appropriate funding to support the NNWG.

Columbia Accident Investigation Board

Observation 10.7-4

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

BACKGROUND

Historically, inspection intervals for Orbiter corrosion have not been driven by mathematical corrosion rate assessments. In our experience, predicting corrosion rates is only effective when the driving mechanism is limited to general surface corrosion in a known environment over a known period of time. To date, general surface corrosion is not an Orbiter problem. Common Orbiter corrosion problems include pitting, crevice, galvanic, and intergranular corrosion attack. These mechanisms are extremely inconsistent and present tremendous difficulty in effectively predicting corrosion rates. Environments are complex, including time histories with intermittent exposure to the extreme temperatures and vacuum of space. Also, with a limited data set, it is difficult to develop and use a database with a reasonable standard deviation. Any calculated results would carry great uncertainty.

NASA IMPLEMENTATION

NASA agrees with the importance of understanding when and where corrosion occurs as a first step towards mitigating it. Given the difficulty in establishing trenchant mathematical models of corrosion rates for the multiple Orbiter environments, NASA will assess mechanisms, magnitudes, and rates of corrosion occurrence. This can be used to prioritize high corrosion occurrence areas. We will also target inspections toward low-traffic and/or hard-to-access areas that are not consistently inspected. Furthermore, predicting the rates of long-term degradation of our corrosion protection systems will be addressed.

Beyond the original Orbiter design life of 10 years/100 flights, corrosion inspection intervals have been driven by environment, exposure cycles, time, materials, and configuration. These inspection intervals have generally been extremely conservative. In the cases where the intervals were found to not be conservative enough, we have revised our interval requirements and expanded the scope of concern accordingly.

When we do find corrosion, NASA's standard procedure is to immediately repair it. If the corrosion is widespread in an area or a configuration, specific fixes are incorporated or refurbishments are implemented. In the few cases where this is not possible, such as when the rework cannot be completed without major structural disassembly, engineering assessments are completed to characterize the active corrosion rate specific to the area of concern, and inspection intervals are assigned accordingly, until the corrosion can be corrected. Relative to the general aviation industry, our approach to corrosion repair is extremely aggressive and conservative. In the past, NASA has worked closely with the U.S. Air Force to review corrosion prevention programs for potential application to the Orbiter Program. Several successes from Air Force programs have already been implemented, such as the use of water wash-downs and corrosion preventative compounds.

STATUS AND FORWARD WORK

Recently, a Phase II proposal to expand the scope and authority of the present Orbiter Corrosion Control Board was reviewed by the Aging Vehicle Assessment Committee. Funding authorization has been received, and NASA, United Space Alliance, and Boeing are working to develop and implement an expanded corrosion control program. This activity will include a review of the current state of the art in corrosion control tools and techniques, followed by consideration for implementation into the future Orbiter corrosion control program.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Orbiter Project Office	Completed	Direct appropriate funding to develop a sustained Orbiter Corrosion Control Board.
Orbiter Project Office	Jun 04	Develop an advanced Orbiter Corrosion Control Program to detect, trend, analyze, and predict future corrosion issues.

Columbia Accident Investigation Board

Observation 10.8-1

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

Note: NASA has closed this observation through the formal Program Requirements Control Board process. The following summary details NASA's response to the observation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board observation.

BACKGROUND

Concerns regarding the use of these materials were initiated due to the brittle fracture mode observed on some A-286 Stainless Steel Leading Edge Subsystem Carrier Panel bolts. Specifically, it was argued that lubricant materials consisting of Teflon and/or Molybdenum Disulfide should not be used due to their potential to contribute to a stress corrosion cracking fracture mechanism at elevated temperatures. Traces of perfluorinated polyether grease and Molybdenum Disulfide (lubricants) were found on the carrier panel bolt shank and sleeve. However, no Teflon was found during the failure analysis of carrier panel fasteners.

A-286 fasteners in the presence of an electrolyte must also be exposed to elevated temperatures for stress corrosion cracking to be of concern. However, fastener installations are protected from temperature extremes (the maximum temperatures seen, by design, are less than 300ºF).

NASA IMPLEMENTATION

NASA conducted interviews with ground technicians at Kennedy Space Center (KSC); these interviews indicated that the use of Braycote grease as a lubricant may have become an accepted practice due to the difficult installation of this assembly. Braycote grease contains perfluorinated polyether oil, Teflon, and Molybdenum Disulfide materials. According to design drawings and assembly procedures, the use of lubricants should not have been allowed in these fastener installations.

As a result of these findings, NASA directed United Space Alliance (USA) to institute appropriate corrections to their fastener installation training and certification program. USA shall emphasize to its technicians to follow exactly the installation instructions for all Orbiter fastener installations. Any deviation from specific instructions will require disposition from engineering before implementation. USA will further emphasize that lubricants cannot and should not be used in any fastener installation, unless specifically authorized.

In addition, NASA has implemented an engineering review of all discrepancy repairs made on Orbiter hardware at KSC. An engineering review will occur to provide the appropriate checks and balances if a lubricant is required to address a specific fastener installation problem.

STATUS

NASA and USA have implemented corrective actions to ensure that lubricant will not be used in fastener applications unless explicitly approved by engineering.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC/USA Ground Operations	Mar 04 (Completed)	Update fastener training and certification program for USA technicians; require deviations from instructions to be approved before implementation

Columbia Accident Investigation Board

Observation 10.8-2

Galvanic coupling between aluminum and steel alloys must be mitigated.

BACKGROUND

Galvanic coupling between dissimilar metals is a well-recognized Orbiter concern. As galvanic couples between aluminum and steel alloys cannot be completely eliminated, the Space Shuttle Program (SSP) must implement appropriate corrosion protection schemes.

The SSP Orbiter element requirements are in full compliance with this observation. Currently, according to the Boeing Orbiter Materials Control Plan, "Metals shall be considered compatible if they are in the same grouping as specified in Military-Standard (MIL-STD)-889 or the difference in solution potential is ≤ 0.25 Volts." Otherwise, mitigation for galvanic corrosion is required. Per NASA requirement Marshall Space Flight Center-Specification (MSFC-SPEC)-250, "…when dissimilar metals are involved… the fasteners shall be coated with primer or approved sealing compounds and installed while still wet or for removable or adjustable fasteners, install with corrosion preventative compound." Where there are exceptions, such as fastener installations that are functionally removable, we depend on scheduled inspections of the fastener hole.

NASA IMPLEMENTATION

Since Orbiter galvanic couples are generally treated with corrosion mitigation schemes, the time-dependent degradation of approved sealing compounds must be addressed. Recent inspections have raised concern in areas where significant galvanic couples exist, even in the presence of sealing materials.

STATUS AND FORWARD WORK

Design changes are being considered in areas where significant galvanic couples exist. Examples of recent design modifications include electrical ground paths in the Orbiter nose cap and on the metallic fittings of the External Tank doors. In the future, NASA will take action to be more proactive in addressing this vehicle-wide concern.

The SSP Aging Vehicle Assessment Committee has approved a proposal to expand the scope and authority of the Orbiter Corrosion Control Board. This activity included a review of the time-dependent degradation of approved sealing compounds.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Kennedy Space Center	Jun 04	Develop an advanced Orbiter Corrosion Control Program, including implementation of an aging materials evaluation as applied to galvanic couple seal materials on Orbiter hardware.
SSP	TBD	Present to the SSP Program Requirements Control Board for direction and funding.

Columbia Accident Investigation Board

Observation 10.8-3

The use of Room Temperature Vulcanizing 560 and Koropon should be reviewed.

Note: NASA has closed this observation through the formal Program Requirements Control Board process. The following summary details NASA's response to the observation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board observation.

BACKGROUND

Concerns regarding the use of Room Temperature Vulcanizing (RTV) 560 and Koropon materials were initiated due to the brittle fracture mode observed on some A-286 Stainless Steel Leading Edge Subsystem Carrier Panel bolts. Specifically, it was argued that trace amounts of contaminants in these materials could, at elevated temperatures, contribute to a Stress Corrosion Cracking (SCC) of the bolts. It was also proposed that these contaminants might accelerate corrosion, particularly in tight crevices.

SCC of A-286 material is only credible at high temperatures. This is not a concern as all fastener installations are protected from such temperature extremes (the maximum temperatures seen, by design, are less than 300°F).

NASA IMPLEMENTATION

NASA completed materials analyses on multiple A-286 bolts that exhibited a brittle-like fracture mode. Failure analysis included fractography, metallography, and chemical analysis. Furthermore, a research program was executed to duplicate and compare the bolt failures experienced on *Columbia*. This proved conclusively that the brittle-looking fracture surfaces were produced during bolt failure at temperatures approaching 2000°F and above. This failure mode is not a concern with the A-286 Stainless Steel Leading Edge Subsystem Carrier Panel bolts, as all fastener installations are protected from such temperature extremes.

In addition to failure analysis, both RTV 560 and Koropon were assessed for the presence of trace contaminants. Inductively Coupled Plasma analyses were completed on samples of both materials. The amount and type of trace contaminants were analyzed and determined to be insignificant.

RTV 560 and Koropon were selected for widespread use in the Shuttle Program because they prevent corrosion. All corrosion testing and failure analysis performed during the life of the Shuttle Program have not shown deleterious effects from either product. Several non-Shuttle aerospace companies have used Koropon extensively as an anticorrosion primer and sealant. To date, problems with its use in the military and industry have not been identified.

Both of these materials may eventually fail in their ability to protect from corrosion attack, but do not fail by chemically breaking down to assist corrosion mechanisms. Thus, NASA concluded that trace contaminants in Koropon and RTV 560 do not contribute to accelerated corrosion or SCC mechanisms.

In addition to answering this specific observation, NASA is assessing the long-term performance of all nonmetallic materials used on the Orbiter through a vehicle-wide aging materials evaluation. This effort is ongoing and will continue in support of the Orbiter for the remainder of its service life.

STATUS

NASA considers that these materials have been reviewed, and present no risk for supporting accelerated corrosion and/or SCC mechanisms. Appropriate long-term additional studies have been initiated.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program	Mar 04 (Completed)	Review use of RTV 560 and Koropon

Columbia Accident Investigation Board

Observation 10.8-4

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

Note: NASA has closed this observation through the formal Program Requirements Control Board process. The following summary details NASA's response to the observations and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board observation.

BACKGROUND

Initial concerns regarding the use of these A-286 stainless steel fastener materials were initiated due to the brittle fracture mode observed on some Leading Edge Subsystem Carrier Panel bolts. The concern about residual compressive stresses, and to some extent the concerns about Koropon, Room Temperature Vulcanizing 560, Teflon, and Molybdenum Disulfide, emanated from a conjecture that the brittle fracture of some of the bolts could have been caused by Stress Corrosion Cracking (SCC).

For SCC to occur, each of the following conditions must exist:

- Material of concern must be susceptible to SCC
- Presence of an active electrolyte
- Presence of a sustained tensile stress

Additionally, SCC of A-286 fasteners is a concern only under exposure to high temperatures. All fastener installations are protected from such temperature extremes.

NASA IMPLEMENTATION

To address the concern that sustained tensile stress might have contributed to SCC, NASA completed materials analyses on multiple A-286 bolts that exhibited a brittle-like fracture mode (i.e., minimal ductility, flat fracture). The failure analysis included fractography, metallography, and chemical analysis. Furthermore, a research program was executed to duplicate and compare the bolt failures experienced on Columbia. This proved conclusively that the brittle-looking fracture surfaces were produced during bolt failure at temperatures approaching 2000ºF and above. The observed intergranular fracture mechanism is consistent with grain boundary embrittlement at elevated temperatures, along with potential effects from liquid metal embrittlement from vaporized aluminum. The effects of high temperature exposures on A-286 stainless steel materials are not consistent with the SCC concerns.

In addition to this effort, NASA completed residual stress analyses on several A-286 bolts via neutron diffraction at the National Research Council of Canada. In general, residual stresses were determined to be negligible or compressive in the axial bolt direction. The bolts used on the Space Shuttle have a sufficient compressive stress layer, which is governed by appropriate process controls at the manufacturer.

NASA reviewed the manufacturing and material specifications for the A-286 bolts. This review confirmed that only qualified vendors are contracted, manufacturing process controls are sufficient, and Certificates of Compliance are maintained for material traceability. Furthermore, NASA executes material lot testing on all fasteners procured for use in the Shuttle Program to ensure appropriate quality control.

STATUS

NASA has analyzed the requirements and process for A-286 bolts and found that current processes and controls are adequate.

FORWARD WORK

None.

SCHEDULE

None.

Columbia Accident Investigation Board

Observation 10.9-1

NASA should consider a redesign of the (Hold-Down Post Cable) system, such as adding a cross-strapping cable, or conduct advanced testing for intermittent failure.

Note: This response also encompasses the response to Recommendation D.a-10, Hold-Down Post (HDP) Cable Anomaly.

BACKGROUND

Each of the two Solid Rocket Boosters (SRBs) is attached to the Mobile Launch Platform by four hold-down bolts that are each secured by a 5-in. diameter restraint nut. The restraint nuts each contain two pyrotechnic initiators designed to sever the nuts when the SRBs ignite, releasing the Space Shuttle stack to lift off the launch platform.

Release is normally accomplished by simultaneously firing two redundant pyrotechnic charges called NASA standard initiators (NSIs) on each of eight SRB stud frangible nuts. Two independent ground-based pyrotechnic initiation control (PIC) systems, A and B, are used to receive the command and to distribute the firing signals to each HDP. On STS-112, the system A Fire 1 command was not received by the ground-based PIC system; however, the redundant system B functioned properly and fired all system B NSIs, separated the frangible nuts, and enabled the release of the stud frangible nuts on all posts. As a result, the Shuttle safely separated from the launch platform.

NASA was unable to conclusively isolate the anomaly in any of the failed components. The most probable cause was determined to be an intermittent connection failure at the launch platform-to-Orbiter interface at the tail service mast (TSM) caused by the dynamic vibration environment after main engine start. Several contributing factors were identified, including groundside connector corrosion at the TSM T-0 umbilical, weak connection spring force, potential nonlocked Orbiter connector savers, lack of proper inspections, and a blind (non-visually verified) mate between the ground cable and the Orbiter connector saver.

The STS-112 investigation resulted in the replacement of all T-0 ground cables after every flight, a redesign of the T-0 interface to the PIC rack cable, and replacement of all Orbiter T-0 connector savers. Also, the pyrotechnic connectors will be prescreened with pin retention tests and the connector saver mate process will be verified using videoscopes. The *Columbia* Accident Investigation Board (CAIB) determined that the prelaunch testing procedures for this system may not be adequate to identify intermittent failure. Therefore, the CAIB suggested that NASA consider a redesign of the system or implement advanced testing for intermittent failures.

NASA IMPLEMENTATION

Five options for redesign of this system were presented to the Orbiter Project Configuration Control Board on August 20, 2003. The recommended redesign configuration provides redundancy directly at the T-0 umbilical, which was determined to be the primary contributing cause of the STS-112 anomaly. The selected option results in the least impact to hardware (fewer connectors, less wiring, less weight added), can be implemented in a reasonably short time period, and requires only limited modifications to existing ground support equipment. Orbiter and groundside implementations are not affected as they interface at the same T-0 pins.

Kennedy Space Center (KSC) has implemented a number of processing changes to greatly reduce the possibility of another intermittent condition at the TSM. The ground cables from the Orbiter interface to the TSM bulkhead plate are now replaced after each use; reuse after inspection was previously allowed. The ground connector springs that maintain the mating force against the Orbiter T-0 umbilical are all removed and tested to verify the spring constants meet specification between each flight. Cables from the TSM bulkhead plate to the PIC rack were previously inspected for damage, replaced as needed, and thoroughly tested. The Orbiter T-0 connector savers are inspected before each flight and are now secured with safety wire before the launch platform cables are connected. New ground cables are thoroughly inspected before mate to the Orbiter. In addition, the connection process was enhanced to provide a bore scope optical verification of proper mate.

For STS-114 return to flight (RTF), the Space Shuttle Program (SSP) is implementing several design changes and enhancements to further reduce the risk of a similar event. The Orbiter Project is adding redundant command paths for each Arm, Fire 1, Fire 2, and return circuits from the Orbiter through separate connectors on the Orbiter/TSM umbilical. The ground support equipment cables will be modified to extend the signals to the ground PIC rack solid-state switches. This modification adds copper path redundancy through the most dynamic and susceptible environment in the PIC system. Additionally, the KSC Shuttle Processing Project is redesigning and replacing all electrical cables, from the Orbiter T-0 umbilical through the TSMs, to their respective distribution points. The new cables will be factory constructed with a more robust insulation and be better suited for the environment in which they are used. This new cable design also eliminates the old style standard polyimide ("Kapton") wire insulation that can be damaged by handling and degrades with age.

SSP technical experts have investigated laser-initiated ordnance devices and have concluded that there would be no functional improvement in the ground PIC system operation. Although laser-initiated ordnance has good capabilities, no conclusive benefit for use on the Space Shuttle systems has been identified. Additionally, use of laser-initiated ordnance would have only changed the firing command path from the ground PIC rack to each of the ordnance devices. This would not change or have had any impact on master command path failures experienced during the STS-112 launch, since they would still be electrical copper paths.

NASA has been engaged for more than three years with the joint Department of Defense, NASA, Federal Aviation Agency, and industry aging aircraft wiring community to develop, test, and implement fault-detection methods and equipment to find emerging wire anomalies and intermittent failures before they prevent electrical function. Several tools have been developed and tested for that purpose, but no tool is available with a conclusive ability to guarantee total wire function, especially under dynamic conditions that cannot be tested in place just before use.

STATUS

A cross-strapping cable was not recommended as part of the redesign options because of concerns that it would introduce a single point failure that could inhibit both hold-down post pyrotechnic systems. The recommended redesign, plus the previously identified processing and verification modifications, are considered to be sufficient to mitigate the risks identified during the STS-112 anomaly investigation. Actions are in place to investigate additional methods to verify connector mating and system integrity. Several technical issues associated with the implementation of this redesign are continuing to be evaluated.

Proposed hardware modifications and development activity status include

- The TSM cable preliminary redesign is complete and has been designated an RTF mandatory modification by the Shuttle Processing Project.
- The Orbiter Project is implementing the T-0 redundancy modification in the Orbiter cable system and T-0 connectors. KSC will modify groundside circuits accordingly.
- The SSP is not currently considering laser pyrotechnic firing for the Shuttle Program but may readdress the issue in the future as the technology matures and the flight vehicle is upgraded.
- NASA is currently supporting two separate strategies to determine wiring integrity. In addition, NASA is engaged with the Department of Defense and the Federal Aviation Agency to encourage further studies and projects.

FORWARD WORK

The evaluation team for laser initiation of pyrotechnics will continue to monitor hardware development for application to Shuttle hardware. The NASA team will continue to engage in development of emerging wire fault detection and fault location tools with the government and industry wiring community. NASA will advocate funding for tool development and implement all new effective methods.

Additionally, a NASA Headquarters (HQ)-sponsored Independent Assessment (IA) team has been formed to review this anomaly and generically review the T-0 umbilical electrical/data interfaces. While this independent review is not considered a constraint to implementing the redesign, it provides an opportunity to ensure that the original investigation was thorough and to look for additional recommendations or improvements that might be implemented.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP, KSC, USA	Oct 03 (Completed)	Present to SSP Integration Control Board
SSP, KSC, USA	Oct 03 (Completed)	Present to SSP Program Requirements Control Board
SSP, KSC, USA	Nov 03 (Completed)	Design Review
SSP, KSC, USA	Dec 03 (Completed)	Wire Design Engineering
HQ IA Team	Dec 03 (Completed)	Independent Assessment Final Report
HQ IA Team	Mar 04 (Completed)	Wire Installation Engineering
Orbiter Project	Apr 04	Provide redundant firing path in the Orbiter for HDP separation
SSP	May 04	Approve new Operational Maintenance Requirements and Specification Documents requirement for specific ground cable inspections as a condition for mating
SSP	May 04	Report on new technology wire fault detection capability
SSP	May 04	New laser firing study task
Shuttle Integration	Oct 04	Evaluate cross-strapping for simultaneous NSI detonation
Shuttle Processing Project	RTF	Modify, install, and certify the ground cabling to protect against damage and degradation and to implement a redundant ground electrical path to match Orbiter commands

Columbia Accident Investigation Board

Observation 10.10-1

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.

This action also encompasses the action in Recommendation D.a-11, SRB ETA Ring.

BACKGROUND

The External Tank Attach (ETA) rings are located on the Solid Rocket Boosters (SRBs) on the forward end of the aft motor segment (figure O10.10-1). The rings provide the aft attach points for the SRBs to the External Tank (ET). Approximately two minutes after liftoff, the SRBs separate from the Shuttle vehicle.

In late 2002, Marshall Space Flight Center (MSFC) engineers were performing tensile tests on ETA ring web material prior to the launch of STS-107 and discovered the ETA ring material strengths were lower than the design requirement. The ring material was from a previously flown and subsequently scrapped ETA ring representative of current flight inventory material. A one-time waiver was granted for the STS-107 launch based on an evaluation of the structural strength factor of safety requirement for the ring of 1.4 and adequate fracture mechanics safe-life at launch. The most probable cause for the low strength material was an off-nominal heat treatment process. Following SRB retrieval, the STS-107 rings were inspected as a normal part of postflight inspection, and no issues were identified with flight performance. Subsequent testing revealed lower than expected fracture properties; as a result, the scope of the initial investigation of low material strength was expanded to include a fracture assessment of the ETA ring hardware.

NASA IMPLEMENTATION

NASA used a nonlinear analysis method to determine whether the rings met Program strength requirements for a factor of safety of 1.4 or greater. The nonlinear analysis method is a well-established technique employed throughout the aerospace industry that addresses the entire material stress-strain response and more accurately represents the material's ultimate strength capability by allowing load redistribution. Nonlinear analysis demonstrates that all ETA ring hardware meets Program strength requirements.

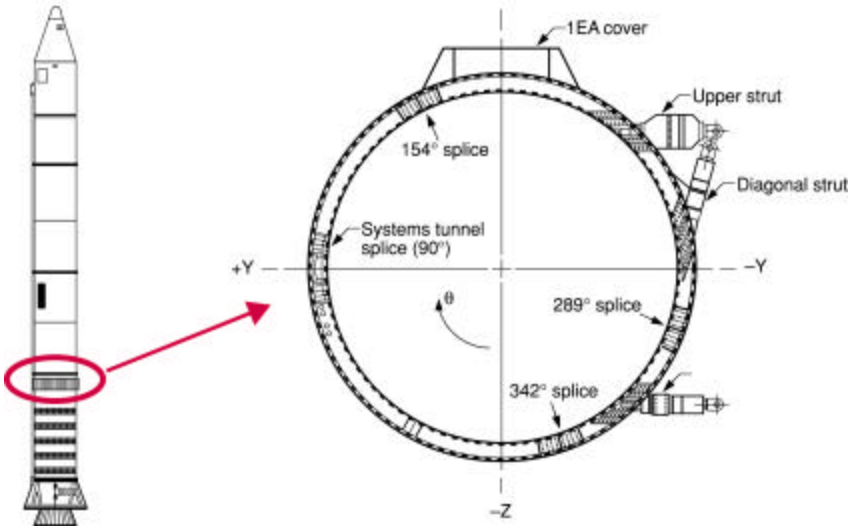


Figure O10.10-1-1. ETA ring location.

In addition to strength analysis, a fracture mechanics analysis will be required to determine the minimum mission life for the rings and to define the necessary inspection interval. Fracture testing on the ETA ring hardware will be performed to determine the appropriate properties for mission-life assessment. NASA will continue to use testing, inspection, and analyses of flight hardware to fully characterize the material for each of the ETA rings in the Shuttle Program inventory. This will provide added assurance that the flight hardware meets Shuttle Program requirements and continues to have an adequate margin for safety above the 1.4 factor of safety requirement.

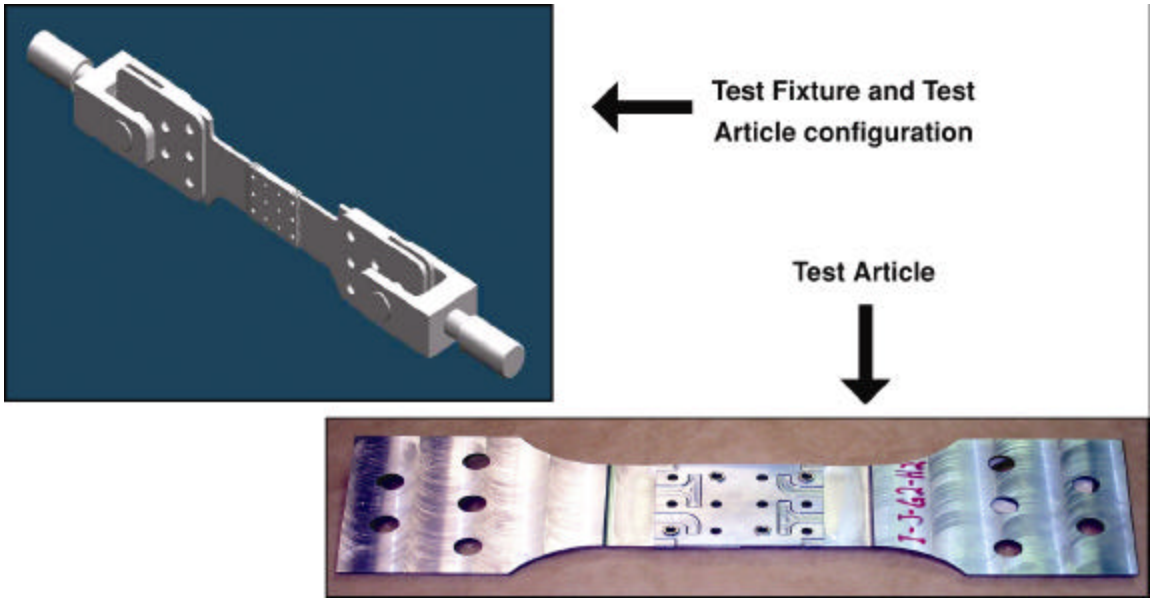


Figure O10.10-1-2. Test articles.

STATUS

The SRB Project has developed and verified by test (figure O10.10-1-2) a nonlinear analysis approach for the 1.4 factor of safety assurance. The hardware materials characterization used in this analysis includes ring web thickness measurements and hardness testing (figure O10.10-1-3) of the splice plates and ring webs.

Serial number 15 and 16 ETA rings exhibited undesirable material variability and are being set aside as the initial candidates for upgrade/replacement. Fracture property testing for the splice plates resulted in unacceptable material properties. Replacement splice plates are being fabricated under controlled processes and lot acceptance testing and will be available for the first two flight sets in April 2004. Any other ring hardware that exhibits similarly unacceptable material or high variability in the hardness measurements will also be set aside for upgrade or replacement. Fracture Control Plan requirements compliance will be ensured by performing extensive nondestructive inspections to re-baseline all areas of the ETA ring hardware.

Figure O10.10-1-3. Harness testing.

Hardware inspections for the first flight set of ETA rings are complete; there were no reportable problems and all areas of the rings met factor of safety requirements. Final safe life assessment is pending fracture property testing, which is scheduled for completion at the end of April 2004.

FORWARD WORK

A funding request for procurement of new ETA rings has been approved. The first new ring is currently scheduled for delivery in January 2006; however, a tiger team has been formed to find ways to expedite this schedule. Hardware inspections for each of the remaining ETA rings in the Space Shuttle Program inventory will continue until replacement hardware becomes available.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SRB Project	Feb 04 (Completed)	New ring procurement funding approved
SRB Project	Jun 04	First flight set ETA rings complete
SRB Project	Jan 06	Delivery of first new ETA ring

Columbia Accident Investigation Board

Observation 10.11-1

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

BACKGROUND

The *Columbia* Accident Investigation Board (CAIB) review of Shuttle test equipment at NASA and contractor facilities revealed the use of antiquated and obsolete 1970s-era technology such as analog equipment. Current state-of-the-art technology is digital rather than analog. Digital equipment is less costly, easier to maintain, and more reliable and accurate. The CAIB recommended that, with the Shuttle projected to fly through 2020, upgrading the test equipment to digital technology would avoid the high maintenance, lack of parts, and questionable accuracy of the equipment currently in use. Furthermore, although the new equipment would require certification for its use, the benefit in accuracy, maintainability, and longevity would likely outweigh the drawbacks of certification costs. Based on the recently announced Vision for Space Exploration, NASA plans to retire the Shuttle following completion of International Space Station assembly, which is planned for the end of the decade.

The Shuttle Program will continue to upgrade test equipment systems to ensure that we maintain the necessary capacity throughout the life of the Shuttle. Decisions on appropriate investments in new test equipment will be made taking into consideration the projected end of Shuttle service life.

NASA IMPLEMENTATION

In 2002, the Space Shuttle Program (SSP) Manager established a Program Logistics Office to provide stronger focus and leadership for long-term sustainability issues such as material, hardware, and test equipment obsolescence. In 2002 and 2003, the Program Logistics Office performed comprehensive supportability reviews of all Program elements and supporting contractors to identify near- and long-term issues, with an emphasis on test equipment. The Program Logistics Office developed a health assessment metric to determine the relative health of the equipment and assist in prioritization of projects for funding. Additionally, the Program Logistics Office is refining and formalizing the health assessment process, now called the Shuttle Health Integrated Metric System (SHIMS), which will provide a formal, annual health assessment of all critical equipment, facilities, and hardware required to support the SSP. This health assessment of all critical equipment will provide visibility into where equipment upgrades are required. This assessment will also evaluate the relative merit of sustaining and repairing old equipment versus procuring new equipment on a case-by-case basis.

STATUS

In 2003, the logistics board approved $32 million towards equipment modernization or upgrade, such as the Space Shuttle Main Engine controller special test equipment (STE), the Orbiter inertial measurement unit, and the Star Tracker STE. Additionally, the Program Logistics Office identified and submitted through the Service Life Extension Program (SLEP) an additional requirement for sustainability to support similar test equipment and obsolescence issues. Certification costs and schedules and the associated Program risks are required elements of the total project package reviewed by the logistics board prior to authority to proceed.

FORWARD WORK

The Program Logistics Office will assess all critical Program equipment, through the use of the SHIMS health assessment tool and annual supportability reviews, and will determine where upgrades are needed to support the Program for the remainder of the Space Shuttle's service life. Identified upgrades will be submitted through the SLEP process to ensure funding of specific projects.

SCHEDULE

This is an ongoing process. Near-term (<5 year) equipment upgrade requirements are being defined by the Program and validated by the SLEP 2004 Sustainability Panel. Longer-term upgrade needs for the remaining service life of the Program will be identified through the annual SHIMS process. Approximately $17 million in

additional test equipment upgrades identified and approved through last year's SLEP summit for fiscal year (FY) 2004 start will be implemented.

Responsibility	Due Date	Activity/Deliverable
SSP	Dec 03 (Completed)	Approve FY04 test equipment upgrades
SLEP Sustainability Panel	Feb 04 (Completed)	Define FY05 test equipment upgrades
SSP	May 04	Approve SHIMS process plan documentation
SSP Development Office	May 04	Provide final Summit II investment recommendations to Space Flight Leadership Council

Columbia Accident Investigation Board

Observation 10.12-1

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

BACKGROUND

The NASA Training and Development Division offers a wide curriculum of leadership development programs to the NASA workforce. The content of internally sponsored programs is developed around the NASA leadership model, which delineates six leadership competencies at four different levels. Each level contains distinct core competencies along with a suggested curriculum. The four levels are executive leader, senior leader, manager/supervisor, and influence leader. NASA also develops leadership skills in the workforce by taking advantage of training and development opportunities at the Office of Personnel Management, Federal Executive Institute, Brookings Institute, and the Center for Creative Leadership, among many other resources. In addition, the Agency sponsors leadership development opportunities through academic fellowships in executive leadership and management, as well as through the NASA-wide Leadership Development Program.

Some NASA centers offer locally sponsored leadership development programs for their first-level and/or mid-level managers and supervisors; these programs are unique to the center, rather than being standardized across NASA. Neither the Agency as a whole nor most of the NASA centers have required, structured, basic supervisor/team lead training programs in place.

To enhance career development opportunities for the NASA workforce, the Agency recognizes that development assignments and career coaching should be a part of an employee's career development. The Agency has begun to address this issue by conducting a mobility study to assess job and development assignments experience across the Agency, developing and offering a formalized program for in-house coaches at each NASA center, and revising criteria for selection into the Senior Executive Service.

NASA IMPLEMENTATION

The NASA Office Of Human Resources has established an Agency team to address the development and implementation of an Agencywide strategy for leadership and management development training. The team is composed of NASA leaders, Agency and center training and development staff, and line managers. The team plans to consult with academia to obtain an external perspective. The Agency office is performing benchmarking of other governmental agencies, major corporations, and universities relating to their leadership and management development programs. The office will also review literature on leadership development from organizations such as the American Society of Training and Development and results of previous benchmarking activity conducted by organizations such as the Corporate Leadership Council.

STATUS

Activities to date include:

- Collection and preliminary analysis of benchmarking data.
- An Agencywide meeting held February 23-27, 2004, with the training community and Enterprise representatives to discuss the current leadership and management career development program and to begin to develop a shared vision, roadmap, and strategy for a more consistent and integrated approach.
- Results from the Agencywide meeting were reviewed by the Management Education Program (MEP 96) class March 8-19, 2004.

FORWARD WORK

Benchmarking will continue, and results will be incorporated into the strategy to be developed by the team. Further, results from the MEP 96 review will be distributed to the team for integration into the strategy. Finally, the strategy will be validated with NASA Senior Leadership.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
HQ/Code FT (Agency Training and Development Division)	Oct 03 (Completed)	Begin Benchmarking Activities
HQ/Code FT	Oct 03 (Completed)	Begin the staff work to form the Agency team
HQ/Code FT	Jan 04 (Completed)	Benchmarking data to date compiled
HQ/Code FT	Apr 04	Draft strategy reviewed/validated by Enterprises/Senior leadership
HQ/Code FT	May 04	Strategy developed and presented to the NASA Associate Deputy Administrator for Institutions and Asset Management

CAIB Report, Volume II, Appendix D.a, "Supplement to the Report"

Volume II, Appendix D.a, also known as the "Deal Appendix," augments the CAIB Report and its condensed list of recommendations. The Appendix outlines concerns raised by Brigadier General Duane Deal and others that, if addressed, might prevent a future accident. The fourteen recommendations contained in this Appendix expand and emphasize CAIB report discussions of Quality Assurance processes, Orbiter corrosion detection methods, Solid Rocket Booster External Tank Attach Ring factor-of-safety concerns, crew survivability, security concerns relating to the Michoud Assembly Facility, and shipment of Reusable Solid Rocket Motor segments. NASA is addressing each of the recommendations offered in Appendix D.a. Many of the recommendations have been addressed in previous versions of the Space Shuttle RTF Implementation Plan and, therefore, its response to those recommendations refers to the location in the Plan where its previously provided response is found. Although the recommendations are not numbered in Appendix D.a, NASA has assigned a number of each of the fourteen recommendations for tracking purposes.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-1 Review Quality Planning Requirements Document Process

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

BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a responsive system for adding or deleting Government Mandatory Inspection Points (GMIPs) and the need for a periodic review of the Quality Planning Requirements Document (QPRD). The Space Shuttle Program, Shuttle Processing Element located at the Kennedy Space Center is responsible for overseeing the QPRD process and implementation of associated GMIPs.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.1, Space Shuttle Program Action 1, and Section 2.2, Observation 10.4-1, of this Implementation Plan. Implementation of this recommendation has been in work since the issuance of the *Columbia* Accident Investigation Board Report, Volume I. NASA commissioned an assessment team, independent of the Space Shuttle Program, to review the effectiveness of the QPRD, its companion document at the Michoud Assembly Facility, referred to as the Mandatory Inspection Document, and the associated GMIPs. NASA continues work to improve this process through its defined implementation plan and will demonstrate our progress with this and future updates to the Return to Flight Implementation Plan.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-2 Responsive System to Update Government Mandatory Inspection Points

Kennedy Space Center must develop and institutionalize a responsive bottom-up system to add to or subtract from Government Inspections in the future, starting with an annual Quality Planning Requirements Document review to ensure the program reflects the evolving nature of the Shuttle system and mission flow changes. At a minimum, this process should document and consider equally inputs from engineering, technicians, inspectors, analysts, contractors, and Problem Reporting and Corrective Action to adapt the following year's program.

BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a responsive system for updating Government Mandatory Inspection Points (GMIPs), including the need for a periodic review of the Quality Planning Requirements Document (QPRD). The Space Shuttle Program's Shuttle Processing Element, located at the Kennedy Space Center, is responsible for overseeing the QPRD process and implementation of associated GMIPs.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.2, Observation 10.4-1, of this Implementation Plan. Implementation of the recommendation has been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. NASA continues to address this issue through its defined implementation plan and will demonstrate progress with this and future updates to the Return to Flight Implementation Plan.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-3 Statistically Driven Sampling of Contractor Operations

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

BACKGROUND

The *Columbia* Accident Investigation Board (CAIB) noted the need for a statistically valid sampling program to evaluate contractor operations. Kennedy Space Center currently samples contractor operations within the Space Shuttle Main Engine Processing Facility; however, the sample size is not statistically significant and does not represent all processing activities.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.2, CAIB Observation 10.5-3, of this Implementation Plan. Corrective measures have been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. NASA continues to address this issue through its defined implementation plan and will demonstrate progress in this and future updates of Observation 10.5-3.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-4 Forecasting and Filling Personnel Vacancies

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

BACKGROUND

The *Columbia* Accident Investigation Board expressed concern regarding staffing levels of Quality Assurance Specialists (QAS) at Kennedy Space Center (KSC) and Michoud Assembly Facility. Specifically, they stated that staffing processes must be sufficient to select qualified candidates in a timely manner. Previously, KSC hired three QAS through a step program; none of them had previous experience in quality assurance. The step program was a human resources sponsored effort to provide training and mobility opportunities to administrative staff. Of the three, only one remains a QAS. In addition to hiring qualified candidates, staffing levels should be sufficient to ensure the QAS function involves more than just inspection. Additional functions performed should include hardware surveillance, procedure evaluations, and assisting in audits.

NASA IMPLEMENTATION

NASA currently uses two techniques for selecting and developing qualified QAS. First, NASA can hire a QAS at the GS-7, GS-9, or GS-11 level, if the candidate meets a predetermined list of requirements and level of experience. QAS candidates at all levels require additional training. Candidates selected at lower grades require additional classroom and on-the-job training before being certified as a QAS. NASA also uses a cooperative education program that brings in college students as part of their education process. This program is designed to develop QAS or quality control technicians for NASA and the contractor. The program is an extensive two-year program, including classroom and on-the-job training. If at the end of the cooperative education program the student does not demonstrate the required proficiency, NASA will not hire the individual.

Hiring practices have also improved. NASA can hire temporary or term employees. Although permanent hiring is preferred, this practice provides flexibility for short-term staffing issues. Examples include replacements for QAS military reservists who deploy to active duty and instances when permanent hiring authority is not immediately available.

Several QAS are deploying a hardware surveillance program. This program will define the areas in which hardware surveillance will be performed, the checklist of items to be assessed, the number of hardware inspections required, and the data to be collected.

STATUS

KSC has addressed the hiring issue. Identified training issues are addressed in Section 2.2, Observation O10.4-3, and a team has been formed to develop, pilot, and deploy a hardware surveillance program.

FORWARD WORK

KSC is running a pilot hardware surveillance program in the Orbiter Processing Facility (OPF), the Hypergolic Maintenance Facility, and the Space Shuttle Main Engine Processing Facility. NASA will expand the surveillance program to the remaining facilities as dictated by pilot program results.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Completed	Develop and implement processes for timely hiring of qualified candidates
KSC	Completed	Develop and implement hardware surveillance program in the OPFs
KC	In work	Deploy hardware surveillance program to all QAS facilities
KSC	In work	Develop reporting metric
KSC	Apr 04	Develop and implement procedure evaluation

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-5 Quality Assurance Specialist Job Qualifications

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

BACKGROUND

The *Columbia* Accident Investigation Board expressed concern regarding staffing qualifications of Quality Assurance Specialists (QAS) at Kennedy Space Center (KSC). Previously, KSC hired three QAS, none of whom had previous experience in quality assurance, through a step program. Of the three, only one remains as a QAS.

NASA IMPLEMENTATION

NASA currently uses two techniques for selecting and developing qualified QAS. First, NASA can hire a QAS at the GS-7, GS-9, or GS-11 level, if the candidate meets a predetermined list of requirements and level of experience. QAS candidates at all levels require additional training. Candidates selected at lower grades require additional classroom and on-the-job training before being certified as a QAS. NASA also uses a cooperative education program that brings in college students as part of their education process. This program is designed to develop QAS or quality control technicians for NASA and the contractor. The program is an extensive two-year program, including classroom and on-the-job training. If at the end of the cooperative education program the student does not demonstrate the required proficiency, NASA will not hire the individual.

NASA will benchmark assurance training programs that are implemented by the Department of Defense (DoD) and Defense Contract Management Agency (DCMA). NASA's present goal is to develop a comparable training program for the quality engineers, process analysts, and QAS. The training requirements will be documented in a formal training records template. Additional information on the training plan is found in Section 2.2, Observation O10.4-3.

STATUS

NASA has benchmarked with DoD and DCMA to understand their training requirements and to determine where the Agency can directly use their training. A team consisting of engineers and QAS in both the Shuttle and International Space Station Programs has been formed to develop and document a more robust training program. The team has evaluated a course on quality assurance skills and a course on visual inspection. The team is gathering its recommendations to improve the overall training program and is expected to present them in April 2004.

FORWARD WORK

KSC will document a comparable training program and update the training templates. Personnel not meeting the new training requirements will be given a reasonable timeframe to complete the training.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Completed	Develop and implement processes for hiring and developing qualified QAS
KSC	Completed	Benchmark DoD and DCMA training programs (from O10.4-3)
KSC	Apr 04	Develop and document improved training requirements (from O10.4-3)
KSC	Jun 04	Complete personnel training (from O10.4-3)

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-6 Review Mandatory Inspection Document Process

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

BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a responsive system for adding or deleting Government Mandatory Inspection Points (GMIPs), including those at the Michoud Assembly Facility (MAF), and the need for a periodic review of the Quality Planning Requirements Document (QPRD). The Shuttle Propulsion Element at the Marshall Space Flight Center is responsible for overseeing the Mandatory Inspection Document process and implementation of associated GMIPs.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.1, Space Shuttle Program Action 1, and Section 2.2, Observation 10.4-1, of this Implementation Plan. Efforts to implement this recommendation have been in work since the issuance of the *Columbia* Accident Investigation Board Report, Volume I. NASA commissioned an assessment team, independent of the Space Shuttle Program, to review the effectiveness of the QPRD and its companion document at the MAF, referred to as the Mandatory Inspection Document, and the associated GMIPs. NASA continues efforts to improve this process through its defined implementation plan and will demonstrate its progress with this and future updates to the Return to Flight Implementation Plan.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-7 Responsive System to Update Government Mandatory Inspection Points at the Michoud Assembly Facility

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

BACKGROUND

The *Columbia* Accident Investigation Board noted the need for a responsive system for updating Government Mandatory Inspection Points (GMIPs), including the need for a periodic review of the Quality Planning Requirements Document (QPRD). The Space Shuttle Program, Shuttle Processing Element, located at the Kennedy Space Center is responsible for overseeing the QPRD process and implementation of associated GMIPs.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.1, Space Shuttle Program Action 1, and Section 2.2, Observation 10.4-1, of this Implementation Plan. Efforts to implement this recommendation have been in work since the issuance of the *Columbia* Accident Investigation Board Report, Volume I. NASA commissioned an assessment team, independent of the Space Shuttle Program, to review the effectiveness of the QPRD, its companion at the Michoud Assembly Facility, referred to as the Mandatory Inspection Document, and the associated GMIPs. NASA continues efforts to improve this process through its defined implementation plan and will demonstrate progress with this and future updates to the Return to Flight Implementation Plan.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-8 Use of ISO 9000/9001

Kennedy Space Center should examine which areas of ISO 9000/9001 truly apply to a 20-year-old research and development system like the Space Shuttle.

BACKGROUND

The *Columbia* Accident Investigation Board report highlighted Kennedy Space Center's reliance on the International Organization for Standardization (ISO) 9000/9001 certification. The report stated, "While ISO 9000/9001 expresses strong principles, they are more applicable to manufacturing and repetitive-procedure industries, such as running a major airline, than to a research-and-development, flight test environment like that of the Space Shuttle. Indeed, many perceive International Standardization as emphasizing process over product." Currently, ISO 9000/9001 certification is a contract requirement for United Space Alliance.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.2, Observation 10.4-4, of this Implementation Plan. Evaluation of this recommendation has been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. NASA continues efforts to improve this process through its defined implementation plan and will demonstrate progress with this and future updates to the Return to Flight Implementation Plan.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-9 Orbiter Corrosion

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

BACKGROUND

The Space Shuttle Program has initiated an action to assess the *Columbia* Accident Investigation Board observations related to corrosion damage in the Orbiters. This action has been assigned to the Orbiter Project Office.

NASA IMPLEMENTATION, STATUS, FORWARD WORK, AND SCHEDULE

This recommendation is addressed in Section 2.2, Observations 10.7-1 through 10.7-4, of this Implementation Plan. Evaluation of this recommendation has been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. NASA demonstrates progress in the Return to Flight Implementation Plan.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-10 Hold-Down Post Cable Anomaly

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

This recommendation is addressed in Section 2.2, Observation 10.9-1, of this Implementation Plan.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-11 Solid Rocket Booster External Tank Attach Ring

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

This recommendation is addressed in Section 2.2, Observation 10.10-1, of this Implementation Plan.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-12 Crew Survivability

To enhance the likelihood of crew survivability, NASA must evaluate the feasibility of improvements to protect the crew cabin on existing Orbiters.

BACKGROUND

The *Columbia* Accident Investigation Board (CAIB) found that, in both the *Challenger* and the *Columbia* accidents, the crew cabin initially survived the disintegration of the Orbiter intact.

NASA IMPLEMENTATION

Implementation of this recommendation has been in work since the release of the *Columbia* Accident Investigation Board Report, Volume I. The Space Shuttle Service Life Extension Program II Crew Survivability Sub-panel recognized the need for the Program to continue funding the vehicle forensic analysis and follow-on thermal and structural hardening analysis. This work plays a part not only as resolution to a CAIB Recommendation but also as a component of furthering the technical understanding of the space/atmosphere-aero interface and conveys knowledge capture for future programs.

STATUS

Specific funding and schedule requirements are to be presented for approval and funding at an upcoming Space Shuttle Program Requirements Control Board (PRCB).

FORWARD WORK

It is expected that analysis completion will require 12-18 months and provide vehicle forensic data as well as recommendations for follow-on activity.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 04	PRCB for funding

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-13 RSRM Segment Shipping Security

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

BACKGROUND

During security program assessments at the ATK Thiokol Reusable Solid Rocket Motor (RSRM) Production Facility, the *Columbia* Accident Investigation Board raised concerns about several elements of the overall security program. Most notable of these concerns was protection of completed segments prior to rail shipment to the Kennedy Space Center (KSC).

NASA IMPLEMENTATION

NASA has conducted a full security program vulnerability assessment of the ATK Thiokol RSRM Production Facility, with the goal of identifying and mitigating security vulnerabilities.

NASA security officials, together with ATK Thiokol Security Program officials, performed an assessment of the RSRM security program from RSRM manufacturing to delivery, inspection, and storage at KSC. The assessment included a review of the ATK Thiokol manufacturing plant to the railhead; participation in the rail shipment activities of RSRM segment(s) to or from KSC; regional and local threats; and rotation, processing, and storage facility security at KSC. Based on this assessment, NASA plans to implement a vulnerability mitigation activity.

STATUS

NASA conducted assessments of several key elements of the ATK Thiokol RSRM operation: December 8–12, 2003, ATK Thiokol RSRM Facilities; January 26–27, 2004, KSC RSRM Facilities; and January 30–February 9, 2004, RSRM Railway Transport Route and Operations. A comprehensive Report of Findings and a separate Executive Summary, both of which will be administratively controlled documents, are being prepared by the assessment team and will be presented to the NASA Office of Security Management and Safeguards, Code X, and to the Marshall Space Flight Center Security Director in April 2004.

SCHEDULE

Security vulnerability mitigation activity is still in the planning stages. Cost and schedule evaluations should be complete by mid May 2004.

Columbia Accident Investigation Board

Volume II, Appendix D.a, Quality Assurance Section, Recommendation D.a-14 Michoud Assembly Facility Security

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

BACKGROUND

During security program assessments at the Michoud Assembly Facility (MAF), the *Columbia* Accident Investigation Board expressed concerns about several elements of the overall security program. Most notable of these concerns is the adequacy of particular security equipment and staffing.

NASA IMPLEMENTATION

NASA conducted a full security program vulnerability assessment of the MAF and External Tank (ET) production activity, with the goal of identifying and mitigating security vulnerabilities.

They assessed the MAF and the ET production security programs from ET manufacturing to delivery, inspection, and storage at Kennedy Space Center (KSC). The assessment included a review of the MAF to the shipping port; shipping activities of the ET to and from KSC; regional and local threats; and Vehicle Assembly Building security at KSC. Based on the assessment, NASA plans to implement a vulnerability mitigation activity.

STATUS

The NASA assessment was conducted from January 26 through January 30, 2004. A comprehensive Report of Findings and a separate Executive Summary, both administratively controlled documents, were prepared by the assessment team and presented to the NASA Office of Security Management and Safeguards, Code X, and to the Marshall Space Flight Center Security Director.

SCHEDULE

Security vulnerability mitigation activity is in the planning stage. Cost and schedule will be established by April 2004.

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.

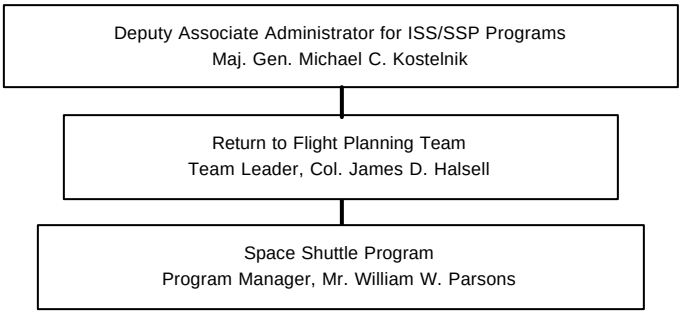


Figure A-1. Original RTFPT organization.

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.

For example, the SSP's Orbiter Project 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.

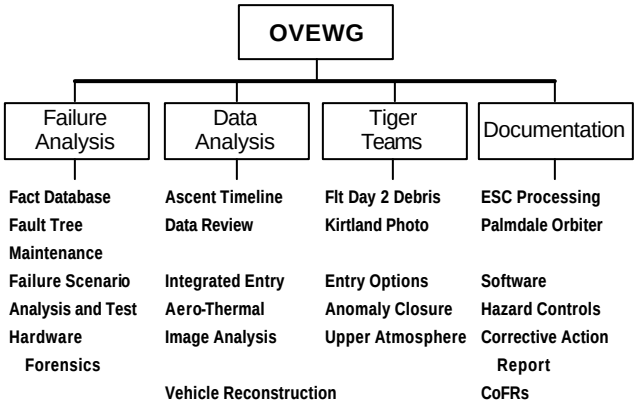


Figure A-2. OVEWG organization.

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 NASA initiatives ("Raising the Bar"), and to determine the fastest path for a safe RTF. The approximately 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 2003, 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) co-chairs. 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, which is a living document chronicling NASA's RTF.

As the Implementation Plan has matured and obtained SFLC approval, NASA has transitioned from planning for RTF to implementing the plan. As intended, the lead role has transitioned from the RTFPT to the Space Shuttle Program, which is now responsible to the SFLC for executing the plan to successful completion. Accordingly, Maj. Gen. Kostelnik decommissioned the RTFPT on June 7, 2004, and transferred all remaining administrative and coordination duties to the Management Integration and Planning Office (MG) of the Space Shuttle Program, under the direction of former astronaut John Casper. The MG office has established a Return to Flight Branch that is responsible for the coordination of RTF constraint closures with the RTF Task Group.

These changes reflect the real progress toward RTF that has been made in the last few months, and NASA's commitment to optimizing our processes and organization as we execute the RTF Plan.

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 charged with approving RTF items and directing the implementation of specific corrective actions. The SFLC can 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*. The membership of the SFLC includes the OSF Center Directors (Johnson Space Center, Kennedy Space Center, Marshall Space Flight Center, and Stennis Space Center) and the Associate Administrator for Safety and Mission Assurance. SFLC meetings are scheduled as needed.

Members of the Return-to-Flight Task Group (RTFTG) are invited to attend the SFLC meetings.

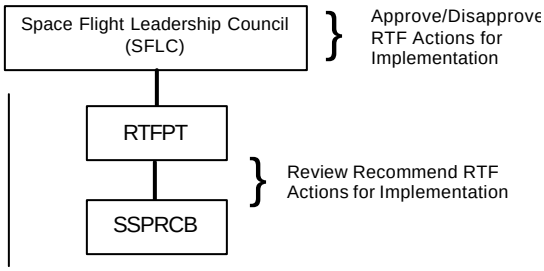


Figure A-3. Space Flight Leadership Council organization for return to flight issue review.

Return to Flight Task Group

Also known 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 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 2003, and has been meeting periodically since. The RTFTG has issued two Interim Reports—one in January 2004, and one in May 2004.

Operational Readiness Review

Before RTF, the SFLC will convene one or more meetings to disposition NASA's internal handling of all RTF constraints. The first such meeting, a Flight Certification Review, was held at the Marshall Space Flight Center on December 11-12, 2003.

RTF Schedule

See figure A-4.

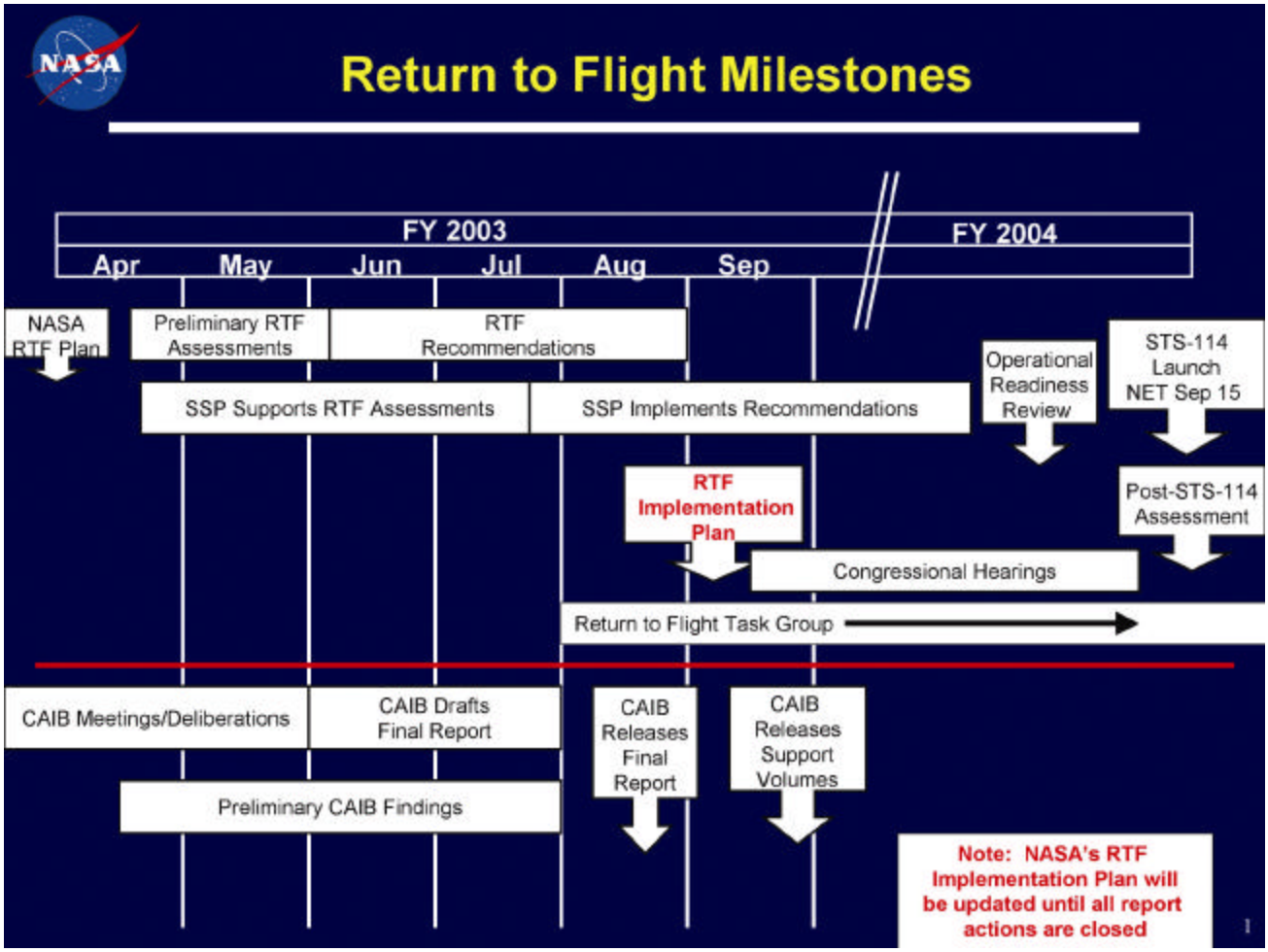


Figure A-4. RTF and RTFTG schedules overlaid with the schedule for release of the CAIB final report.

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.):

Upon 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 prior to 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 the American Society for Public Administration.

Broadnax received his Ph.D. from the Maxwell School at Syracuse University, his B.A. from Washburn University, and his M.P.A from the University of Kansas. He is a Fellow of the National Academy of Public Administration and a former trustee of the Academy's Board. In March, he was installed as President of the American Society for Public Administration for 2003–2004. He is a member of the Syracuse University Board of Trustees, Harvard University's Taubman Center Advisory Board, and United States Comptroller General Advisory Board. He has also served on several corporate and nonprofit boards of directors including the CNA Corporation, Keycorp Bank, Medecision Inc., Rochester General Hospital, Rochester United Way, and the Ford Foundation/Harvard University Innovations in State and Local Government Program, the Maxwell School Advisory Board, and the National Blue Ribbon Commission on Youth Safety and Juvenile Justice Reform in the District of Columbia.

Rear Adm. Walter H. Cantrell, USN (Ret.):

Rear Adm. Cantrell has a long history of successfully solving high-profile, technical issues. He is frequently asked to conduct reviews of complex, politically sensitive programs and to make recommendations for corrective actions.

He graduated from the U.S. Naval Academy in 1958 with a Bachelor of Science degree in Naval Science. He received a Master's degree in Naval Architecture, 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 & 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 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 flights 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 Doctorate 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 Army War College. He has been awarded several military decorations including: Defense Distinguished Service Medal with two oak leaf clusters; the Air Force Distinguished Service Medal with oak leaf cluster; both the Army and Navy Distinguished Service Medals, Silver Star; Purple Heart; Meritorious Service Medal, and two Distinguished Flying Crosses.

Ms. Christine H. Fox:
Vice President and Director, Operations Evaluation Group, Center for Naval Analyses

Christine H. Fox is Vice President and Director of the Operations Evaluation Group at the Center for Naval Analyses, a federally funded research and development center based in Alexandria, Va. In this role she is responsible for approximately 40 field representatives and 45 Washington-based analysts whose analytical focus is on helping operational commanders execute their missions.

Ms. Fox has spent her career as an analyst; assisting complex organizations like the U.S. Navy assess challenges and define practical solutions. She joined the Center for Naval Analysis in 1981 where she has served in a variety of analyst, leadership, and management positions.

Her assignments at the Center include serving as Team Leader, Operational Policy Team; Director, Anti-air Warfare Department; Program Director, Fleet Tactics and Capabilities; Team Leader of Third Fleet Tactical Analysis Team; Field Representative to Tactical Training Group–Pacific; Project Director, Electronic Warfare Project; Field Representative to Fighter Airborne Early Warning Wing-U.S. Pacific Fleet; and Analyst, Air Warfare Division, Operations Evaluation Group.

Before joining the Center, Ms. Fox served as a member of the Computer Group at the Institute for Defense Analysis in Alexandria, where she participated in planning and analyses of evaluations of tactical air survivability during close air support and effectiveness of electronic warfare during close air support.

Ms. Fox received a bachelor of science degree in mathematics and a master of science degree in applied mathematics from George Mason University.

Col. Gary S. Geyer, U.S. Air Force (Ret.):
Consultant

Col. Geyer has 35 years of experience in space engineering and program management, primarily in senior positions in the government and industry that emphasize management and system engineering. He has been responsible for all aspects of systems' success, including schedule, cost, and technical performance.

He served for 26 years with the National Reconnaissance Office (NRO) and was the NRO System Program Office Director for two major programs, which encompassed the design, manufacture, test, launch, and operation of several of our nation's most important reconnaissance satellites. Col. Geyer received the NRO Pioneer Award 2000 for his contributions as one of 46 pioneers of the NRO responsible for our nation's information superiority that significantly contributed to the end of the Cold War.

Following his career at the NRO, Col. Geyer was Vice President for a major classified program at Lockheed Martin and responsible for all aspects of program and mission success. His other assignments have included Chief Engineer for another nationally vital classified program and Deputy for Analysis for the Titan IV Program. Col. Geyer is teaching a Space Design course and a System Engineering/Program Management course at New Mexico State University in Las Cruces, N.M. He has a Bachelor of Science degree in Electrical Engineering from Ohio State University, and a Master's in Electrical Engineering and Aeronautical Engineering from the University of Southern California.

Col. Susan J. Helms, U.S. Air Force
Chief, Space Control Division, Requirements Directorate, Air Force Space Command

After a 12-year NASA career that included 211 days in space, Col. Helms returned to the U.S. Air Force in July 2002 to take a position at Headquarters, U.S. Air Force Space Command. She is currently the Division Chief of the Space Control Division of the Requirements Directorate of Air Force Space Command in Colorado Springs, Colorado. Selected by NASA in January 1990, Helms became an astronaut in July 1991. She flew on STS-54 (1993), STS-64 (1994), STS-78 (1996), STS-101 (2000) and served aboard the International Space Station as a member of the Expedition-2 crew (2001). A veteran of five space flights, Col. Helms has logged 5,064 hours in space, including a world record EVA of 8 hours and 56 minutes.

Col. Helms graduated from the U.S. Air Force Academy in 1980. She received her commission and was assigned to Eglin Air Force Base, Florida, as an F-16 weapons separation engineer with the Air Force Armament Laboratory. In 1982, she became the lead engineer for F-15 weapons separation. In 1984, she was selected to attend graduate school. She received her degree from Stanford University in 1985 and was assigned as an assistant professor of aeronautics at the U.S. Air Force Academy. In 1987, she attended the Air Force Test Pilot School at Edwards Air Force Base, California. After completing one year of training as a flight test engineer, Col. Helms was assigned as a USAF Exchange Officer to the Aerospace Engineering Test Establishment, Canadian Forces Base, Cold Lake, Alberta, Canada, where she worked as a flight test engineer and project officer on the CF-18 aircraft. She was managing the development of a CF-18 Flight Control System Simulation for the Canadian Forces when selected for the astronaut program. As a flight test engineer, Col. Helms has flown in 30 different types of U.S. and Canadian military aircraft.

Col. Helms is the recipient of the Distinguished Superior Service Medal, the Defense Meritorious Service Medal, the Air Force Meritorious Service Medal, the Air Force Commendation Medal, NASA Distinguished Service Medal, NASA Space Flight Medals, and the NASA Outstanding Leadership Medal. Named the Air Force Armament Laboratory Junior Engineer of the Year in 1983 and a Distinguished Graduate of the USAF Test Pilot School, she was the recipient of the R.L. Jones Award for Outstanding Flight Test Engineer, Class 88A. In 1990, she received the Aerospace Engineering Test Establishment Commanding Officer's Commendation, a special award unique to the Canadian Forces.

Mr. Richard Kohrs
Chief Engineer, Kistler Aerospace Corporation

Richard Kohrs has over 40 years of experience in aerospace systems engineering, stress analysis, and integration. He has held senior management positions in major NASA programs from Apollo to the Space Station.

As a member of the Apollo Spacecraft Program's Systems Engineering and Integration Office, he developed the Spacecraft Operations Data Book system that documented systems and subsystem performance and was the control database for developing flight rules, crew procedures, and overall performance of the Apollo spacecraft.

After Apollo, he became Manager of System Integration for the Space Shuttle Program; Deputy Manager, Space Shuttle Program; and then Deputy Director of the Space Shuttle Program at JSC. As Deputy Director, he was responsible for the daily engineering, processing, and operations activities of the Shuttle Program, and he developed an extensive background in Shuttle systems integration. In 1989, he became the Director of Space Station Freedom, with overall responsibility for its development and operation.

After years of public service, he left NASA to become the Director of the ANSER Center for International Aerospace Cooperation (1994–1997). Mr. Kohrs joined Kistler Aerospace in 1997 as Chief Engineer. His primary responsibilities include vehicle integration, design specifications, design data books, interface control, vehicle weight, performance, and engineering review board matters. He received a Bachelor of Science degree from Washington University, St. Louis, in 1956.

Susan Morrisey Livingstone:

Ms. Livingstone has served her nation for more than 30 years in both government and civic roles. From July 2001 to February 2003, Ms. Livingstone served as Under Secretary of the Navy, the second highest civilian leadership position in the Department 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/compartmented programs; integration of Navy-Marine Corps capabilities; audit, IG and criminal investigative programs; and civilian personnel programs. Currently, 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) and on the Board of Directors of The Atlantic Council and the Procurement Round Table; and is a member of NASA's Space Shuttle Return to Flight Task Group, an independent advisory group charged with assessing NASA's implementation of the return to flight recommendations in the *Columbia* Accident Investigation Report.

Before serving as Under Secretary of the Navy, Livingstone was CEO of the Association of the United States Army (AUSA) and deputy chair 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 chair to the Defense Science Board (on logistics transformation).

From 1993 to 1998, Ms. Livingstone served the American Red Cross HQ as Vice President of Health and Safety Services, Acting Senior Vice President for Chapter Services and as a consultant for Armed Forces Emergency Services.

As Assistant Secretary of the Army for Installations, Logistics and Environment from 1989 to 1993, Ms. Livingstone 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, now the Department of Veterans Affairs, in a number of positions including Associate Deputy Administrator for Logistics and Associate Deputy Administrator for Management. During this time, she served as the VA's Senior Acquisition Official and also directed and managed the nation's largest medical construction program at the time. Before her Executive Branch service, Ms. Livingstone 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.B. degree and completed an M.A. 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.

Ms. Livingstone has received numerous awards for her community and national service, including the highest civilian awards from the National Reconnaissance Office, the VA, and the Departments of the Army and Navy. Ms. Livingstone also is 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, 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, Lloyd moved to the Space Station Freedom Program Office in Reston, Va., where he served in various roles culminating in being appointed as the Program's Product Assurance Manager.

In 1993, he became Director, Safety and Risk Management Division in the Office of Safety and Mission Assurance, serving as NASA's "Safety Director" and was appointed to his present position in early 2003. He serves also as an ex-officio member of the NASA Advisory Council Task Force on ISS Operational Readiness. Lloyd holds a Bachelor of Science degree in Mechanical Engineering, with honors, from Union College, Schenectady, N.Y., and a Master of Engineering degree in Industrial Engineering from Texas A&M University, College Station.

Lt. Gen. Forrest S. McCartney, U.S. Air Force (Ret.):
Vice Chairman of the Aerospace Safety Advisory Panel

During Lt. Gen. McCartney's distinguished Air Force career, he held the position of Program Director for several major satellite programs, was Commander of the Ballistic Missile Organization (responsible for Minuteman and Peacekeeper development), Commander of Air Force Space Division, and Vice Commander, Air Force Space Command.

His military decorations and awards include the Distinguished Service Medal, Legion of Merit with one oak leaf cluster, Meritorious Service Medal, and Air Force Commendation Medal with three oak leaf clusters. He was recipient of the General Thomas D. White Space Trophy in 1984 and the 1987 Military Astronautical Trophy.

Following the *Challenger* accident, in late 1986 Lt. Gen. McCartney was assigned by the Air Force to NASA and served as the Director of Kennedy Space Center until 1992. He received numerous awards, including NASA's Distinguished Service Medal and Presidential Rank Award, the National Space Club Goddard Memorial Trophy, and AIAA Von Braun Award for Excellence in Space Program Management.

After 40 years of military and civil service, he became a consultant to industry, specializing in the evaluation of hardware failure/flight readiness. In 1994, he joined Lockheed Martin as the Astronautics Vice President for Launch Operations. He retired from Lockheed Martin in 2001 and is currently the Vice Chairman of the NASA Aerospace Safety Advisory Panel.

Lt. Gen. McCartney has a Bachelor's degree in Electrical Engineering from Auburn University, a Master's degree in Nuclear Engineering from the Air Force Institute of Technology, and an honorary doctorate from the Florida Institute of Technology.

Rosemary O'Leary, J.D., Ph.D.:

Dr. Rosemary O'Leary is professor of public administration and political science, and coordinator of the Ph.D. program in public administration at the Maxwell School of Citizenship and Public Affairs at Syracuse University. An elected member of the U.S. National Academy of Public Administration, she was recently a senior Fulbright scholar in Malaysia. Previously Dr. O'Leary was Professor of Public and Environmental Affairs at Indiana University and cofounder and codirector of the Indiana Conflict Resolution Institute. She has served as the director of policy and planning for a state environmental agency and has worked as an environmental attorney.

Dr. O'Leary teaches graduate courses in Public Organizations and Management, concentrating on organization change, organization culture, and the management of scientific and technical organization.

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

Dr. O'Leary is the author/editor of five books and more than 75 articles on public management. She has won seven national research awards, including Best Book in Public and Nonprofit Management for 2000 (given by the Academy of Management), Best Book in Environmental Management and Policy for 1999 (given by the American Society for Public Administration), and the Mosher Award, which she won twice, for best article by an 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 the university. She has won eight teaching awards as well, including the national Excellence in Teaching Award given by the National Association of Schools of Public Affairs and Administration, and she was the recipient of the Distinguished Service Award given by the American Society for Public Administration's Section on Environment and Natural Resources Administration. O'Leary has served as national chair of the Public Administration Section of the American Political Science Association, and as the national chair of the Section on Environment and Natural Resources Administration of the American Society for Public Administration.

Dr. Decatur B. Rogers, P.E.:
Dean Tennessee State University College of Engineering, Technology and Computer Science

Since 1988, Dr. Rogers has served as the Dean, College of Engineering, Technology and Computer Science, and Professor of Mechanical Engineering at Tennessee State University in Nashville. Rogers served in professorship and dean positions at Florida State University, Tallahassee; Prairie View A&M University, Prairie View, Texas, and Federal City College, Washington, D.C.

Dr. Rogers holds a Ph.D. in Mechanical Engineering from Vanderbilt University; Masters' degrees in Engineering Management and Mechanical Engineering from Vanderbilt University; and a Bachelor's in Mechanical Engineering from Tennessee State University.

Mr. Sy Rubenstein:
Aerospace Consultant

Mr. Rubenstein was a major contributor to the design, development, and operation of the Space Shuttle and has been involved in commercial and Government projects for more than 35 years. As an employee of Rockwell International, the prime contractor for the Shuttle, he was the Director of System Engineering, Chief Engineer, Program Manager, and Division President during 20 years of space programs.

He has received the NASA Public Service Medal, the NASA Medal for Exceptional Engineering, and the AIAA Space Systems Award for his contributions to human spacecraft development. Mr. Rubenstein, a leader, innovator, and problem solver, is a fellow of the AIAA and the AAS.

Mr. Robert Sieck:
Aerospace Consultant

Mr. Sieck, the former Director of Shuttle Processing at the Kennedy Space Center (KSC), has an extensive 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 Spaceflight 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 USAF 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.

He worked for RCA's Missile and Surface Radar Division in Moorestown, N.J. from 1958 to 1962 in the project office of the Ballistic Missile Early Warning System (BMEWS) being built for the USAF. From 1957 to 1958, Tate served in the Army as an artillery and guided missile officer at Fort Bliss, Texas.

He received a Bachelor's degree in marketing from the University of Scranton in 1956 and a law degree from Western State University College of Law in Fullerton, Calif., in 1970. In his final year of law school, his fellow students awarded him the Gold Book Award as the most outstanding student. In 1991, he received the Frank J. O'Hara award for distinguished alumni in science and technology from the University of Scranton.

Mr. Tate is a member of numerous aerospace and defense associations including the AIAA, the National Space Club, and the National Space Institute, where he serves as an advisor. He also served as a permanent civilian member of the NASA Senior Executive Service Salary and Performance Review Board.

Dr. Kathryn C. Thornton:
Faculty, University of Virginia

After eleven years with NASA, Dr. Thornton left NASA on August 1, 1996, to join the faculty of the University of Virginia. Selected by NASA in May 1984, Dr. Thornton became an astronaut in July 1985. Her technical assignments have included conducting flight software verification in the Shuttle Avionics Integration Laboratory (SAIL), serving as a team member of the Vehicle Integration Test Team (VITT) at KSC, and serving as a spacecraft communicator (CAPCOM). A veteran of three space flights, Dr. Thornton flew on STS-33 in 1989, STS-49 in 1992, and STS-61 in 1993. She has logged over 975 hours in space, including more than 21 hours of extravehicular activity (EVA).

After earning her Ph.D. at the University of Virginia in 1979, Dr. Thornton was awarded a NATO Postdoctoral Fellowship to continue her research at the Max Planck Institute for Nuclear Physics in Heidelberg, West Germany. In 1980, she returned to Charlottesville, Virginia, where she was employed as a physicist at the U. S. Army Foreign Science and Technology Center.

Mr. William Wegner:
Consultant

Mr. Wegner graduated from the U.S. Naval Academy in 1948. He subsequently received Masters' degrees in Naval Architecture and Marine Engineering from Webb Institute in New York. In 1956 he was selected by Adm. Hyman Rickover to join the Navy's nuclear program and was sent to the Massachusetts Institute of Technology, where he received his Master's degree in Nuclear Engineering. After serving in a number of field positions, including that of Nuclear Power Superintendent at the Puget Sound Naval Shipyard, he returned to Washington. He served as deputy director to Adm. Rickover in the Naval Nuclear Program for 16 years and was awarded the DoD Distinguished Service Award and the Atomic Energy Commission's distinguished service award.

In 1979, he retired from Government service, and formed Basic Energy Technology Associates with three fellow naval retirees. During its 10 successful years of operation, it provided technical services to over 25 nuclear utilities and other nuclear-related activities. Wegner has served on a number of panels including the National Academy of Sciences that studied the safety of Department of Energy nuclear reactors. From 1989 to 1992, he provided technical assistance to the Secretary of Energy on nuclear-related matters. He has provided technical services to over 50 nuclear facilities. Mr. Wegner served as a Director of the Board of Directors of Detroit Edison from 1990 until retiring in 1999.

Lt. Col. David Lengyel:
Executive Secretary, Return to Flight Task Group

Since February 2003, Lt. Col. Lengyel has served on the administrative staff of the *Columbia* Accident Investigation Board (CAIB). Prior to this, he was Executive Director of the Aerospace Safety Advisory Panel for almost two years.

From 1999 through 2000, he served a tour of duty as the Manager of the Moscow Technical Liaison Office (MTLO) for the International Space Station (ISS) Program in Russia. The MTLO interfaces with Russian contractors and space agency personnel to monitor and track the progress of Russian segment elements and Soyuz/Progress vehicles, as well as to provide technical liaison between U.S. and Russian engineering/mission integration personnel.

Lt. Col. Lengyel joined NASA in October 1993 as the third Executive Officer to Administrator Daniel S. Goldin. He served in several program operations and payloads capacities within the ISS and Shuttle-Mir Programs at JSC from 1994 to 1998. He led an analytical assessment of Shuttle-Mir lessons learned for application to the ISS.

Prior to joining NASA, he was a senior aircrew-training instructor for McDonnell-Douglas in St. Louis. He conducted pilot training for the FA-18 Hornet and F-15 Eagle for both foreign and domestic customers.

He is a Lieutenant Colonel in the Marine Corps Reserves and has accumulated over 2000 hours flight time in the F-4S Phantom II, OV-10 Bronco, and FA-18 Hornet.

Lt. Col. Lengyel holds a Bachelor of Science degree from the U.S. Naval Academy, a Masters of Business Administration from the University of Missouri, and a Masters of Arts in International Affairs from Washington University in St. Louis.