

Return to Flight Task Group



Final Report
July 2005

A photograph of the Space Shuttle Columbia during launch. The shuttle is ascending vertically, leaving a massive, bright white plume of smoke and fire. The scene is captured from a low angle, with the shuttle appearing to rise from a body of water in the foreground. The sky is a clear, pale blue. The shuttle's external tank and boosters are visible, and the orbiter is attached to the top. The overall atmosphere is one of power and grandeur.

Final Report

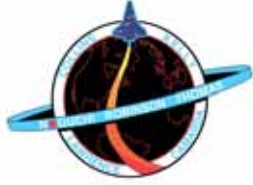
of the

Return to Flight Task Group

**Assessing the Implementation of the
Columbia Accident Investigation Board
Return-to-Flight Recommendations**

July 2005

On the Front Cover



The STS-114 patch design signifies the return of the Space Shuttle to flight and honors the memory of the STS-107 *Columbia* crew. The blue Shuttle rising above Earth's horizon includes the Columbia constellation of seven stars, echoing the STS-107 patch and commemorating the seven members of that mission. The crew of STS-114 will carry the memory of their friends on *Columbia* and the legacy of their mission back into Earth orbit. The dominant design element of the STS-114 patch is the planet Earth, which represents the unity and dedication of the many people whose efforts allow the Space Shuttle to safely return to flight. Against the background of the Earth at night, the blue orbit represents the International Space Station (ISS), with the EVA crewmembers named on the orbit. The red sun on the orbit signifies the contributions of the Japanese Space Agency to the mission and to the ISS program. The multi-colored Space Shuttle plume represents the broad spectrum of challenges for this mission, including Orbiter inspection and repair experiments, and bringing supplies to the International Space Station. (Courtesy of NASA)

On the Title Page

Discovery heads for the International Space Station during the STS-114 return-to-flight launch on July 26, 2005.

On the Back Cover

The seven stars of the Columbia constellation are in memory of the crewmembers lost on STS-107.

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INTRODUCTION TO THE RETURN TO FLIGHT TASK GROUP

On February 1, 2003, the Space Shuttle *Columbia* disintegrated while returning to Earth during the STS-107 mission, killing the crew of seven. Within hours, the independent Columbia Accident Investigation Board (CAIB) was appointed by the NASA Administrator.

Determining the most-probable physical cause of the *Columbia* accident – foam debris from the External Tank impacting the reinforced carbon-carbon on the Orbiter wing leading edge – was the more-straightforward part of the investigation conducted by the accident board. Unlike many accident boards, however, the CAIB elected to delve deeper into the accident than simply determining the physical cause. It was obvious to the board very early-on that there was an underlying problem with leadership, management, and culture at NASA, and specifically within the Space Shuttle Program. Ultimately, the CAIB placed as much weight on these causal factors as on the more easily understood and correctable physical cause of the accident.

The CAIB released the first volume of its final report on August 26, 2003, containing 29 specific recommendations and numerous findings and observations for changes to the vehicle, to the Space Shuttle Program, and to NASA in general. Among those recommendations were 15 that the accident board believed should be implemented prior to returning the Space Shuttle to flight.

On April 14, 2003, then-NASA-Administrator Sean O’Keefe wrote Lt. Gen. Thomas P. Stafford, U.S. Air Force (Ret.), requesting that the Stafford Task Force on International Space Station Operational Readiness undertake an assessment of NASA’s plans to return the Space Shuttle to flight. The Stafford Task Force is a standing body chartered by the NASA Advisory Council, an independent advisory group to the NASA Administrator.

One month later, Lt. Gen. Stafford responded to the Administrator with a plan to activate a sub-organization with Col. Richard O. Covey, U.S. Air Force (Ret.), leading the day-to-day effort of conducting an independent assessment of the 15 CAIB return-to-flight recommendations. As a result, on July 18, 2003, a Return to Flight Task Group (RTF TG, or simply, the Task Group) was chartered under the Federal Advisory Committee Act (Public Law 92-463, as amended) with Lt. Gen. Stafford and Col. Covey as co-chairs.

Over the past two years, using expertise from academia, aerospace industry, the federal government, and the military, the RTF TG assessed the actions taken by NASA to implement the 15 CAIB return-to-flight recommendations plus one additional item the Space Shuttle Program assigned to itself as a “raising the bar” action. During this time the Task Group conducted fact-finding activities, reviewed documentation, held public meetings, reported the status of its assessments to the Space Flight Leadership Council, and released three interim reports. The assessments of the Task Group, although based primarily on data provided by the Space Shuttle Program, were independent of that program and were intended to provide the NASA Administrator an evaluation of the progress NASA made toward meeting the intent of the CAIB recommendations.

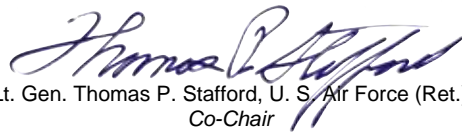
The Task Group completed their last assessments on June 27, 2005; this report does not contain data released after that date (excepting a few photographs). Although this report is being released after the landing of STS-114, pertinent information contained herein was briefed to the appropriate NASA officials prior to the launch of STS-114.

As the Task Group delivers this final report to the NASA Administrator, Congress, and the American public, we take this opportunity to emphasize that this report is strictly advisory. Only NASA can, and should, make the determination if the vehicle, supporting infrastructure, and management organization are sufficiently robust to continue flying.

Final Report of the Return to Flight Task Group

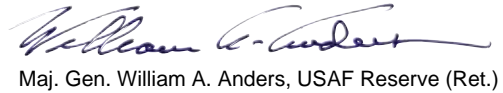


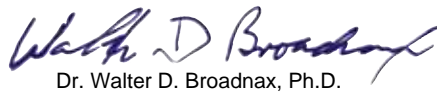
The Signatures on these pages are applicable to the Body and Appendices contained in this Final Report,
Not to the Individual Member Observations contained in Annex A.


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Final Report of the Return to Flight Task Group


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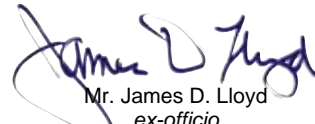

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Discovery, as STS-114, rolls out of the Vehicle Assembly Building at the Kennedy Space Center on her way to Launch Complex 39B for the first flight of a Space Shuttle since the loss of *Columbia* on February 1, 2003.

ORGANIZATION OF THE RTF TG FINAL REPORT

This final report is organized into an executive summary, six numbered sections, various appendices, and one annex.

The Executive Summary provides an overview of the efforts by NASA toward implementing the return-to-flight recommendations of the Columbia Accident Investigation Board (CAIB) and a summary of the Task Group's assessments of each. Also included is an assessment of a "raising the bar" action that the Space Shuttle Program assigned to itself above and beyond the CAIB recommendations. The Executive Summary was delivered to the NASA Administrator and posted on the RTF TG website on June 28, 2005; however, the version contained herein has been slightly edited without affecting its content.

Section 1 is a short, general introduction to the Space Shuttle Program and its current place in the Agency's long-term plans.

Section 2 attempts to show the interrelationships among the various recommendations since, in many cases, the implementation and assessment crossed multiple CAIB recommendations. This section also contains an assessment from the Task Group's Integrated Vehicle Assessment Sub-Panel that cuts across several recommendations.

Section 3 is the Task Group's formal assessment of each of the CAIB return-to-flight recommendations, in numerical order. First, the original language of the CAIB recommendation is provided, followed by the Task Group's interpretation of that recommendation. Next is any relevant background information that might assist the reader in understanding the recommendation. This is followed by an explanation of the steps NASA took to implement the recommendation. For the most part, the NASA implementation comes from NASA's *Implementation Plan for Space Shuttle Return to Flight and Beyond*, using whatever edition was current on the date the Task Group deliberated closing their assessment. Additional information from the closure packages submitted by NASA, requests for information, and fact-finding activities are also included as necessary to ensure an adequate description. This is followed by the Task Group's assessment of the Agency's progress up to the date of the deliberation, and the final status of the assessment. Observations and minority views, if any, regarding a particular recommendation follow the assessment.

Section 4 describes open work the RTF TG will transition to the Aerospace Safety Advisory Panel (ASAP) or other appropriate organizations.

Section 5 introduces the Task Group, its function, the members, and the staff who supported it. Also discussed is the organization of the Task Group, a bit of its history and changes in personnel, policies, procedures, and processes, and a brief summary of the three interim reports issued by the Task Group prior to this final report.

Section 6 provides a summary of the 11 plenary meetings of the Task Group. This gives a brief insight into the progress made along the way to this final report.

Various appendices contain the charter, short biographies of the members, a list of the staff who supported the Task Group, dates of fact-finding activities, and an acronym list.

Annex A contains a set of observations by individual Task Group members that are provided to assist the NASA Administrator in understanding any issues or other items they may have observed during the assessments. This section allows members of the Task Group an opportunity to make "observations on safety or operational readiness" as allowed by the RTF TG charter.



Discovery lingers at the foot of Launch Complex 39B in the evening twilight on April 6, 2005. The Space Shuttle sits atop a Mobile Launcher Platform transported on top of a Crawler-Transporter. (NASA photo courtesy of Scott Andrews)

EXECUTIVE SUMMARY

It has been 29 months since *Columbia* was lost over East Texas in February 2003. Seven months after the accident, the Columbia Accident Investigation Board (CAIB) released the first volume of its final report, citing a variety of technical, managerial, and cultural issues within NASA and the Space Shuttle Program. To their credit, NASA offered few excuses, embraced the report, and set about correcting the deficiencies noted by the accident board. Of the 29 recommendations issued by the CAIB, 15 were deemed critical enough that the accident board believed they should be implemented prior to returning the Space Shuttle to flight. Some of these recommendations were relatively easy, most were straightforward, a few bordered on the impossible, and others were largely overcome by events, particularly the decision by the President to retire the Space Shuttle by 2010.

The Return to Flight Task Group (RTF TG, or simply, the Task Group) was chartered by the NASA Administrator in July 2003 to provide an independent assessment of the implementation of the 15 CAIB return-to-flight recommendations. An important observation must be stated up-front: neither the CAIB nor the RTF TG believes that all risk can be eliminated from Space Shuttle operations; nor do we believe that the Space Shuttle is inherently unsafe. What the CAIB and RTF TG do believe, however, is that NASA and the American public need to understand the risks associated with space travel, and that NASA must make every reasonable effort to minimize such risk.

Since the release of the CAIB report, NASA and the Space Shuttle Program expended enormous effort and resources toward correcting the causes of the accident and preparing to fly again. Relative to the 15 specific recommendations that the CAIB indicated should be implemented prior to returning to flight, NASA has met or exceeded most of them – the Task Group believes that NASA met the intent of the CAIB for 12 of these recommendations. The remaining three recommendations were so challenging that NASA could not comply completely with the intent of the CAIB, but conducted extensive study, analyses, and hardware modifications that resulted in substantive progress toward making the vehicle safer. It must be emphasized, however, that the inability to fully comply with all of the CAIB recommendations does not imply that the Space Shuttle is unsafe.



Workers in the Launch Control Center at the Kennedy Space Center watch *Discovery* during her slow trip to LC-39B.

Although the scorecard is impressive, it alone does not tell the complete story. The Task Group applauds NASA for its efforts, but urges continued vigilance is required to prevent another accident. Spaceflight is a demanding pursuit, and the President, Congress, NASA, and the American public must provide the proper resources and environment to ensure it is conducted in the safest and most efficient manner possible.

It is important to reiterate: the NASA Administrator and his staff – not the CAIB or the RTF TG – will ultimately determine if the remaining risk is sufficiently low to allow the Space Shuttle to continue flying. The Task Group cannot, and will not, make a determination of the safety or reliability of the next flight; that is NASA's responsibility.

On the hardware side, Solid Rocket Booster Bolt Catcher was redesigned in order to qualify it to existing requirements. Numerous changes have been made to reduce debris shedding from the External Tank. The ET has been modified to eliminate the bipod ramp foam that was the physical cause of the *Columbia* accident. The procedures for manual application of foam insulation have been changed to include greater process control and quality inspection. Much has been learned about foam and ice and what causes them to shed from the External Tank during ascent. Heaters have been added to areas of the External Tank to impede the formation of ice, and various other flaws in the design and manufacture of the tank were discovered and corrected along the way. Nevertheless, despite diligent work, it has proven impossible to completely eliminate debris shedding from the External Tank. The hard fact of the matter is that the External Tank will always shed debris, perhaps even pieces large enough to do critical damage to the Orbiter.



Before a group of photographers, *Discovery* is hoisted into a vertical position in the transfer aisle of the Vehicle Assembly Building at the Kennedy Space Center. After this the Orbiter was lifted into a High Bay to be mated with a waiting set of Solid Rocket Boosters and an External Tank.

Prior to the *Columbia* accident, surprisingly little was known about the actual impact resistance of the Orbiter Thermal Protection System, especially the Reinforced Carbon-Carbon (RCC) that is used on the wing leading edges and nose cap. A great deal of effort – using both theoretical analysis and physical testing – has been expended over the past two years to quantify the durability and strength of the Orbiter Thermal Protection System, particularly its ability to withstand debris impacts. However, because of the limited amount of time remaining before the Space Shuttle fleet is retired, NASA has chosen to implement only a limited number of improvements to harden the Orbiter to withstand debris strikes.

It was therefore prudent to develop a capability to repair damage to the Orbiter before entry; a similar effort was cancelled in 1980 when it became apparent that it was unlikely to produce any meaningful results prior to the first flight of *Columbia* in 1981. Unfortunately, repairing damage to the Orbiter Thermal Protection System again proved to be technically challenging almost to the point of impossibility. The Thermal Protection System was not designed to be repaired on-orbit, and virtually every approach developed thus far has serious limitations. While work will continue, it is likely that only very limited on-orbit repairs will be possible for the remaining flights of the Space Shuttle.

The last resort, if debris does again cripple an Orbiter, is to provide a safe haven capability aboard the International Space Station where a Space Shuttle crew can await a rescue vehicle. NASA has made good progress in identifying the challenges associated with this concept, and the Task Group feels that a workable solution is in hand, although using it will certainly mean the end of the Space Shuttle Program, and very possibly the International Space Station Program also. Additionally, this capability is only planned for STS-114 and STS-121.

Along with the changes to the External Tank and Orbiter, NASA has implemented a host of improvements to the infrastructure and tools available to the Space Shuttle Program. Improved ground-based cameras will track the Space Shuttle during ascent, as will airborne cameras mounted on WB-57 aircraft. New cameras and instrumentation have been installed on the External Tank, Solid Rocket Boosters, and Orbiter. Agreements to use National assets are in place, and instruments on the International Space Station and the newly-installed Orbiter Boom Sensor System will inspect the Orbiter for damage. Dozens of new analytical models attempt to explain debris shedding, debris transport methods, and potential damage.

The CAIB went beyond the technical issues that were the physical cause of the *Columbia* accident and cited “management” and “culture” shortcomings as equally culpable. Therefore, the accident board made a number of recommendations for changes to how the Agency, especially the Space Shuttle Program, functions.

The Task Group feels that NASA has met the intent of the CAIB management recommendations, although all of them remain works in progress. The establishment of an Independent Technical Authority within the Chief Engineer’s office moves technical requirements out of the direct control of the Space Shuttle Program management chain. This provides a check-and-balance when it becomes necessary to approve waivers or deviations to a technical requirement, since the Independent Technical Authority is not constrained by budget or schedule pressures that may be present within the program. Although initiated prior to the release of the CAIB report, the establishment of the NASA Engineering and Safety Center (NESC) has created an independent body that provides technical assessments across the Agency. A restructured Safety and Mission Assurance (SMA) organization increases the independence of SMA personnel. Reorganizing the systems engineering and systems integration activities within the Space Shuttle Program clears up several ambiguities that led to confused communications between elements.

The Mission Management Team (MMT), much maligned by the CAIB, has been reconstituted and has undergone extensive training, with multiple simulations of alternative scenarios, including consideration of the use of the International Space Station as a safe haven for the

crew of a damaged Orbiter, and the launch of a rescue mission. Refurbished facilities for the MMT provide a more conducive environment for their deliberations during each flight. It appears to the Task Group that the changes to the MMT have revitalized this group, but we stress that NASA must not allow this capability to atrophy as it had prior to the *Columbia* accident.

Publicly, NASA has said that the first two return-to-flight missions are “test flights” to assess the performance of the modified External Tank and to evaluate repair materials and techniques on orbit. In reality, however, the flights are planned as much for servicing the International Space Station as for testing. NASA intends to carefully monitor the performance and condition of the Space Shuttle during these two flights. For example, the launch rules require specific daylight conditions at the Kennedy Space Center and during External Tank separation to facilitate detailed imagery of the Orbiter and External Tank.

Risk acceptance and management are fundamental to leadership in hazardous technical activities and are the ultimate responsibility of any leader. Very few human endeavors, particularly related to high-energy activities involving advanced technologies, are completely free of risk. Space flight in general, and human space flight in particular, is such that it is impossible to drive the risk to zero. While the return-to-flight efforts have eliminated or minimized many known risks, Space Shuttle missions will always be “accepted risk” operations. This requires that the people involved understand, document, and ultimately accept the risk associated with that activity. NASA must be vigilant to prevent the development of a false sense of security by accepting faulty assumptions, or otherwise inappropriate analyses, to justify return to flight and continued Space Shuttle operations.

As the CAIB opined, “NASA is a federal agency like no other. Its mission is unique, and its stunning technological accomplishments, a source of pride and inspiration without equal, represent the best in American skill and courage. At times NASA’s efforts have riveted a nation, and it is never far from public view and close scrutiny from many quarters.” With this in mind, the Task Group believes that NASA must always strive for the highest level of accomplishment, to exceed the expectations of the Nation, and to do what is right, despite easier options that may present themselves.

Assessment Summaries

Listed in numerical order, this is a summary of the Task Group assessments of the Agency’s implementation of the 15 CAIB return-to-flight recommendations. More detail may be found in other sections of this report.

CAIB Recommendation 3.2-1: External Tank Debris Shedding. The physical cause of the loss of *Columbia* and its crew was a breach in the Reinforced Carbon-Carbon on the leading edge of the left wing. This was the result of an impact by a piece of insulating foam that separated from the left bipod ramp section of the External Tank. During entry this breach allowed superheated air to penetrate through the leading edge insulation and progressively melt the aluminum structure of the left wing, resulting in a weakening of the structure until increasing aerodynamic forces caused loss of control, failure of the wing, and the break-up of the Orbiter. To prevent a recurrence, the CAIB wrote this recommendation to initiate an aggressive program to eliminate all debris shedding from the External Tank.

Unfortunately, it has proven impractical to eliminate all debris shedding from the External Tank. Therefore, NASA went to extensive lengths to better understand the debris environment and the amount of impacts the Orbiter could tolerate without critical damage. Most efforts were ultimately focused on achieving a balance between the debris shed by the ET and the ability of the Orbiter to tolerate the debris.

The Agency and its contractors modified the External Tank to eliminate the bipod ramp foam that was the physical cause of the *Columbia* accident. The processes for manual application of foam insulation have been changed to include greater process control and quality inspection. An extensive effort has resulted in a new understanding of foam and ice and what causes them to shed from the tank during ascent. Heaters have been added to areas of the External Tank to impede the formation of ice, and various other flaws in the design and manufacture of the tank were discovered and corrected along the way.

The RTF TG concluded that NASA did not meet the intent of CAIB Recommendation 3.2-1. Despite a great deal of excellent work on the part of the Agency and its contractors, the External Tank still sheds debris that could potentially cripple an Orbiter. The extensive work to develop debris models and transport analysis was, until recently, hampered by a lack of rigor in both development and testing. The debris-allowable requirements provided to the ET Project did not match what was later determined to be the impact tolerance of the Orbiter. That being said, the Task Group believes that the ET Project worked diligently to successfully meet the requirements they were provided; unfortunately, those requirements were later determined to be inadequate.

CAIB Recommendation 3.3-1: Reinforced Carbon-Carbon Non-Destructive Inspection.

The accident board was surprised at how little was known about the impact resistance and effects of aging on the Reinforced Carbon-Carbon used as part of the Orbiter Thermal Protection System. They recommended that NASA re-baseline all of the RCC components on each remaining Orbiter and also take advantage of advanced non-destructive inspection technology that was not available when the Space Shuttle Program began.

The RTF TG concluded that NASA met the intent of CAIB Recommendation 3.3-1 after the Agency removed all nose cap, chin panel, and wing leading edge RCC from each of the Orbiters and returned them to the manufacturer for evaluation. Testing methods used by the manufacturer included the same evaluations done during the original acceptance testing, as well as new technologies. It should be noted that this action did not physically change the condition of the Orbiter.

CAIB Recommendation 3.3-2: Orbiter Hardening. The *Columbia* accident clearly demonstrated that the Orbiter Thermal Protection System, including the Reinforced Carbon-Carbon panels and acreage tiles, was vulnerable to impact damage from the existing debris environment.

The RTF TG concluded that despite tremendous effort by NASA and its contractors, the Agency did not fully meet the intent of CAIB Recommendation 3.3-2, due to the present lack of a long-term approach to RCC hardening and the amount of remaining non-standard work coming out of the various design verification reviews. An early long-term plan for Orbiter hardening was abandoned after the National Policy decision to retire the Space Shuttle fleet no later than 2010. Nevertheless, through an extensive test and analysis effort, the Agency has learned a great deal about the impact resistance of the Orbiter and has better defined damage criteria. NASA has provided some increased hardening through hardware changes, but the Orbiter is still vulnerable to the debris environment created by the External Tank. The Space Shuttle Program has acknowledged the possibility of critical debris damage and has developed an accepted risk rationale.

CAIB Recommendation 3.4-1: Ground-Based Imagery. The *Columbia* post-accident investigation was hampered by the lack of high-resolution imagery of the vehicle during ascent. The CAIB was concerned about the need to have an adequate number of appropriately located cameras that operated properly to provide photographic coverage of the Space Shuttle from launch through separation of the Solid Rocket Boosters.

The RTF TG concluded that NASA met the intent of CAIB Recommendation 3.4-1 by

increasing the number and capability of ground camera assets. Also, the Agency has arranged for airborne assets to mitigate the effects of cloud cover and improve higher altitude resolution, at least for the first two launches. From a hardware asset perspective, these changes should ensure an adequate capability to provide three useful views.

CAIB Recommendation 3.4-2: High-Resolution Images of External Tank. Although the Space Shuttle Program routinely attempted to photograph the External Tank after separation using hand-held cameras on the flight deck and film cameras in the Orbiter umbilical wells, none of these images were downlinked to the ground, and the STS-107 images were therefore unavailable to the CAIB. The accident board recommended that high-resolution imagery of the ET be obtained on each flight and downlinked to the ground as soon as practical after achieving orbit.

The RTF TG concluded that NASA met the intent of CAIB Recommendation 3.4-2 by planning to use handheld camera images taken from the Orbiter flight deck and the addition of a digital umbilical well camera. The images from these cameras will be downlinked for evaluation during the first days on orbit.

CAIB Recommendation 3.4-3: High-Resolution Images of Orbiter. This was a concern to the CAIB because their investigation was hampered by the lack of high-resolution images. The accident board recommended that NASA provide a capability to obtain and downlink high-resolution images of the underside of the Orbiter wing leading edge and the forward portion of the Thermal Protection System tiles under both wings.

The RTF TG concluded that NASA met the intent of CAIB Recommendation 3.4-3 through the addition of the Orbiter Boom Sensor System (OBSS) with two sensor packages and the R-Bar Pitch Maneuver (RPM) imagery from the ISS. A full scan of the wing leading edge and nose cap will be accomplished by OBSS on Flight Day 2 with the capability for specific, detailed inspections on later flight days. Additional imagery is provided through several cameras on the External Tank and Solid Rocket Boosters. The Task Group cautions, however, this on-vehicle imagery suite does not provide complete imagery of the underside of the Orbiter or guarantee detection of all potential impacts to the Orbiter.

CAIB Recommendation 4.2-1: Solid Rocket Booster Bolt Catcher. While investigating the cause of the *Columbia* accident, the CAIB noted that the Solid Rocket Booster bolt catchers had not been properly flight-qualified. Each SRB is connected to the External Tank by four separation bolts: three at the bottom plus a larger one at the top that weighs approximately 65 pounds. Bolt catchers cover each bolt to capture the pieces after the bolt is explosively separated during staging. Static and dynamic testing, conducted as a result of the accident board's inquiries, demonstrated that the bolt catchers flown on STS-107 had a factor of safety of 0.956, rather than 1.4 required by specification.

The RTF TG concluded that NASA has gone well beyond the intent of the CAIB in answering CAIB Recommendation 4.2-1. Instead of simply qualifying the existing bolt catchers, NASA undertook an extensive redesign, and then qualified the new design.

CAIB Recommendation 4.2-3: Two Person Closeout Inspections. While reviewing various security aspects of the Space Shuttle Program to eliminate terrorist activity or sabotage as possible causes of the *Columbia* accident, the CAIB noted a lapse in procedures at various NASA installations. There were several processes that did not require two people to be present when an area on the flight vehicle was closed-out (sealed prior to flight). Although unlikely, this could allow an individual to sabotage the vehicle without being observed, and was also against the general policy of "two sets of eyes are better than one" that provides additional technical and safety checks during closeouts. It is important to note, however, that the CAIB found no evidence that willful damage was a cause of the accident (Finding 4.2-12).

The RTF TG concluded that NASA had met the intent of CAIB Recommendation 4.2-3 through revised procedures at all locations that now require at least two people to be present during a closeout.

CAIB Recommendation 4.2-5: Kennedy Space Center Foreign Object Debris Definition. During January 2001 the Kennedy Space Center generated new and non-standard definitions for Foreign Object Debris (FOD). The term “processing debris” was applied to debris found during the routine processing of the flight hardware. The term FOD applied only to debris found in flight hardware after final closeout inspections. These definitions were unique to the Space Shuttle Program at KSC. Because debris of any kind has critical safety implications, the CAIB wanted the standard, industry-wide definition reestablished for FOD.

The RTF TG concluded that NASA met the intent of CAIB Recommendation 4.2-5 when KSC and the United Space Alliance changed the definition of “Foreign Object Debris” to be consistent with the recognized and accepted industry standard. Further, the Agency has removed the misleading category of processing debris that caused concern. They have improved the training of the workforce and implemented several improvements above and beyond the expectations defined in the CAIB recommendation.

CAIB Recommendation 6.2-1: Consistency with Resources. The CAIB explicitly recognized the legitimate use of schedules to drive a process, but was concerned, however, that the line between “beneficial” schedule pressures and those that become detrimental cannot be defined or measured. In the case of *Columbia*, the CAIB discovered that pressure on the Space Shuttle Program was created by the schedule for construction of the International Space Station. Indeed, the planned February 2004 completion of Node 2 of the ISS was being touted as a measure of NASA’s ability to maintain a schedule that had been promised to Congress.

The RTF TG concluded that NASA met the intent of CAIB Recommendation 6.2-1, since new tools and processes put in place by the Agency should preclude this type of undue schedule pressure in the future. The Task Group cautions, however, that resource sufficiency is also tied to the scheduled retirement date for the Space Shuttle. Any evaluation of plans to keep the Space Shuttle in service past 2010 should include a reassessment of actions and upgrades not undertaken by NASA, and any long-term items already deleted from work and acquisition cycles, including the Service Life Extension Program.

CAIB Recommendation 6.3-1: Mission Management Team Improvements. The performance of the Mission Management Team (MMT) during the flight of *Columbia* has been widely criticized. Many of the additional capabilities embedded in other recommendations from the CAIB, such as imagery from various sources and vehicle damage tolerance maps, are intended to support MMT activities for the return to flight. The CAIB recommended that the MMT receive additional training to deal with potential crew and vehicle safety contingencies beyond the launch and ascent phases of flight.

The RTF TG concluded that NASA has met the intent of CAIB Recommendation 6.3-1 by developing a new training plan for the MMT. With the passage of time, the Task Group has been able to observe the implementation of most aspects of the plan. Numerous simulations have been conducted, including more than 10 involving live, face-to-face exercises of various parts of the next mission. The various delays in launching STS-114 have allowed the MMT to further refine its procedures and have resulted in continual improvement. The Mission Management Team has made notable progress in addressing the CAIB concerns, and the Agency has demonstrated a commitment to continual MMT improvement.

CAIB Recommendation 6.3-2: National Imagery and Mapping Agency Memorandum of Agreement. There was considerable public discussion of the decision during the flight of *Columbia* to forego requesting the assistance of other federal agencies in assessing the

condition of the Orbiter, including any possible damage. The CAIB wanted the Space Shuttle Program to have the procedures in place to get all possible data to investigate a potential problem. This included having the proper personnel maintain the appropriate security clearances to access data from National assets.

The RTF TG has concluded that NASA has met the intent of CAIB Recommendation 6.3-2. A revised Memorandum of Agreement is in place between NASA and the National Geospatial-Intelligence Agency (NGA – the successor to NIMA), and appropriate security clearances have been obtained by various NASA personnel. The coordination required to use this capability has also been exercised in various MMT simulations.

CAIB Recommendation 6.4-1: Thermal Protection System Inspection and Repair. This was a four-part CAIB recommendation. The RTF TG only assessed the parts of this recommendation applicable to inspection and repair for the return-to-flight effort.

After long and often spirited discussion, the RTF TG concluded that NASA did not meet the intent of CAIB Recommendation 6.4-1 relative to repair of the Orbiter Thermal Protection System; the inspection part included in the assessment of Recommendation 3.4-3 did meet the intent of CAIB. The basic debate within the Task Group was more one of process than of fact; everybody agrees that the repair options on STS-114 “are what they are.” The Task Group opinion – by a slim margin – was that each of the repair options that comprise the repair capability must be sufficiently tested and vetted so that NASA could implement it in an emergency situation with confidence that it would perform as expected. To date, the tile and RCC repair techniques developed by the Agency are not considered sufficiently mature to be a practicable repair capability for STS-114.

CAIB Recommendation 9.1-1: Detailed Plan for Organizational Change. The CAIB expected NASA to return to flight relatively quickly, and the accident board did not want to restrict this activity by requiring major organizational changes. Instead, the CAIB wrote a separate recommendation that NASA produce a detailed plan to implement the organizational changes embodied in three other recommendations – R7.5-1, Independent Technical Authority; R7.5-2, Safety and Mission Assurance; and R7.5-3, Systems Engineering and Integration. However, getting ready for the first return-to-flight mission took much longer than initially expected, allowing NASA to proceed with many of the organizational changes recommended by the CAIB. The Task Group elected to assess the actual changes, in addition to the plan.

The Task Group believes that embodied in Recommendation 9.1-1, however, are a myriad of organizational and management issues raised by the CAIB, including “culture.” The CAIB used the term “culture” throughout its report, although there are neither specific recommendations to change culture nor any suggestions on how this might be accomplished. Therefore, organizational culture, although important, was not considered a return-to-flight issue and was not evaluated by the Task Group.

The RTF TG concluded that NASA has met the intent of CAIB Recommendation 9.1-1 because the Agency has a mature plan to restructure the organization as envisioned by the accident board. The assessment of the actual changes, however, is mixed. The planned implementation of the Independent Technical Authority comports with CAIB intent, but resistance to this formulation still exists – it will take time to see if the process is robust enough to overcome the internal opposition. The planned response to R7.5-2 is intentionally not consistent with the CAIB recommendation – NASA simply disagrees that the best organization is for the field centers’ Safety and Mission Assurance Offices to report directly to Headquarters; the Task Group is sympathetic to the NASA position. Implementation of R7.5-3 is uneven, with improved integration and system analysis but with some worrisome gaps in system engineering capability.

CAIB Recommendation 10.3-1: Digitize Closeout Photos. During the *Columbia* investigation, the accident board encountered numerous engineering drawings that were inaccurate. Further, they discovered that a large number of engineering change orders had not been incorporated into the drawings. Tied in with this, in many instances CAIB investigators were not able to access needed closeout photography for several weeks.

The RTF TG has concluded that NASA has met the intent of CAIB Recommendation 10.3-1. Standardized 6.1-megapixel cameras have been acquired for use in closeout and configuration photography. NASA identified enhancements to the Shuttle Image Management System (SIMS) database, and necessary upgrades are complete. Updated training material has been developed for users of the SIMS database, and users have received training at KSC, JSC, and MSFC. Through several integrated launch countdown simulations, the Space Shuttle Program staff have confirmed that the modifications to the SIMS database satisfy their needs.

The CAIB recommendation assumed that the Space Shuttle Program would continue for the long term, and it indicated that the digital photography should be an interim solution pending the digitizing and updating of all Space Shuttle engineering drawings (R10.3-2). However, based on the decision to retire the Space Shuttle no later than 2010, the Task Group concurs with NASA's decision that it does not make economic sense to expend the resources to make major changes in the drawings. The digital closeout photography provides an adequate solution until the end of the program. The Task Group cautions, however, that should the decision be made to extend the Space Shuttle Program past 2010 – or to use elements of it for a new heavy-lift vehicle – the appropriate engineering drawings should be resolved.

Raising the Bar Action SSP-3: Contingency Shuttle Crew Support. The CAIB report mentioned the feasibility of providing contingency life support on board the International Space Station for stranded Space Shuttle crewmembers until repair or rescue could be accomplished. The accident board, however, did not issue a specific recommendation to either evaluate or implement such a capability. As part of the return to flight efforts, NASA developed a capability called Contingency Shuttle Crew Support aboard the ISS for STS-114 and STS-121. Since this capability was an option of last-resort in several scenarios evaluated by the RTF TG, the Task Group elected to evaluate the capability as part of this report.

The RTF TG concluded that NASA has developed analyses and plans for CSCS which will offer a viable emergency capability for crew rescue. NASA set a raising the bar action and exceeded it by a significant margin. The Task Group commends NASA for excellent work on SSP-3.

Integrated Vehicle Assessment. To assess the ability to perform an integrated vehicle external damage assessment, the RTF TG established the Integrated Vehicle Assessment Sub-Panel (IVASP). With the addition of new cameras and sensors, NASA needed a method to capture and integrate the information gained from these sensors, use that information to perform a damage assessment, and present that information in a way that supported critical decision-making regarding potential damage and options to mitigate that damage.

Beginning from scratch, NASA has developed a process that holds the promise of integrating a variety of new and disparate types of data into information that can support these complex decisions during flight. They have documented these processes, vetted them, trained to them, and revised them accordingly. As we have said, NASA needs an ability to manage risk during flight; NASA's processes to integrate these sensor data into information that can support damage assessments represent a significant step in that direction.

The Task Group commends NASA for its progress in this area and recommends that this work continue after STS-114. We further suggest that this process could even serve as a model for other cross-NASA integration projects.

Concluding Thought

To focus solely on the CAIB return-to-flight recommendations as a measure of the safety of STS-114 is inappropriate. The Task Group, while concluding that three recommendations were not fulfilled in their entirety, was not chartered to reach any conclusion regarding the safety of the next flight. Indeed, addressing the CAIB recommendations has been only a part of the Agency's vast work leading to return to flight. It is improper to calculate, on the basis of the Task Group's assessments, the likelihood of success for the next and subsequent flights. It is the responsibility of NASA, and only NASA, to define and accept the remaining risk for STS-114 and all subsequent missions.

The Columbia Accident Investigation Board provided a valuable service to the *Columbia* families, NASA, and the Nation by determining the cause of the accident and prescribing steps to reduce the risk for subsequent flights. As with most accident boards, the CAIB set a high standard, perhaps one that was not achievable given the technology, funding, and schedule available to the Space Shuttle Program. Not everything the CAIB recommended could be accomplished, but this does not reflect poorly on the dedication or capabilities of the NASA workforce. The work accomplished since February 2003 has led to an improved vehicle and an enhanced understanding of its capabilities and limitations. In addition, NASA has begun to address organizational changes that should clarify lines of communication and responsibilities to provide an enhanced safety culture. Perhaps the most important lesson from the accident is a renewed respect for the risks inherent in space travel and the need to continually monitor and assess those risks.



Discovery sits at Launch Complex 39B at the Kennedy Space Center awaiting launch as STS-114.

1 BACKGROUND

It has been 24 years since the first launch of *Columbia* marked the beginning of the Space Shuttle Program's flight phase. During the course of 113 missions, the program suffered two tragic flight accidents, costing the lives of 14 astronauts. Despite this, the Space Shuttle is the most reliable human spacecraft ever built; reports of it being inherently unsafe do not fully take into account the physics or technology involved in boosting a payload off the surface of the Earth.

Space, by its nature, is a hostile environment posing unique risks for any undertaking, especially those involving humans. The speeds, pressures, temperatures, and stresses involved in space flight are unparalleled in the normal Earth-bound environment in which we all live. There are other environments in which humans operate – in the deep sea, for instance – that are equally as harsh, at least in some respects, but none are as unforgiving as space flight.

Everybody involved with the Space Shuttle Program strives – as they should, and must – for perfection. But all understand that despite their best efforts, it is highly unlikely they will ever be able to make space travel risk free. Nevertheless, perfection must continue to be the goal, for anything less is clearly unacceptable.

When the Columbia Accident Investigation Board (CAIB) issued its final report in August 2003, it included several recommendations that ultimately were not met. The CAIB understood this possibility, but it is the job of any accident board to identify all of the deficiencies it uncovers during its deliberations. The CAIB went further than most accident boards since it was dealing with a very complex and publicly-visible program. As the accident board wrote in its final report, "It is our view that complex systems almost always fail in complex ways, and we believe it would be wrong to reduce the complexities and weaknesses associated with these systems to some simple explanation."

Then-Administrator Sean O'Keefe embraced the CAIB recommendations and directed the Agency to implement all of them. This was undoubtedly the correct motivation at the time; the Space Shuttle was expected to remain in service for another 20 years or more. However, circumstances change. For the American space program, a major shift occurred on January 14, 2004, when President George W. Bush announced the Vision for Space Exploration that will send astronauts back to the moon, and eventually to Mars. As part of this Vision, the President ordered that the Space Shuttle be retired no later than 2010, only 5 years after the return-to-flight of *Discovery*.

This shift in National Policy had a major effect on the effort to return the Space Shuttle fleet to flight. NASA determined that there was no longer sufficient time, nor would it be prudent, to implement several of the CAIB recommendations; others must be reconsidered from a budgetary and schedule perspective given the limited number of missions remaining to be flown before the Space Shuttle is retired.

The Return to Flight Task Group was not chartered to pass judgment on the CAIB report, but rather to assess the Agency's implementation of the 15 recommendations the accident board indicated should be completed prior to returning to the Space Shuttle to flight. It was completely within the purview of NASA to determine if the recommendations were still valid given the new circumstances surrounding the future of the program. In several instances, NASA decided that it was not feasible to implement the CAIB recommendations in their entirety. The Task Group understands, and in some instances concurs, with the reasoning behind these decisions, but must still determine the Agency's compliance with the recommendations as written and without reference to recent changes in the National Policy for space exploration.

Over the course of its 25-year history, the Space Shuttle Program has averaged just over four flights per year, a rate that has never allowed the system to fully mature as its designers originally intended. Nevertheless, the Space Shuttle has transported more people, from more countries, into space than all other launch vehicles combined. However, as the CAIB report correctly pointed out, the Space Shuttle is not now, has never been, nor will ever be, an “operational” vehicle. Instead, it is a developmental vehicle performing a dangerous mission in a known high-risk environment. Measured against similar systems, it has excelled at its task, but it can, and should have, done better.

The Task Group – like the CAIB before it – does not believe that the Space Shuttle is an inherently unsafe vehicle. On the contrary, the Task Group believes it is a remarkable technological achievement that has served the Nation well for over 20 years. NASA and the aerospace industry have learned a great deal in those years, and the next vehicle will, hopefully, be safer and more reliable than the Space Shuttle. Nevertheless, constant vigilance will always be required to ensure NASA does not become complacent about the dangers of space flight. But we would be deceiving ourselves, and the American public, if we proclaimed that space travel will ever be “safe.” As the CAIB observed, “Building rockets is hard.” Building rockets for human travel is even harder.

The United States has committed to human spaceflight, and in doing so, has also committed to accepting the risks associated with that endeavor, with the belief that our knowledge, skill, and perseverance will allow us to succeed. This will never be a safe, easy, or routine undertaking. The Administration, Congress, and the American public must be made aware of the dangers inherent in the technology and environments of space exploration. They must be assured that NASA and its contractors have done, and will continue to do, everything within their power to minimize the risks involved in this great undertaking. But they must also realize that it is likely that another accident will happen in the future; if not with Space Shuttle, then with whatever vehicle replaces it.

The Space Shuttle Program must strive to identify and understand every potential risk – technical and programmatic – to the vehicle and crew. It must eliminate risk wherever possible, take steps to mitigate those risks that it can not eliminate, and carefully monitor those risks that it cannot control. The program must ensure that it is its own harshest critic since the vehicle and its environments are so complex that nobody will ever understand them better than the program itself. To accomplish this, NASA leadership must provide proactive oversight to ensure that the Space Shuttle Program does not overlook risks by being “too close to the problem.” In turn, the program must be completely honest with itself, NASA leadership, Congress and the American public, never minimizing the risks inherent in space flight, never making it appear to be easier than it is, and never forgetting that the price of failure is too high. Nothing less will honor the legacy of the 14 astronauts who perished in *Challenger* and *Columbia*.

The orange glow of the setting sun paints a silhouette of *Discovery* (on the right) as it rolls out to Launch Complex 39B at the Kennedy Space Center in preparation for the first mission after the loss of *Columbia*.



2 RELATIONSHIPS AMONG THE RECOMMENDATIONS

A large majority of the CAIB return to flight recommendations rely on the results of other recommendations and should be placed in context to properly evaluate and appreciate the volume of work accomplished by NASA over the last two years. In many instances, the Task Group could not easily assess one recommendation without considering others. With few exceptions (R4.2-5; KSC Foreign Object Debris, and R4.2-3, Two Person Closeout Inspections), all of the technical and operational recommendations were closely linked via their relationship to the overall risk acceptance rationale used by NASA. In addition, the Agency's response to the management recommendations influenced how the other recommendations were ultimately implemented.

There was initial consideration within the Task Group of combining the assessments of several recommendations in this report, but ultimately it was believed that each assessment should stand alone – to the extent possible – to make it easier for the reader to locate the particular recommendation. However, it was also felt that it was necessary to explain the relationships among the recommendations.

A similar quandary apparently confronted NASA. An early attempt within the NASA Safety and Mission Assurance community to integrate the intent of the recommendations into a whole came in the form of the Thermal Protection System Risk Reduction Framework, presented below. Using this framework, a larger picture emerges of the NASA implementation of the CAIB return-to-flight recommendations.

2.1 Thermal Protection System Risk Reduction Framework

The most important technical issue to be resolved before returning to flight was preventing ascent debris from causing critical damage to the Orbiter Thermal Protection System. The Space Shuttle Program Safety and Mission Assurance Manager described a proposed framework for thermal protection system risk reduction to the RTF TG at the April 2004 plenary. This framework, starting with primary hazard control, further delineated appropriate warning devices and special procedures to mitigate the risk of the primary hazard control not being completely satisfied, and directly encompassed several of the CAIB return-to-flight recommendations. The Task Group found this useful for putting various recommendations in context with one another.

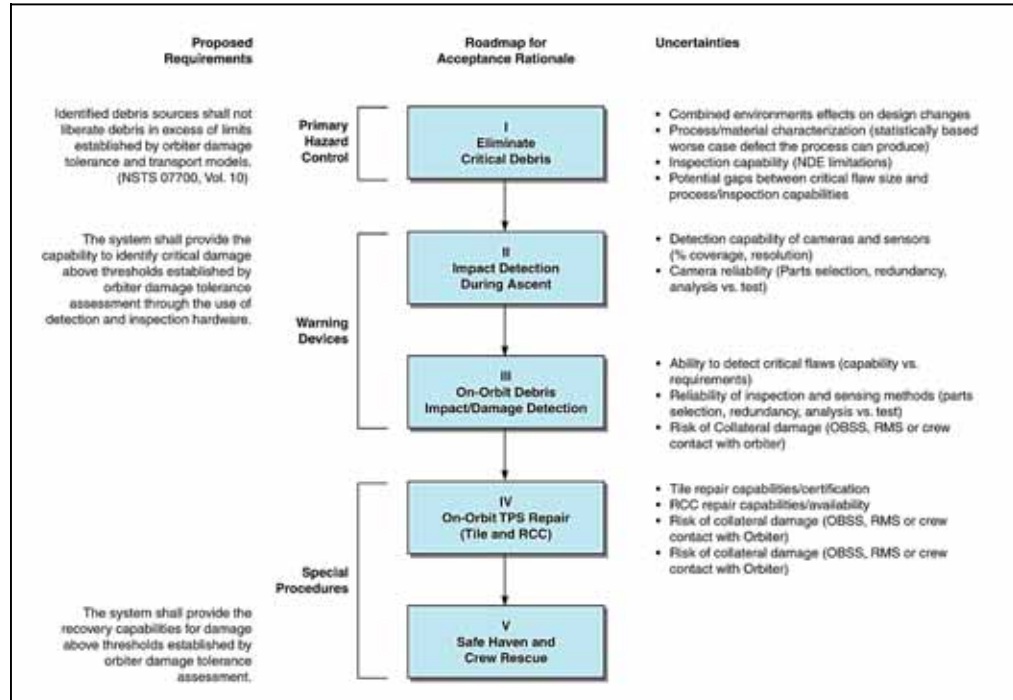
The primary hazard control, or the first step in the roadmap, was to “Eliminate Critical Debris.” This was a combination of subparts: understand and improve the current ability of the Orbiter to withstand debris impacts (R3.3-2), ensure that the reinforced carbon-carbon panels currently in use were not already damaged (R3.3-1), and attempt to eliminate ascent debris (especially from the External Tank, R3.2-1, and SRB bolt catchers, R4.2-1).

Warning devices encompassed the second and third steps in the roadmap. The second step, “Impact Detection During Ascent,” covered ground-based imagery (R3.4-1), high-resolution imagery of the ET (R3.4-2), observation cameras mounted on the ET and SRBs (a component of R3.4-3), data from National assets (R6.3-2), and data from the wing leading edge impact detection system (a component of the inspection portion of R6.4-1). Step III, “On-Orbit Debris Impact/Damage Detection,” dealt with the Orbiter Boom Sensor System (OBSS) and R-Bar Pitch Maneuver imagery taken from the International Space Station that are part of the inspection portion of R6.4-1 and which provide the high-resolution capability to meet R3.4-3.

An implicit step in this roadmap was the integration of data from the warning devices into an assessment of any damage sustained by the Orbiter Thermal Protection System during the mission. The combination of that data with the knowledge of the capability of the Orbiter to enter with damage (the second part of R3.3-2) and closeout photography depicting the last

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known state of the Orbiter (R10.3-1), results in a determination of whether repair (the other part of R6.4-1) needs to be initiated. Additionally, test and analysis provide the rationale to continue with entry or invoke the safe haven offered by Contingency Shuttle Crew Support (CSCS – SSP-3). The integration of this data has been the primary focus of the Task Group’s Integrated Vehicle Assessment Sub-Panel (IVASP) and is further addressed in Section 2.2. At the Task Group’s urging, MMT simulations (R6.3-1) and component simulations (R3.3-2 and R6.4-1) exercised the resulting process. However, the Task Group cautions that limitations in these inspection capabilities may still allow damage to go undetected.



The last two steps, which hopefully will never need to be exercised during a mission, are called “Special Procedures.” Step IV, “On-Orbit TPS Repair (Tile and RCC),” is addressed in the repair portion of R6.4-1. The final step of the roadmap, “Safe Haven and Crew Rescue,” is the focus of the “raising the bar” action for CSCS (SSP-3) that the Space Shuttle Program assigned to itself, and is not a direct response to a CAIB recommendation.

On the management side, expanding the role of the Space Shuttle Integration Office to address the entire Space Shuttle system (R7.5-3) enabled the new Systems Engineering and Integration Office (SEIO) to lead the effort to understand the effects of debris, to assess the remaining risk due to critical debris, and to integrate the in-flight TPS assessment activities. Many of the efforts in the paragraphs above entail development activities, and therefore carry the possibility that some requirements may not be met and waivers will need to be processed. Restoring specific engineering technical authority, independent of programmatic decision-making (R7.5-1) and increasing the authority, independence, and capability of the Safety and Mission Assurance (SMA) organizations (R7.5-2) provide independent voices in the waiver and resulting risk acceptance deliberations that the CAIB felt were missing at the time of the *Columbia* accident (R9.1-1).

Clearly, the more thoroughly critical debris can be eliminated (via a combination of reducing debris from the tank and increasing the ability of the Orbiter to withstand impacts), the less important the repair capability (with its attendant prerequisite ability to detect damage which needs to be repaired) or the rescue capability becomes. The more confidence in the detection and repair capabilities there is, the less the need for a crew safe haven and rescue function

exists. The crew rescue capability is only a last resort (no matter the confidence one has in it) because in this case, the crew is saved; however, the damaged Orbiter is not salvaged. In addition, invoking CSCS would have significant impacts on the ISS, including the possible need to evacuate the station.

All of the steps in the roadmap have remaining uncertainties associated with them (see the column on the right of the diagram). There still exists a possibility that the Orbiter could sustain critical damage to the TPS. Limited actions were taken to harden the Orbiter, and there is a potential that debris from the External Tank could again critically damage an Orbiter during ascent. If such damage occurs, there is some risk that it could go undetected, not be repairable, or that a rescue mission could not be launched in time. Probabilistic analysis was used to quantify the residual risk of critical damage to the Orbiter Thermal Protection System from debris and is discussed in Section 3.3 as part of R3.3-2. Other risks are captured in the Integrated Hazard Reports.

NASA acknowledges that the elimination of all critical debris is not attainable; therefore the Agency has analyzed and formally accepted the remaining risk as a condition for the return to flight.

2.1.1 Summary

Many within the RTF TG were encouraged with this proposed “top-down” approach for hazard reduction. Similarly, it would have been beneficial if NASA had performed a top-down requirements flow-down that recognized the relationship between seemingly disconnected system elements with cross-cutting functional connectivity. Some members of the Task Group expressed an interest in seeing this implementation technique applied to all items in the *NASA Implementation Plan*, but no evidence of this approach was found by the Task Group. The failure to accomplish these tasks may ultimately result in unintended consequences from a lack of integration between elements.

The basic outline of the roadmap presented at the April 2004 plenary was eventually incorporated into a Headquarters document, *The Integrated Risk Acceptance Approach For Return To Flight*, intended to define the overall rationale for STS-114. The Task Group notes, however, this document has not been formalized – it has no author, no document number, no approval page, apparently no configuration management – and does not directly correlate to any program requirements. Nevertheless, progress has been made in incorporating risk reduction as part of various program, element, and project activities.

2.2 Integrated Vehicle Assessment

The RTF TG established the Integrated Vehicle Assessment Sub-Panel (IVASP) to combine insights from the Operations, Technical, and Management Panels in order to assess NASA’s ability to perform an integrated external damage assessment of the Orbiter based on a variety of data sources in direct support of real-time decision-making for Space Shuttle operations.

2.2.1 The NASA Response

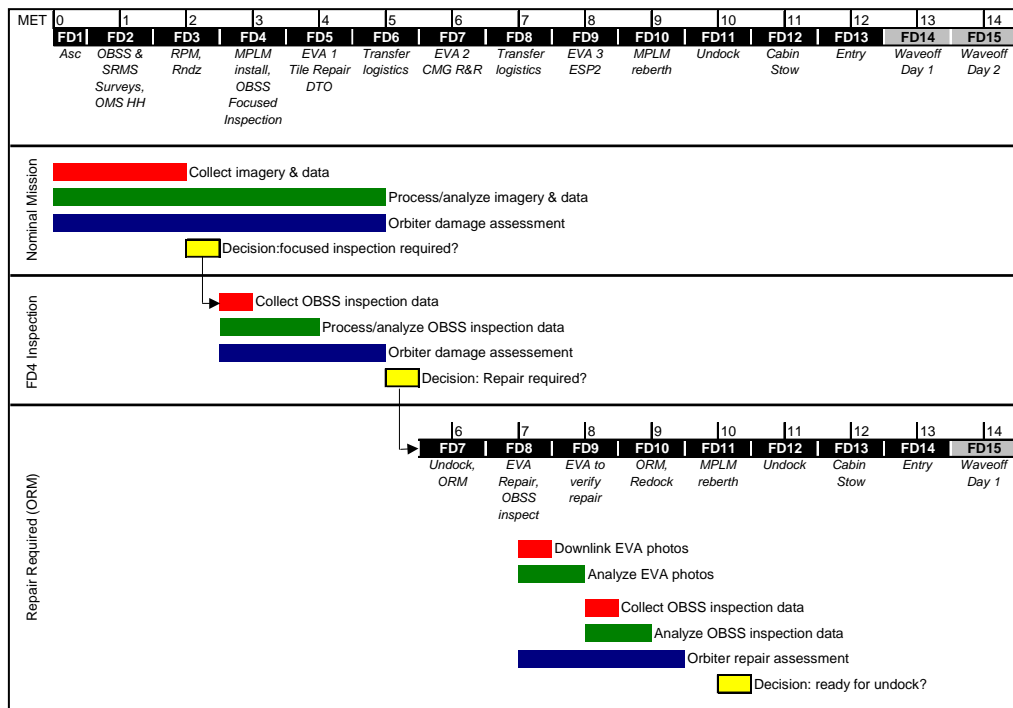
As part of their return to flight effort, NASA developed a Orbiter Thermal Protection System readiness determination concept. This is documented in NSTS 60540, *STS-114 Operations Integration Plan for Thermal Protection System Assessment*, baselined April 12, 2005. This document states its intended purpose as, “This Operations Integration Plan (OIP) is the agreement on the responsibilities and tasks which directly relate to the integration activities associated with the successful system engineering, integration, and verification of the Space Shuttle return to flight activities associated with the assessment of the TPS. These operations are intended to provide the processes for transforming the data from the TPS assessment

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systems into information that can be used by Mission Management to make a timely TPS entry readiness, repair, or safe haven determination. This document constitutes an agreement on the part of participating organizations concerning products and tasks described.”

The OIP is the response to Program Requirements Control Board (PRCB) Directive S064005, Action 14-1, to develop an integrated operations concept for ascent film and video, Orbiter umbilical well cameras, Orbiter Boom Sensor System inspection, wing leading-edge instrumentation, and external resources. The document also includes the plan for integration of pad walk down debris reports, ascent radar, Solid Rocket Booster recovery reports, International Space Station photography during the R-bar Pitch Maneuver, and debris transport analysis. In addition, the OIP includes an Annex, *Orbiter Damage Assessment Process*, that documents the damage assessment process, and the decision timeline required to support a safe entry assessment. The document focuses specifically on a description of the operations, the work and analysis to be performed, process dependencies, process flows, process responsibilities, and the verification requirements from an integrated perspective.

NASA timeline to collect, process and assess ascent and on-orbit data to determine the state of the Orbiter Thermal Protection System during a mission.



The OIP was developed based on the assets baselined for STS-114 with a daylight launch constraint; however, many of the processes outlined in this document are generic in nature and could apply to any Space Shuttle mission. Nevertheless, due to the evolutionary nature of the specific complement of assets, it was necessary to address the specific STS-114 configuration for the baseline release of the OIP. It is currently NASA’s intent to update the document for future missions as the asset configurations and timelines required to support decision-making change, as well as to capture changes to the process deemed necessary to better support decision-making.

2.2.2 RTF TG Assessment

The Task Group commends the OIP and Damage Assessment Annex developers. Beginning from scratch, they have evolved a process that holds the promise of integrating a variety of new and disparate types of data into information that can support complex decision-making

during flight. To do this, the developers had to work across NASA boundaries to identify the best organization to be responsible for each data source. They had to secure commitments from these organizations to produce data analysis reports on a specified timeline and to share those reports through the OIP. They have also identified and established new positions of authority required to set priorities on data collection and analysis to meet emerging real-time needs. They have conducted an aggressive training plan to exercise each component of the assessment process as well as the MMT use of the information. Finally, they fully documented the process so that it can be evolved as data sources change, studied by new participants in the process, and evaluated by outside observers.

The Task Group recognizes that the OIP and Damage Assessment Annex will continue to mature through STS-114 and, hopefully, beyond. NASA needs an ability to manage risk during flight, and these two documents represent a significant step in that direction. The CAIB recommendations identified specific data necessary to better understand the risk to the Orbiter of a debris impact. The Operations Integration Plan was developed to integrate the data from the new data sources developed for return-to flight and the Damage Assessment Annex was developed to clearly define how those data would be interpreted. We see the Space Shuttle Program's experience in these development initiatives as having potential that goes beyond the specific Thermal Protection System assessment sources developed for STS-114. It represents an approach that pulls information from across NASA boundaries into a consolidated, integrated "whole." There will likely be other anomalous situations during flight where such an approach could help the decision-makers assess and manage risk.

2.2.3 RTF TG Observations

During its assessment of the OIP, the Task Group had several observations.

2.2.3.1 OIP/Damage Assessment Annex Development and Documentation

NASA should continue to support and resource the OIP and Damage Assessment Annex processes. Furthermore, their accomplishments should serve as a model for tackling other integration challenges that NASA faces.

The Space Shuttle Program published several draft versions of the STS-114 Operations Integration Plan, culminating in the baseline version on April 12, 2005. Beginning in December 2004, NASA conducted a series of component simulations (sims), designed to test specific pieces of the OIP, and mini-integration simulations, designed to test parts of the process that involve integration. As elements of the OIP matured, they were incorporated into MMT simulations. These led to MMT sim #12, conducted in March 2005 that specifically included a number of Orbiter Thermal Protection System incidents requiring assessment. The Space Shuttle Program conducted a component sim the week prior to this MMT and used the outputs of the component sim as inputs to the full-scale MMT sim.

The Space Shuttle Program also released a revised version of the Orbiter Damage Assessment Process Annex on March 1, in time to support MMT sim #12. The IVASP reviewed the first version of this Annex in December 2004. The current revision is more mature and includes a detailed description of the processes the program will use to take the data collected and integrated through the OIP and use it to actually assess the status of the Thermal Protection System. The Annex further includes frameworks for risk-versus-risk assessments for both tile and RCC damage and repair activities. This Annex should continue to be exercised in the component and mini-integration sims scheduled before flight. The Space Shuttle Program should update both the OIP and Annex before flight to incorporate the lessons they have learned from their work through the sims, as well as incorporate final decisions for STS-114 resulting from the Debris DVR, the Program DCR, the FRR, and model validation.

2.2.3.2 Structured Assessment during Flight

During flight, the information and understanding gained from the STS-114 experience will be invaluable for future mission data integration. The Operations Integration Plan and Damage Assessment Process Annex developers should put in place a structured process to capture records of the data collected and the processes used to integrate and assess it during flight. The results of a review of this information coupled with the experiences of the participants should form the basis for the post-STS-114 OIP/Annex revisions.

2.2.3.3 Critical Damage/Debris Size Definition

The Space Shuttle Program must continue to mature its critical damage and critical debris assessments and incorporate the results into the OIP and Annex. The results of these assessments determine the operation and processing of some of the key sensors, such as those on OBSS. This could change the timelines the OIP has developed to ensure the data will be available to support the damage assessment process and associated key decisions.

2.2.3.4 Camera Requirements Analysis

During MMT sim #12, the participants debated the significance of the loss of a suite of ground cameras. Some participants felt that the camera's "Criticality 3" status made clear that they were not a constraint to flight, while others felt that the loss would preclude collection of important mission-essential information. Before the launch of STS-114, the Task Group believes that the relative importance of each camera (as well as all STS-114 inspection and imagery capabilities) should be pre-determined, to the extent possible, so that there is a clearer basis for these decisions. The Task Group is not recommending that the criticality of these cameras be changed. Rather we believe that, with all the cameras and sensors now available to NASA, the implications of the loss of a particular sensor need to be clear as the trade-offs are debated. This is even more of a factor for STS-114 since one of its explicit objectives is to document the debris environment actually experienced.

Because many of the cameras are redundant and because data are available at different times, this determination requires analysis. We believe the OIP developers have the expertise to do this work and the OIP is the best place to document the results. The Task Group recognizes that, for some views, there are so many cameras that it would be extremely time-consuming to detail all the permutations. While we still believe the full analysis should be done and documented eventually, it would be prudent for the OIP developers to focus on those views where there is little or no redundancy so that the implications of the loss of one or more of those systems are clear in time for the launch of STS-114.

Additionally, resources must be made available to sustain the enhanced imagery capability that feeds the inspection and damage assessment for the remainder of the Space Shuttle Program. There are inherent risks in space flight and the ability to observe and analyze the state of the vehicle to a high degree of confidence will always be required. It is imperative that NASA accept the responsibility to protect this capability, to use it for all missions, and continue to evaluate methods to improve it within limits for the duration of the Space Shuttle Program and for future programs.

2.2.4 Summary

The OIP and its Damage Assessment Annex represent a significant step toward developing a process to integrate and assess a variety of important information from disparate sources. The Task Group commends NASA for its progress in this area and recommends that this work continue after STS-114. The Task Group further suggests that the development of the OIP and its Annex could serve as a model for other cross-NASA integration projects.

3 ASSESSMENT OF THE CAIB RECOMMENDATIONS

What follows is a section for each of the 15 Columbia Accident Investigation Board (CAIB) return-to-flight recommendations and the “raising-the-bar” SSP-3 action; the three Chapter 7 recommendations (R7.5-1, R7.5-2, and R7.5-3) that are subordinate to R9.1-1 are covered in Section 3.14. In each case the section repeats the original recommendation word-for-word, gives the RTF TG interpretation of the recommendation, provides a brief background (often taken directly from the CAIB report), details the NASA implementation, and concludes with the Task Group’s final assessment of the progress NASA made toward implementing the recommendation.

The section entitled “NASA Implementation” contains descriptions taken from the appropriate version of the NASA *Implementation Plan for Space Shuttle Return to Flight and Beyond*, based on the date for the individual assessment was deliberated. (The RTF TG generally called this document the *NASA Implementation Plan* for brevity.) Additional information from the closure packages submitted by NASA, requests for information, and fact-finding activities are also included as necessary to ensure an adequate description. In general, the description presented in this section is a snapshot of the progress made when the Task Group concluded its assessment; in many cases, things changed between then and the release of this report. It is not the intent of the Task Group to “put words in NASA’s mouth” and in case of disagreement between this document and any official NASA publication, the NASA document shall prevail.

The following table summarizes the Task Group’s assessment of the CAIB return-to-flight recommendations.

3.1	3.2-1	External Tank Debris Shedding	June 27, 2005	Not Met
3.2	3.3-1	Reinforced Carbon-Carbon Non-Destructive Inspection	February 17, 2005	Met
3.3	3.3-2	Orbiter Hardening	June 27, 2005	Not Met
3.4	3.4-1	Ground-Based Imagery	June 8, 2005	Met
3.5	3.4-2	High-Resolution Images of External Tank	December 16, 2004	Met
3.6	3.4-3	High-Resolution Images of Orbiter	June 8, 2005	Met
3.7	4.2-1	Solid Rocket Booster Bolt Catcher	December 16, 2004	Met
3.8	4.2-3	Two-Person Closeout Inspections	December 16, 2004	Met
3.9	4.2-5	Kennedy Space Center Foreign Object Debris Definition	December 16, 2004	Met
3.10	6.2-1	Consistency with Resources	June 8, 2005	Met
3.11	6.3-1	Mission Management Team Improvements	June 8, 2005	Met
3.12	6.3-2	National Imagery and Mapping Agency Memorandum of Agreement	December 16, 2004	Met
3.13	6.4-1	Thermal Protection System Inspection and Repair	June 27, 2005	Not Met
3.14	9.1-1	Detailed Plan for Organizational Change	June 8, 2005	Met
3.15	10.3-1	Digitize Closeout Photos	December 16, 2004	Met
3.16	SSP-3	Contingency Shuttle Crew Support	June 8, 2005	n/a



Discovery, atop a Mobile Launcher Platform (MLP), crawls toward Launch Complex 39B on April 6, 2005. The MLP is moved by the Crawler-Transporter underneath. The crawler stands 20 feet high, 131 feet long and 114 feet wide and moves on eight tracks, each containing 57 cleats weighing one ton each. The crawler moves at a maximum speed of approximately 0.8 mile per hour while carrying the 3 million pound Space Shuttle stack. Note the "We're Behind You, Discovery" banner on the MLP.

3.1 CAIB Recommendation 3.2-1 – External Tank Debris Shedding

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.

3.1.1 RTF TG Interpretation

Eliminate all sources of critical debris in locations where liberated debris might impact the Orbiter, eliminate the bipod strut foam entirely if possible, and determine the foam void size that produces debris of an acceptable size based on the transport and energy analyses.

3.1.2 Background

The *Columbia* accident clearly demonstrated that the Orbiter Thermal Protection System, including the reinforced carbon-carbon (RCC) panels and acreage tiles, was vulnerable to impact damage from the existing debris environment. As a result, the Columbia Accident Investigation Board (CAIB) issued recommendations to eliminate debris (R3.2-1), determine the structural integrity of the RCC (R3.3-1), harden the Orbiter (R3.3-2) against impacts, and to develop on-orbit repair capabilities (R6.4-1).

The External Tank (ET) is the largest element of the Space Shuttle system. Because it is the common element to which the Solid Rocket Boosters and the Orbiter are connected, the ET serves as the main structural component during stacking, launch, and ascent. Lockheed Martin builds the tank at the Michoud Assembly Facility, Louisiana, under contract to the NASA Marshall Space Flight Center.

The External Tank is 153.8 feet long, 27.6 feet in diameter, and comprises three major sections: the forward (upper) liquid oxygen tank, the aft (lower) liquid hydrogen tank, and the intertank area between them. The ET holds 143,351 gallons of liquid oxygen at minus 297 degrees Fahrenheit and 385,265 gallons of liquid hydrogen at minus 423 degrees Fahrenheit.



ET-120, the External Tank originally scheduled for use on STS-114, arrives at the Kennedy Space Center. Various anomalies with this tank forced the program to switch to ET-121, the tank originally scheduled for STS-121.

Several different types of foam insulating material are applied to the ET. The acreage foam that covers the majority of the ET prevents the formation of ice as moist ambient air comes in contact with the aluminum skin of the ET when it is filled with cryogenic propellants. Other types of foam and lightweight ablator materials are designed to protect the External Tank from aerodynamic heating as the vehicle accelerates during ascent. The ET was designed to be economical to produce since it is the only “throw away” portion of the otherwise reusable Space Shuttle. The construction techniques chosen – both for economy and to minimize weight – made it infeasible to use an internal insulation instead of the acreage foam.

NASA maintains that foam remains the only viable technical solution for providing a lightweight, efficient, external thermal protection system. However, foam poses a variety of manufacturing challenges. For example, it is subject to small voids during application, especially around complex geometries such as joints or protrusions. This problem is exacerbated by the fact that foam for complicated areas must be manually applied, instead of the more consistent automated process that is used for the smooth areas. Using non-destructive inspection to find inconsistencies or defects in the foam is an engineering challenge that has eluded a reliable technical solution. NASA has conducted several searches for non-destructive inspection techniques in industry and research institutions and has made repeated attempts to develop a method of inspecting the foam for correct application; to date these have only been partially successful. As an alternative to inspection, NASA has incorporated strict process controls for both automated and manual foam applications.

The accident board found that foam loss had occurred on more than 80 percent of the 79 missions for which imagery was available, and foam was lost from the left bipod ramp on nearly 10 percent of the 72 missions where the left bipod ramp was visible following ET separation. It was foam debris from the left bipod ramp that caused the *Columbia* accident. For about 30 percent of all missions, there was no way to determine if foam was lost; these were either night launches, or the External Tank bipod ramp areas were not in view when the images were taken. The ET was not designed to be recovered after separation, depriving NASA of physical evidence that could help pinpoint why foam separates from it. Photography of the ET after separation – although routinely accomplished – was not a priority for the Space Shuttle Program prior to the *Columbia* accident.

A complete description of the External Tank and this problem, as explained by the accident board, may be found in the CAIB final report, Volume I, Section 3.2.

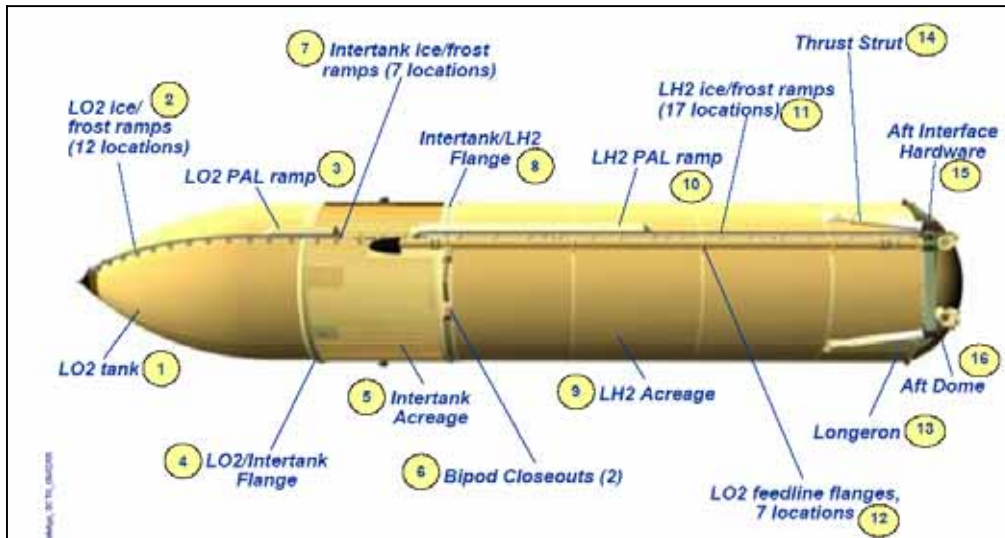
3.1.2.1 ET Debris Sources

During the early 1990s, NASA attributed several instances of foam loss to de-bonds or voids in the “two-tone foam” bond layer on the intertank area forward of the bipod ramp. It was thought that when the intertank foam was liberated, it peeled portions of the bipod ramp off with it. Corrective action taken after STS-50 in June 1992 included the implementation of a two-gun spray technique in the ET bipod ramp area to eliminate the two-tone foam configuration. This appeared to have solved the problem until the sixth bipod ramp event occurred during STS-112 on October 7, 2002, two flights prior to STS-107.

A bipod ramp like the one shown here was the debris that doomed *Columbia* on her last flight. These ramps have been completely eliminated from the modified External Tanks.



After the STS-112 bipod ramp foam loss event, the ET Project began developing concepts to redesign the bipod ramp; this activity was still under way at the time of the STS-107 accident. The dissection of bipod ramps conducted for the *Columbia* accident investigation indicated that defects resulting from a manual foam spray operation over an extremely complex geometry could produce foam loss.



NASA evaluated 16 areas of the ET thermal protection system for debris shedding. Eventually five areas of foam (numbers 5, 6, 8, 10, 13) plus a source of ice debris at the LO2 feedline bellows (not shown) were selected for improvement or redesign based on their likelihood to liberate critical debris.

The LO2 and LH2 PAL (protuberance air load) ramps are designed to reduce adverse aerodynamic loading on the ET cable trays and pressurization lines. PAL ramp foam loss was observed on two flights, STS-4 and STS-7. The most likely cause of these losses were earlier repairs and cryo-pumping (air ingestion) into the super-lightweight ablator (SLA) panels under and adjacent to the PAL ramps. Configuration changes and repair criteria were revised early in the program, to mitigate recurrence of these failures. The PAL ramps are large, thick, manually sprayed foam areas that use a less complex spray process than that used on the bipod; however, if liberated the ramps could become large debris.

Another area of special interest was the intertank that separates the LO2 tank from the LH2 tank. The area where the intertank connects to the pressurized hydrogen tank is called the LH2/intertank flange. Imagery taken after ET separation showed repeated loss of foam from this flange area prior to STS-107.

Further investigation showed that another potential source of debris was the LO2 feedline, a large external pipe that runs the length of the External Tank. Bellows are located at three joints along the feedline to accommodate thermal expansion and contraction. The bellows shields are covered with foam, but the ends are exposed. Because of the cryogenic fluids in the pipe, ice and frost form when moisture in the air contacts the cold surface of the exposed bellows as well as on five brackets that hold the feedline to the ET.

Space Shuttle Program requirements included provisions for ice on the feedline bellows, brackets, and adjacent lines. However, ice in these areas is a potential source of debris in the critical debris zone – the area from which liberated debris could impact the Orbiter. Ice has been seen on all missions, and after a review of flight history, NASA believes a portion of the historical debris damage was the result of ice impacts.

It should be noted that, despite extensive analysis and tests, to date, neither the CAIB nor NASA have been able to absolutely determine the root cause for the loss of the bipod ramp foam during the last flight of *Columbia*. Additionally, the accident board also was not able to determine that the SRB bolt catchers, while an unlikely cause, could be definitively excluded as a potential cause of the left wing damage on *Columbia*.

3.1.3 NASA Implementation

After the *Columbia* accident, NASA initiated a three-phase approach to eliminate the potential for debris shedding – such as ice and foam – from the External Tank. Phase 1 included those

activities completed prior to the return-to-flight that would control critical debris on tanks already constructed. NASA determined that the Phase 2 activities were not required for return to flight, but rather focused on continuous improvement including debris elimination enhancements that could be incorporated into the ET production line for new tanks. Phase 3 would have examined additional means of further reducing ET debris potential; however, NASA does not plan to implement Phase 3 since the Space Shuttle is scheduled to be retired at the end of the decade.

NASA made several modifications to the External Tank to reduce foam and ice debris during ascent. Although all are considered successful, testing and analysis show that the ET can still shed critical debris.



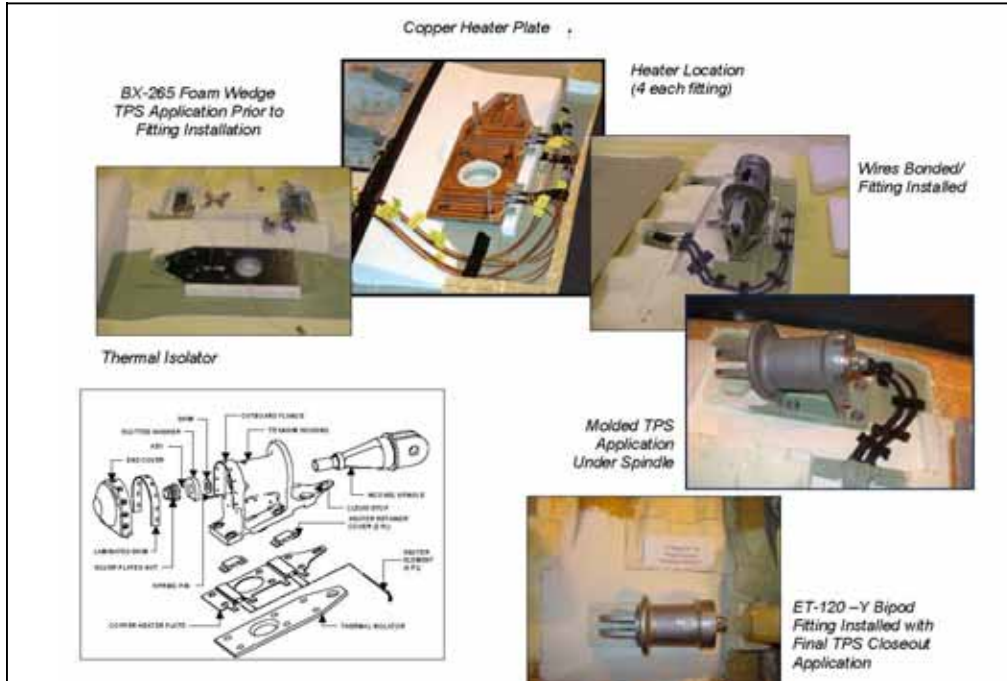
As part of the Phase 1 effort for return to flight, NASA modified the areas of known critical debris sources, although NASA has never determined the root cause for all instances of foam shedding. This included redesigning the forward bipod fitting and associated thermal protection system closeout, redesigning the LH2/intertank flange thermal protection system closeout, and reducing ice formation on the LO2 feedline bellows. ET intertank venting was increased to reduce popcorning masses in the ET foam.

In addition to addressing these known areas of debris, NASA has reassessed all areas of the ET to verify the robustness of the thermal protection system configuration, including both automated and manual spray applications. Special consideration was given to the LO2 and LH2 PAL ramps due to size and location. Although there is no significant history of foam liberation from the longeron area, the ET Project took the conservative path of removing and reapplying part of this area with an improved foam application process.

NASA also pursued a testing program to understand the root causes of foam shedding from various areas (with varying degrees of success) and developed alternative design solutions to reduce the debris loss potential. Additionally, NASA is continuing the development of two non-destructive inspection techniques – tetrahertz imaging and backscatter radiography – to conduct ET thermal protection system inspection without damaging the fragile insulating foam. During Phase 1, non-destructive inspection was used on the LO2 and LH2 PAL ramps as engineering information only; certification of the foam was achieved primarily through verifying the application and design.

The bipod fitting design, fitting closeout, and heater system were reviewed during the ET Design Certification Review. The verification included thermal tests to determine the

capability of the design to preclude prelaunch ice, 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 simulated flight environments. Wind tunnel testing has verified the thermal protection system closeout performance when exposed to the expected ascent aerodynamic and thermal environments.



The most visible change to the External Tank was the elimination of the bipod ramps on the forward ET attach point and the installation of heaters in the same area. The loss of one of these foam ramps was responsible for the loss of *Columbia*.

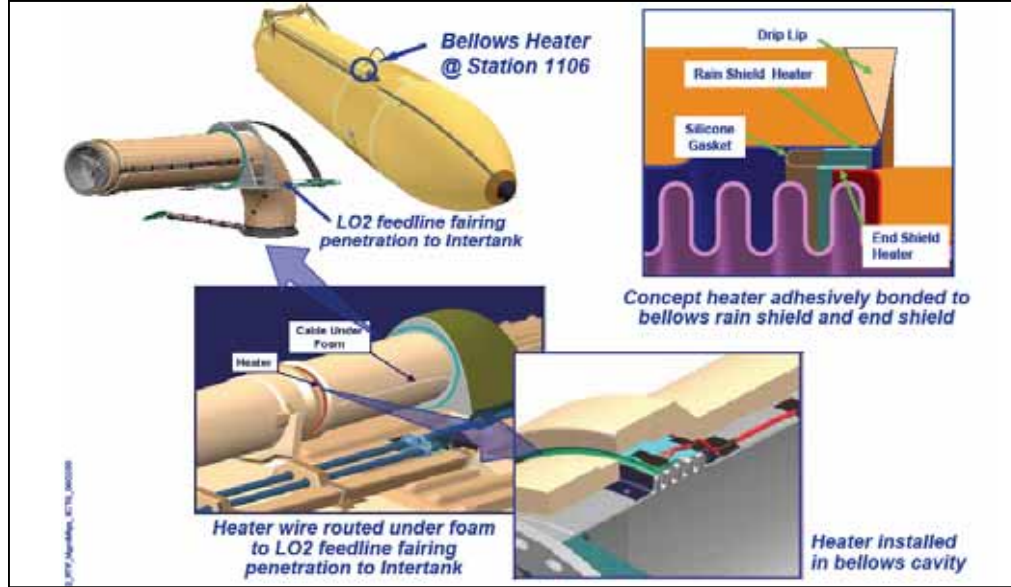
Initially, NASA selected a “drip lip” to reduce ice formation on the three LO2 feedline bellows. The drip lip diverts condensate from the bellows and significantly reduces ice formation. However, since the drip lip alone was not sufficient to completely eliminate the ice, NASA continued to pursue complementary solutions. By April 2005, analysis of the ice formation, estimates of the liberated ice, and transport analyses identified the residual ice at the forward LO2 feedline bellows location as an unacceptable debris source; therefore, additional reduction of ice at the forward location was required before return to flight and resulted in moving the launch date from May 2005 to July 2005.



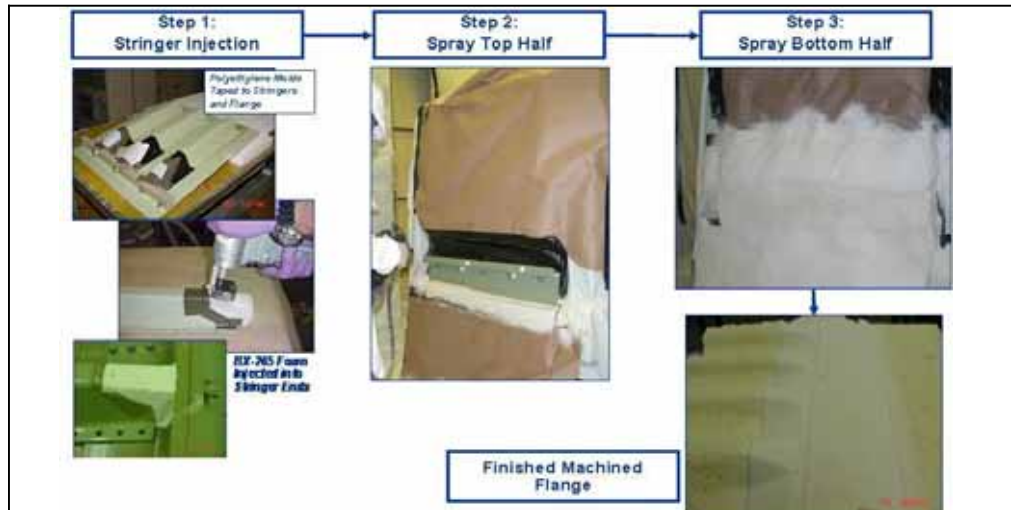
Three photos showing ice accumulation on the forward LO2 feedline bellows. The drip lip was initially chosen for return to flight, but ultimately the heater was installed to further mitigate the problem.

During the delay, NASA installed a heater in the forward LO2 bellows cavity to reduce ice formation to an acceptable level. Bonding of the heaters required removal and replacement of a 3-inch wide strip of foam along the existing drip lip and LO2 feedline surface. The heater has been installed in the tanks that will be used for STS-114, STS-121, and all future flights. No modifications other than the drip lips have been implemented for the mid and aft bellows for STS-114; NASA continues to assess other ice mitigation techniques for these locations for future flights.

Details of the bellows heater installation. This heater was installed at the Michoud Assembly Facility on the third post-Columbia ET (ET-119), but was retrofitted at the Kennedy Space Center on the first two tanks (ET-120 and 121).



NASA determined the primary root cause of foam loss in the intertank/LH2 tank flange area was the gaseous nitrogen used as a safety purge in the intertank coming into contact with the extremely cold hydrogen tank dome and condensing into liquid. The liquid nitrogen migrated through intertank joints, fasteners, vent paths, and other penetrations into the foam and then filled voids in the foam caused by variability in the manual foam application. During ascent, the LN2 returned to a gaseous state, pressurizing the voids and causing the foam to detach. With this knowledge, NASA evaluated the LH2/intertank closeout design to minimize foam voids and nitrogen leakage from the intertank into the foam.



The new three-step enhanced closeout process for the LH2 intertank area.

The solution ultimately chosen for this area was replacement of the existing intertank closeout with a three-step enhanced closeout process. NASA is relying on the enhanced process in the LH2 intertank area to reduce the presence of defects within the foam to reduce or eliminate void formations in the area of the flange joining the LH2 tank to the intertank.

Because NASA believed the PAL ramps had a satisfactory flight history and there was no evidence of foam loss since the last configuration change after STS-7, the baseline approach for return to flight was to develop sufficient certification data to accept the minimal debris risk of the existing design. However, a portion of the LH2 PAL ramp spans the high-risk LH2

flange closeout. The forward 10 feet of the 38-foot-long LH2 PAL ramp was removed to access the underlying intertank/LH2 tank flange closeout and then replaced using an improved manual spray application process.

Changes were also implemented on the intertank thrust panels to increase venting to reduce foam loss from “popcorning” and additional changes to the aft longeron were made to reduce likelihood of foam cracks and ice balls.

The improved processes developed for the manual application of foam on the ET were used in limited areas of the External Tanks slated for STS-114 and STS-121 because those tanks had been completed prior to the *Columbia* accident. The use of these improved processes will be expanded on future tanks depending on how far through the manufacturing process those tanks had progressed prior to the introduction of the processes.

Since the Phase 2 and Phase 3 efforts are not directly related to STS-114, they are not covered here. Details of these efforts may be found in the NASA Implementation Plan.

Improved non-destructive inspection capabilities will provide greater knowledge of the condition of the External Tank foam in critical areas and the integrity of the Orbiter RCC prior to launch. Although an improvement, these capabilities use the best available technology to provide a view of what is beneath the surface, but will not allow NASA to verify the precise condition of foam. NASA has elected to accept the risk associated with the limitations of the available non-destructive inspection capabilities.

NASA intended to use a “lead tank/trail tank” approach to support the return to flight activities, with the trail tank (ET-121, intended for STS-121) or a launch-on-need rescue mission) not shipping until after the final Design Certification Review (DCR). Because the final DCR was rescheduled after the required ship date for the trail ET, the Space Shuttle Program reassessed the risk of shipping the trail ET after the DCR versus the risk of shipping prior to DCR to protect the capability for a rescue mission (STS-300). Since the ET DCR Pre-Board on February 23-25, 2005 did not disclose any issues that would prevent shipping the trail tank, the program decided the approach with the least total risk was to ship the trail ET on March 5, prior to the first ET DCR Board on March 8, 2005.

NASA acknowledges that the elimination of all critical debris is not attainable, and has analyzed and formally accepted the remaining risk as a condition for the return-to-flight. Additional information on this risk analysis can be found in Section 3.3 (R3.3-2).

3.1.4 RTF TG Assessment

For two days beginning on September 30, 2003, several members attended a series of informal one-on-one meetings with members of the ET Project at the Michoud Assembly Facility. Numerous fact-finding activities were held at a variety of locations throughout 2004. Subsequently, the RTF TG attended the External Tank DCR Pre-Board on February 24-25, 2005 and the ET Program DCR on March 8-9, 2005. The Task Group also attended the second ET DCR on June 20, 2005 that addressed the addition of the feedline bellows heater.

To their credit, the External Tank DCRs were accomplished in a traditional manner, including formal data packages, screening of discrepancies, pre-boards, and formal boards. The two most significant issues for the DCR Board in March 2005 were pertaining to the verification of “use as-is” foam insulation on ET-120 (for STS-114) and ET-121 (for STS-121), and the limited amount of data from formal certification testing. The approach taken for the use as-is foam was to “verify by similarity” using data from the dissection of ET-94 (the thermal protection system on ET-94 was carefully examined by removing parts of it during the accident investigation). The ET Project documented all exceptions to the verification process

in a new document, NSTS 60555, *Verification Limitations for the External Tank Thermal Protection System*, instead of processing individual waivers.

As observed during the fact-finding, the ET Project conducted an extensive effort to understand the root causes of foam and ice debris generation, and this has resulted in new knowledge about foam and ice and what causes them to be shed from the tank during ascent. The ET Project determined that the most likely cause of debris generation was the “adhesive/cohesive” failure mode and used this as their basis of acceptance based on observed subsurface void size. Other failure modes, including “knit line failure” and “surface/kissing debonds” in acreage areas, were not addressed through design or process modifications. These additional failure modes offer a potential for the production of debris, although flight history has indicated that this debris production has not been previously observed. The processes for manual application of foam insulation have been changed to include greater process control and quality inspection. The Task Group notes that investigations into ice formation came very late during the return-to-flight effort due to the amount of time spent evaluating foam.

The ET Project implemented an aggressive program to eliminate critical foam and ice debris and met the initial debris-allowable requirements allocated to them by the Space Shuttle Program. Even so, the debris-allowable requirements provided to the ET Project did not match what was later determined to be the impact tolerance of the Orbiter. Thus, in spite of a great deal of excellent work on the part of the Agency and its contractors, the External Tank can still shed debris that could potentially result in critical damage to the Orbiter. It should be noted that the potential to liberate critical debris has been significantly reduced.

In the final analysis, the Task Group believes that the ET Project worked diligently and successfully met the requirements they were provided; unfortunately, those requirements were later determined to be inadequate. Updated requirements have been delayed mainly because the development of debris models and transport analysis has been hampered by a lack of rigor in both development and testing. However, as discussed in Section 3.3 (R3.3-2), the Space Shuttle Program has developed an accepted-risk rationale for the return to flight which was approved by program and agency leadership.

The RTF TG assessment of NASA’s actions was completed at the June 27, 2005 meeting. The intent of CAIB Recommendation 3.2-1 has not been met.

3.1.5 RTF TG Observation

Although the Space Shuttle Program has performed an extensive effort to reduce debris for return to flight, there still is the potential – although reduced – for foam and ice to cause critical damage to the Orbiter.

The Task Group believes that the Space Shuttle Program should continue their program to eliminate critical debris by aggressively working off the limitations documented in NSTS 60555, *Verification Limitations for the External Tank Thermal Protection System*.

The Task Group also notes that the processes for manual application of foam insulation on the ET have changed to include greater process control and quality inspection. These processes are costly, but the Task Group feels that these processes should be maintained over time.

3.1.6 RTF TG Minority Opinion

The ET Project and Space Shuttle Program have initiated an aggressive program to eliminate ET debris and, within the exceptions and limitations as documented in NSTS 60555, *Verification Limitations for the External Tank Thermal Protection System*, and the Technical Panel believes that NASA met the intent of CAIB recommendation 3.2-1.

3.2 CAIB Recommendation 3.3-1 – Reinforced Carbon-Carbon Non-Destructive Inspection

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.

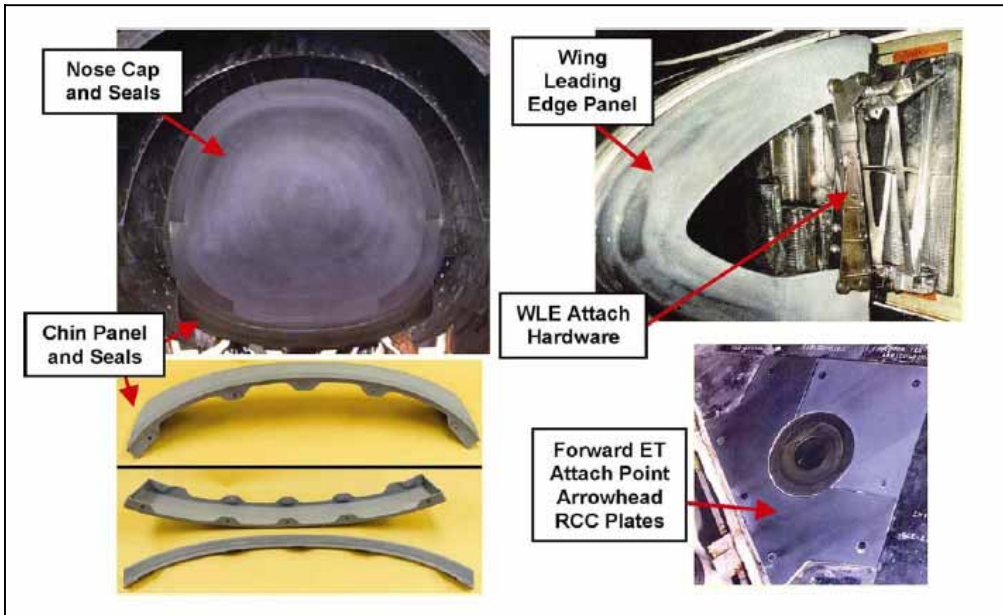
3.2.1 RTF TG Interpretation

Rebaseline the reinforced carbon-carbon components by recycling through the original inspection process, and also using advanced technology as appropriate.

3.2.2 Background

The *Columbia* accident clearly demonstrated that the Orbiter Thermal Protection System, including the reinforced carbon-carbon (RCC) panels and acreage tiles, was vulnerable to impact damage from the existing debris environment. As a result, the Columbia Accident Investigation Board (CAIB) issued recommendations to eliminate debris (R3.2-1), determine the structural integrity of the RCC (R3.3-1), harden the Orbiter (R3.3-2) against impacts, and to develop on-orbit repair capabilities (R6.4-1)

An advanced composite called reinforced carbon-carbon (RCC) is used on the Orbiter wing leading edge, nosecap, chin panel, and forward ET attach point. RCC is a graphite-impregnated rayon fabric laminate, further impregnated with phenolic resin and layered, one ply at a time, in a unique mold for each part, then cured, rough-trimmed, drilled, and inspected. The part is then packed in calcined coke and fired in a furnace to convert it to carbon and is made denser by three cycles of furfuryl alcohol vacuum impregnation and firing.



To mitigate oxidation, the outer layers of the carbon substrate are converted into a 0.02-to-0.04-inch-thick layer of silicon carbide in a chamber filled with argon at temperatures up to 3,000 degrees Fahrenheit. As the silicon carbide cools, “craze cracks” form because the thermal expansion rates of the silicon carbide and the carbon substrate differ. The part is then repeatedly vacuum-impregnated with tetraethyl orthosilicate to fill the pores in the substrate, and the craze cracks are filled with a sealant.

The development of RCC by Ling-Temco-Vought (now Lockheed Martin Missiles and Fire Control) was key to meeting the wing leading edge requirements for the Orbiter Thermal Protection System. Each wing leading edge consists of 22 RCC panels, numbered from 1 to 22 moving outward on the wing (the nomenclature is “5-left” or “5-right” to differentiate, for example, the two number 5 panels). Because the shape of the wing changes from inboard to outboard, each panel is unique.

The rate of oxidation is the most important variable in determining the mission life of RCC components. Oxidation of the carbon substrate results when oxygen penetrates the microscopic pores or fissures of the silicon carbide protective coating. The subsequent loss of mass due to oxidation reduces the load the structure can carry and is the basis for establishing a mission life limit. The oxidation rate is a function of temperature, pressure, time, and the type of heating. Repeated exposure to the Orbiter’s normal flight environment degrades the protective coating and accelerates the loss of mass. Currently, the mass loss of flown RCC components cannot be directly measured. Instead, mass loss is predicted analytically using a methodology based on rates experimentally derived from simulated entry environments. This approach then uses derived entry temperature-time profiles of various portions of RCC components to estimate the actual entry mass loss.

The accident board determined that the on-vehicle inspection techniques in use at the time of the *Columbia* accident were inadequate to assess the structural integrity of the RCC components and attachment hardware. There were two aspects to the problem: (1) how NASA assessed the structural integrity of RCC components and attach hardware throughout their service life, and (2) how NASA verified that the flight-to-flight RCC mass loss caused by aging did not exceed established criteria. Structural integrity was thought to be ensured by wide design margins, and at the time, comprehensive non-destructive inspection was conducted only when the component was manufactured. Mass loss was monitored through a destructive test program that periodically sacrificed flown RCC panels to verify that the actual material properties of the panels were within the predictions of the mission life model.

3.2.3 NASA Implementation

After the *Columbia* accident, the Space Shuttle Program conducted an initial assessment of commercially-available equipment capable of verifying the structural integrity of RCC hardware while it is on the vehicle. A technical interchange meeting held in May 2003 included experts from across the country. A variety of non-destructive inspection technologies with potential for near-term operational deployment were presented to the Program Requirements Control Board (PRCB) in January 2004: (1) flash thermography, (2) ultrasound (wet and dry), (3) advanced eddy current, (4) shearography, and (5) radiography.

Thermography, contact ultrasonics, eddy current, and radiography were selected as the most promising techniques that could be developed in less than 12 months to be used for on-vehicle inspection. The PRCB approved the budget for the development of these techniques. Ultimately, contact ultrasonics was deemed less promising than the other techniques and its development was discontinued. The remaining techniques will continue to be developed and fielded at the Kennedy Space Center. The data they produce will complement and enhance the protection against abnormal flight and processing damage offered by current inspections.

The normal RCC post-flight inspection requirements now consist of visual, tactile, and infrared thermography on the installed (i.e., *in-situ*) RCC components (wing leading edge panels, nose cap, and chin panel). Contingency inspections (eddy current, ultrasonic, radiography) will be performed if there are any suspicions of impact damage to the RCC by virtue of instrumentation, photographic, thermography, or visual post-flight inspection.

RCC structural integrity and mass loss estimates were validated by off-vehicle non-destructive inspection of RCC components and destructive testing of flown wing leading edge

panels. All wing leading edge panels, seals, nosecones, and chin panels were removed from *Discovery*, *Atlantis*, and *Endeavour* and returned to the Lockheed Martin facility in Dallas, Texas, for comprehensive non-destructive inspection. Inspections included a mix of ultrasonic, X-ray, and eddy current techniques. In addition, NASA has introduced off-vehicle flash thermography for all wing leading edge panels and accessible nosecone and chin panel surfaces; any questionable components are subjected to a CAT scan. This data will be used to support development of future *in-situ* non-destructive inspection techniques.

In addition, 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 values used for design and projected mission life.

The RCC Problem Resolution Team was also given approval for a plan to evaluate attach hardware through non-destructive inspection and destructive testing. Detailed hardware non-destructive 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.



Jim Landy, a specialist with United Space Alliance, examines a wing leading edge carbon-carbon panel using flash thermography. A relatively new procedure at KSC, thermography uses high intensity light to heat areas of the panels. The panels are then immediately scanned with an infrared camera. As the panels cool, any internal flaws are revealed.

3.2.4 RTF TG Assessment

Members of the RTF TG conducted fact-finding at the Kennedy Space Center on September 24, 2003. NASA submitted a closure package on April 7, 2004, and sufficient progress had been made for the Task Group to conditionally close this assessment at the April 16, 2004, public meeting. There were four conditions on the closure: an updated version of the Operations and Maintenance Requirements and Specifications Document, File 3, Volume 9, to include the inspection of the RCC panels, the closure of all Material Review and Problem Reports from the *Discovery* and *Atlantis* RCC non-destructive inspections, the receipt of PRCB Directive S064002 closing the NASA review of non-destructive inspection techniques, and the closure of the remaining RTG TG requests for information regarding impact test data.

As of December 2004, the RTF TG had received two of the items required for closure; the PRCB Directive and the RCC impact test data. The Operations and Maintenance Requirements and Specifications Document updated for inspection of RCC panels and closure packages for all MR/PRs from detailed RCC non-destructive inspection were delivered on February 2, 2005.

One other item of concern to the Task Group, an anomaly discovered in the noscap from *Endeavour*, was satisfactorily explained by NASA. The damage occurred during a sealant refurbishment process; other RCC had previously been subjected to the same process without incident. It was concluded that the noscap had a latent manufacturing flaw and was not cause for concern about any of the RCC on *Discovery*.

The RTF TG assessment of NASA's actions was completed at the February 17, 2005 teleconference meeting. The intent of CAIB Recommendation 3.3-1 has been met.

3.2.5 RTF TG Observation

The Task Group stresses that these inspections only verified the RCC against its original "as-built" manufacturing specifications and did not materially change the RCC or its impact resistance; this recommendation did not call for any change to the material. The original manufacturing specifications for RCC never envisioned the need for repair, nor were they written with the knowledge of the actual debris environment. This makes the elimination of debris shedding (R3.2-1) and Orbiter hardening (R3.3-2) all the more important. The Task Group also strongly endorses the continuation of non-destructive inspections of the RCC for the remainder of the Space Shuttle Program, the documentation of flight-to-flight inspections in the OMRSD, and the documentation of non-destructive inspection standards for RCC.



Billy Witt, a midbody shop mechanic with United Space Alliance, checks a part used for installation of a reinforced carbon-carbon panel to the leading edge of the wing of an Orbiter. Note the insulation between the RCC panel and the wing spar.

3.3 CAIB Recommendation 3.3-2 – Orbiter Hardening

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.

3.3.1 RTF TG Interpretation

Develop a detailed plan for an Orbiter hardening program including testing and modeling to determine the impact resistance of the Thermal Protection System. For the first Orbiter returning to flight, the actual impact resistance of installed material and the effect of likely debris strikes should be known. Implement hardware changes as defined in the hardening program.

3.3.2 Background

The *Columbia* accident clearly demonstrated that the Orbiter Thermal Protection System, including the reinforced carbon-carbon (RCC) panels and acreage tiles, was vulnerable to impact damage from the existing debris environment. As a result, the Columbia Accident Investigation Board (CAIB) issued recommendations to eliminate debris (R3.2-1), determine the structural integrity of the RCC (R3.3-1), harden the Orbiter (R3.3-2) against impacts, and to develop on-orbit repair capabilities (R6.4-1).

The development of RCC by Ling-Temco-Vought (now Lockheed Martin Missiles and Fire Control) was key to meeting the wing leading edge requirements for the Orbiter Thermal Protection System. Each wing leading edge consists of 22 RCC panels, numbered from 1 to 22 moving outward on the wing (the nomenclature is "5-left" or "5-right" to differentiate, for example, the two number 5 panels). Because the shape of the wing changes from inboard to outboard, each panel is unique.

It had always been known that the impact resistance of the acreage tiles that cover the majority of the Orbiter was limited, but flight experience indicated the tiles could tolerate some damage. The reinforced carbon-carbon used on the nose and wing leading edges was thought to have better impact resistance and damage tolerance. The *Columbia* accident and subsequent testing revealed that the impact tolerances for both RCC and acreage tiles were lower than believed. In addition, careful examination of flight data revealed that the debris environment was somewhat worse than had been thought, with both foam and ice from the External Tank frequently impacting the Orbiter during ascent.

3.3.3 NASA Implementation

NASA selected 17 hardening options to be implemented in three phases. Based primarily on maturity and schedule, four projects were identified as Phase I options for implementation before return to flight: front spar "sneak flow" protection for the most vulnerable and critical RCC panels 5 through 13; main landing gear corner void elimination; forward Reaction Control System carrier panel redesign to eliminate bonded studs; and installing thicker outer thermal panes in side windows 1 and 6.

NASA also selected two Phase II options for implementation after return to flight: "sneak flow" front spar protection for the remaining RCC panels 1 through 4 and 14 through 22, and the main landing gear door perimeter tile material change. Both of these Phase II projects are in the final design phase and will be executed during Orbiter Major Modification periods or during extended between-mission flows.

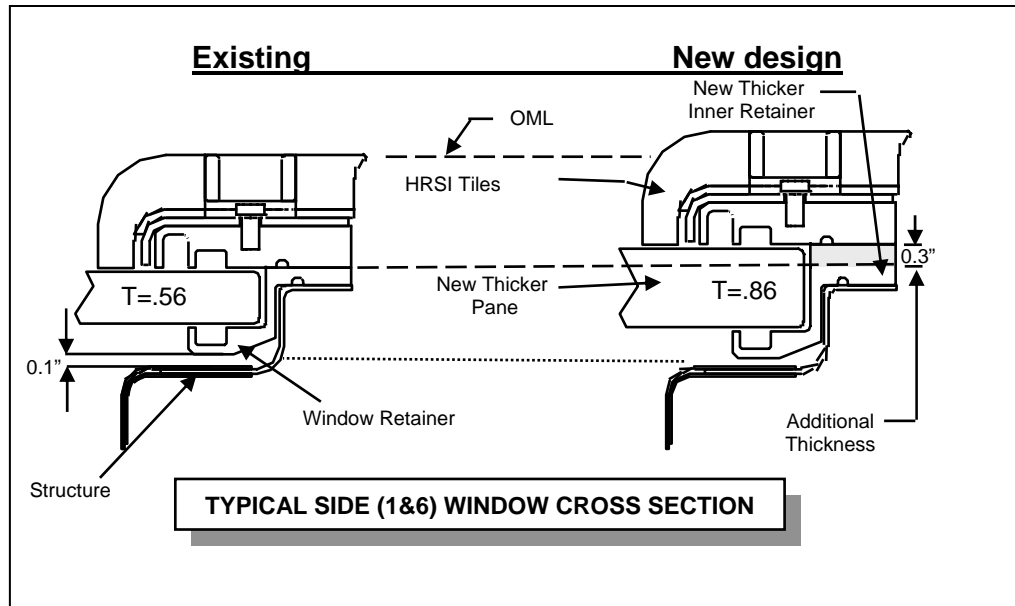
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Since the Phase II and Phase III efforts are not directly related to the return to flight of STS-114, they are not covered in any more detail in this report. Further details of these efforts may be found in the *NASA Implementation Plan*.

The 17 projects examined for Orbiter hardening, along with the associated phase for each and its status when this assessment was made.

Family	Redesign Proposal	Phase	Status
WLESS	"Sneak Flow" Front Spar Protection (RCC #5 - 13)	I	Installed/final cert approval pending
	"Sneak Flow" Front Spar Protection (RCC #1 - 4, 4 - 22)	II	Final cert approval pending
	Lower Access Panel Redesign/BRI 18 Tile Implementation	III	BRI-18 tile continues to be in qual & cert
	Insulator Redesign	III	On hold for higher priority arc-jet testing
	Robust RCC	III	Schedule and cost of implementing this option is not in synch with Agency's vision to retire Shuttle in 2010
Landing Gear and ET Door Thermal Barriers	Main Landing Gear Door Corner Void	I	Installed/final cert approval pending
	Main Landing Gear Door Perimeter Tile Material Change	II	In Final Design phase
	Nose Landing Gear Door Thermal Barrier Material Change	III	In Assessment/lower priority to RTF
	External Tank Door Thermal Barrier Redesign	III	In Assessment/lower priority to RTF
Vehicle Carrier Panels - Bonded Stud Elimination	Forward RCS Carrier Panel Redesign - Bonded Stud Elimination	I	Installed/ final cert approval pending
Side Windows	Thicken Windows #1 and #6	I	Windows installed on OV-103 and OV-104/final cert approval pending
Tougher Lower Surface Tiles	Tougher Periphery (BRI 18) Tiles around MLGD, NLGD, ETD, Window Frames, Elevation Leading Edge and Wing Trailing Edge.	III	Qual & Cert in work. BRI 18 tile has been authorized for installation on all three Orbiters
	Tougher Acreage (BRI 8) Tiles and Ballistics SIP on Lower Surface.	III	Qual & Cert in work
Instrumentation	TPS Instrumentation	III	On-hold until post RTF
Elevon Cove	Elevon Leading Edge Carrier Panel Redesign	III	In Assessment/lower priority to RTF
Tougher Upper Surface Tiles	Tougher Upper Surface Tiles.	III	Development complete/ authorization pending for qual & cert
Vertical Tail	Vertical Tail AFSI High Emissance Coating	III	This option will be eliminated since it only increases the Orbiter's capability in the event of an abort during ascent. Trajectory can be designed to minimize vertical tail temperature.

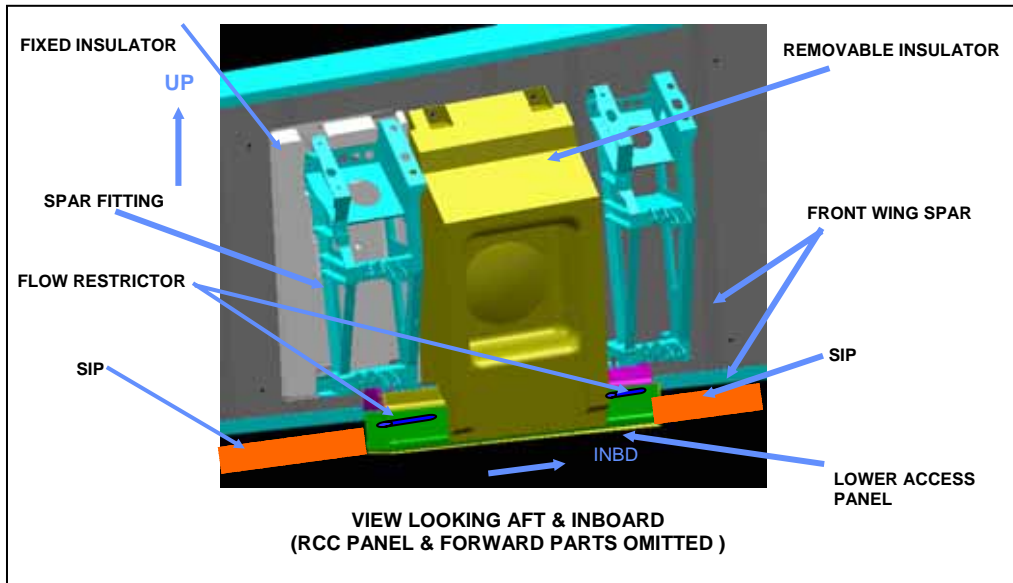
The new outer thermal panes installed in windows 1 and 6 are 0.30-inch thicker than the original panes. This necessitated changing the Thermal Protection System tiles surrounding the windows.



3.3.3.1 *Impact and Damage Tolerance*

Using both test and analysis, the Orbiter Damage Impact Assessment Team determined the impact and damage tolerance of tile, RCC, and the Orbiter windows to External Tank foam, ice, and ablator debris. Impact tolerance is the ability of the Orbiter Thermal Protection System materials to withstand impacts before damage occurs. Damage tolerance is defined as the level of damage from a debris strike that can be tolerated while still safely completing the mission, especially entry.

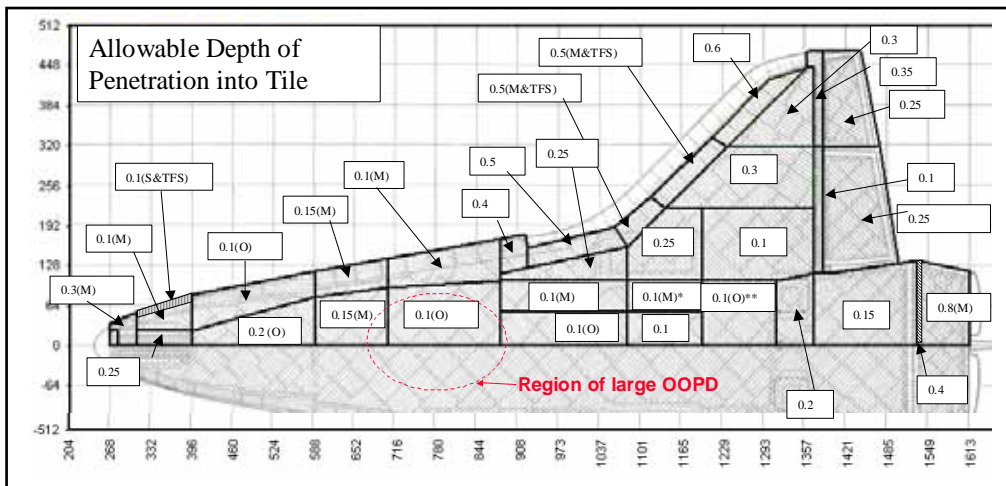
Preliminary impact tolerance data was used as the basis for the ET Project's work to certify the ET for foam debris generation. Subsequent test and analysis confirmed that the worst-on-worst damage tolerance of the tile and RCC was less than the ET certification limit.



Flow restrictors and additional insulation were added behind wing leading edge RCC panels 5 through 13; the other panels will receive similar modifications after the return to flight.

3.3.3.2 Tile Impact and Damage Tolerance

Tests to determine TPS tile impact tolerance – using foam, ice, and ablator projectiles – have been completed at several field centers and other test facilities using both acreage and special configuration tiles, and both new and aged tiles. These tests indicated that, although tile is not very resistant to impact, it tolerates entry heating well even with damage. Overall, testing shows tile to be tolerant to moderate levels of impact damage; tile damage tolerance depends on tile thickness among other factors, which varies by location. As a result, certain areas of reduced thickness, such as those tiles adjacent to the main landing gear doors, are more susceptible to critical damage. Based on tests and on flight history, NASA developed and certified zone and cavity definitions for tile with similar structural and thermal characteristics to determine the depth of allowable damage penetration into the tile before critical damage occurs and repair is necessary. These zones take into account aerodynamic heating, impact angle, and tile thickness, but assume rectangular damage where the length and width dimensions are a function of depth.



Since the heating loads vary across the Orbiter, the amount of damage that can be tolerated also varies. This chart shows the allowable depth of penetration into areas of acreage tiles that has been certified as safely tolerable. The red outline shows the region of large out of plane deflection (OOPD).

In addition, analysis of the Space Shuttle’s flight history indicated that tile damage fell into three impact classes: (1) numerous, shallow impacts primarily on the forward chine and fuselage; (2) fewer, deeper impacts primarily on the lower surface; and (3) umbilical area impacts. The majority of historical damage fell into the first category, and was likely caused by foam popcorning rather than large foam divots; increased ET intertank venting is expected to reduce popcorning masses in the ET foam. The second category of damage, with fewer deeper impacts, was most likely the result of ice from the ET bellows and brackets and ET foam divots; this category of damage is the most likely to require repair. Finally, the umbilical area had a mixture of both small and large impacts from a unique subset of sources including ET umbilical ice, baggies, Kapton tape, and ET fire detection paper. Debris transport analysis suggests that most of the impacts came from “local” sources rather than from the forward ET. As a result, NASA expects little change to the damage in the umbilical area.

3.3.3.3 RCC Impact and Damage Tolerance

Impact and damage tolerance testing on the RCC was performed at several NASA field centers and other test facilities, using both RCC “coupons” (small samples of material) and full-scale RCC panels. It was found that RCC is impact tolerant but not damage tolerant, since even minor cracks or coating loss can be critical and prevent safe entry. Structural and thermal testing of damaged RCC samples established how much damage can be tolerated and still allow a safe return for the crew and vehicle. Test-verified models established impact tolerance thresholds for foam and ice against tile and RCC. These impact tolerance thresholds are the levels at which detectable damage begins to occur.

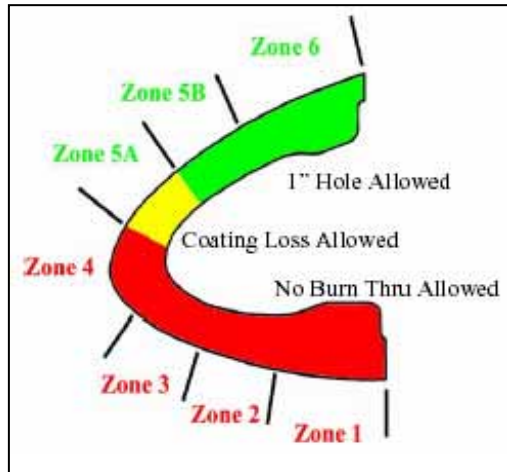
Arc-jet testing showed that the RCC cannot tolerate any significant loss of coating from the front surface in areas that experience full heating on entry. This is of concern because impacts can create subsurface delamination of the RCC that is undetectable through imaging scans.

Testing indicates that loss of front-side coating in areas that are hot enough to oxidize and/or promote full heating of the damaged substrate can cause unacceptable erosion damage in the delaminated areas. However, for subsurface delamination to be a concern there needs to be front-side damage, thus eliminating the concern of “hidden” damage. Further testing and modeling have shown that, although the hottest areas on the wing leading edge (the bottom and apex surfaces) cannot tolerate any significant coating loss, other cooler areas (such as the top surface of the wing leading edge) can tolerate some amount of

coating loss and subsurface delamination. Testing and model development work has produced a map of the damage tolerance capabilities of the wing leading edge RCC depending on panel and location (top, apex, or bottom surface).

Testing is also complete on window impact from debris, including butcher paper, ablator material, foam, Tyvek®, aluminum oxide, and small/fast ogive foam. NASA’s debris transport analysis suggests that very small ogive foam has the potential to impact the Orbiter windows, but impact tolerance tests indicate that the windows can withstand these impacts without sustaining critical damage. Testing also indicated that butcher paper – used to cover the forward reaction control system thrusters at the launch pad – caused unacceptable damage to the windows. As a result, NASA replaced butcher paper covers with Tyvek covers (similar to what large FedEx® envelopes are made of) that will not cause critical damage.

Each RCC panel was split into seven zones, and the level of damage that could be tolerated was evaluated for each zone. The zones on the bottom of the panel and the apex cannot tolerate any substantial damage due to the thermal environment these areas are subjected to during entry.



3.3.3.4 Orbiter Hardening

NASA has completed implementation of the four Phase I Orbiter hardening tasks. Beyond the return to flight, NASA will continue to pursue Phase II and III hardening options and will implement those that are feasible at the earliest possible opportunity.

3.3.3.5 Risk Assessment

NASA identified, categorized, and assessed all known potential debris sources in order to assess the risk to the vehicle of debris. Most debris sources could be determined to be no threat to the Orbiter either because the debris was liberated before it gained enough velocity and kinetic energy to damage the Orbiter, was too small to be of concern (0.0002 lbm or less), or the transport analysis showed there was no path to take the debris from the source to any Orbiter structure. This left only a handful of debris sources of concern to be scrutinized and assessed for the potential to liberate debris that could cause critical damage to the Orbiter.

The program's "worst-on-worst" analysis of three of the remaining debris sources – acreage foam from the LH2 tank, LO2 tank and the intertank – showed they would not shed foam that could cause more damage than the Orbiter could safely enter with.

A Monte Carlo probabilistic analysis was done for five foam areas (LO2/intertank ice/frost ramps, LO2 tank to intertank flange, LH2 tank to intertank flange, LO2 PAL ramp, and bipod closeout) and four ice locations (mid and aft feedline bellows, and forward and mid feedline brackets). There were two independent approaches for the Monte Carlo analysis: one for foam debris, which used physics-based models for foam liberation, and another for ice debris, which had to rely on engineered distributions based on a very limited set of test data for ice liberation. It is the Agency's opinion that there is a great deal of conservatism in both approaches, but NASA has not been able to drive out the conservatisms from the models, mostly due to modeling limitations, a lack of time to generate ice-specific damage maps for tile, and limited test data not matching flight data. Each of the resulting probabilities for critical damage to RCC due to foam or ice liberation is less than 1 in 10,000; for tile, the probabilities range from 1 in 100 to 1 in 10,000. The four highest probabilities for critical damage to tile are for ice from the mid feedline bellows and second feedline bracket locations, and foam from the LO2 ice/frost ramps and the LO2 tank to intertank flange.

NASA determined that the residual risk to several of the remaining areas was enveloped by the probabilistic assessments: the LH2 ice/frost ramp foam residual risk was enveloped by the LO2/intertank ice/frost ramps, the LH2 PAL ramp by the LO2 PAL ramp, and the three aft-most feedline bracket locations by the forward and mid feedline brackets. The potential for ice on the forward feedline bellows location was greatly reduced by the addition of a heater in that area, and the remaining ice that could form in that location will be controlled by launch commit criteria, documented in NSTS 08303, *Ice/Debris Inspection Criteria*.

One debris source, ice around the umbilical doors, could not be shown by any means other than flight history to be an acceptable risk. NASA's rationale for accepting this risk was that there is no transport mechanism to RCC or the windows and flight history showed that while there is a moderate amount of damage on most flights in this area, none has been severe.

3.3.4 **RTF TG Assessment**

members of the RTF TG conducted the first fact-finding trip for this recommendation on October 28-30, 2003, a trip to Southwest Research Institute (SwRI) to witness a foam "shoot" against an RCC wing leading edge panel. Additional fact-finding during 2004 included numerous Debris Summits, and the Task Group attended the Orbiter Design Certification Review on February 7-11, 2005. Members of the Task Group also attended a series of System

Design Certification Reviews and Design Verification Reviews for Debris from February through June, 2005, culminating in the (final) Debris DVR Board on June 24, 2005. Members also attended the Delta System DCR on June 23, 2005.

This recommendation had two primary parts, Orbiter hardening and determining the impact resistance and the effect of likely debris strikes on the Orbiter TPS. Out of the Agency's effort in the area of Orbiter hardening, a hardware program was initiated that provided some minor improvements that supported return to flight. The STS-114 improvements include thicker thermal panes for side windows 1 and 6, limited "sneak flow" front spar protection, main landing gear door corner void elimination, and modifications to the forward RCS carrier panel; additional items will be incorporated on later flights. A long-term program to provide robust RCC was dropped due to the decision to retire the Space Shuttle by 2010.

The other part of this recommendation was a program to characterize the effects of debris strikes on the Orbiter Thermal Protection System. NASA embarked on a major effort toward that end. A program to determine the impact resistance of the TPS was performed and supported by a significant level of testing and analysis with independent peer reviews. Results from early testing and analysis were used to define ET debris allowable and Space Shuttle inspection criteria. As the testing and analysis effort matured, these early results were found to overestimate the impact and damage tolerances of the Orbiter TPS and a risk acceptance rationale had to be developed by the Space Shuttle Program.

An extensive effort was made to model the effects of debris impacts and validate them against the available test data. These models will be used to assess damage sustained during flight. The foam assessments are reasonably well understood; however the Space Shuttle Program is struggling with understanding the effects of ice debris and had not finalized this effort when the Task Group's assessment was completed. The NASA Engineering and Safety Center (NESC) stated at the June 24, 2005 Debris Verification Review Board, "Based on the available test data and analysis results, the NESC has concluded that the feedline brackets, bellows, and ET umbilical ice debris environment is not sufficiently characterized or understood to assign the level of risk. To establish the flight rationale for STS-114, additional work is required to develop adequate controls for ice."

The Orbiter is still vulnerable to the debris environment created by the External Tank. The Space Shuttle Program has acknowledged the possibility of critical debris damage and has accepted the remaining risk.

The RTF TG concluded at the June 27, 2005, meeting that NASA did not meet the intent of CAIB Recommendation 3.3-2, in spite of tremendous effort by NASA and its contractors. Two reasons were cited: the present lack of a long-term approach to RCC hardening – an early long-term plan for Orbiter hardening was abandoned after the National Policy decision to retire the Space Shuttle fleet no later than 2010 – and the amount of remaining non-standard open work on ice debris, risk analysis, and verification of damage models.

3.3.5 RTF TG Observation

Although the Space Shuttle Program has performed an extensive effort to reduce debris for return to flight, there still is the potential – although reduced – for foam and ice to cause critical damage to the Orbiter; NASA will need to continue to reassess their accepted risk rationale flight-to-flight.

3.3.6 RTF TG Minority Opinion

The Technical Panel believes that, with the completion of the documented open work, the Space Shuttle Program met the intent of the CAIB recommendation.

3.4 CAIB Recommendation 3.4-1 – Ground-Based Imagery

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.

3.4.1 RTF TG Interpretation

The *Columbia* post-accident investigation was hampered by the lack of high-resolution imagery of the vehicle during ascent. The existing ground-based camera locations were a legacy of earlier programs and their locations were not optimized for the ascent trajectory of recent Space Shuttle missions. Further, due to equipment problems and a lack of clear requirements to maintain this equipment, imagery was not always usable, as was the case for the STS-107 launch. The Columbia Accident Investigation Board (CAIB) was concerned about the need to have an adequate number of appropriately-located cameras that operated properly to provide photographic coverage from more than one view of the Space Shuttle from launch through separation of the Solid Rocket Boosters.

3.4.2 Background

Of the dozen ground-based camera sites used to obtain images of the Space Shuttle during ascent, five were normally used to track the vehicle from liftoff until it was out of view. Due to view angles and atmospheric limitations, two sites did not capture the STS-107 debris event. Of the remaining three sites positioned to “see” at least a portion of the event, none provided a clear view of the actual debris impact to the wing. The first site lost track of *Columbia* during ascent, the second site was out of focus – because of an improperly maintained lens – and the third site captured only a view of the upper side of the left wing. The CAIB noted that camera problems had also hindered the *Challenger* investigation 17 years earlier. Although the initial debris strike during STS-107 was discovered via image analysis, NASA’s post-launch evaluation of the impact was hampered by the lack of multiple views from high-resolution, high-speed ground cameras. The CAIB also found the quality of existing imagery – of all recent Space Shuttle launches – to be less than ideal.



Long-range tracking camera (E-207) photo of STS-95 in October 1998 at SRB separation shows the resolution limitations of ground tracking.

Multiple views of launch and ascent from varying angles provide important data for engineering assessment and the detection of unexpected anomalies. Images may also be used to assess debris shedding in flight, including the origin, size, and trajectory of the objects. Because of resolution limitations, however, this imagery is not intended to pinpoint the exact nature of potential damage to the vehicle. Finally, in keeping with the CAIB view that the Space Shuttle should be treated as a developmental flight vehicle, imagery assets should be used to measure its performance for the duration of the Space Shuttle Program.

3.4.3 NASA Implementation

A suite of improved ground-based and airborne cameras has been deployed to provide the ability to capture three complementary views of the Space Shuttle during launch and ascent. This will allow a better understanding of the ascent environment and the performance of the vehicle within this environment. Ground imagery may also allow the detection of ascent debris and identify potential damage locations on the Orbiter for detailed on-orbit assessment. There are four types of imagery that NASA will acquire from the ground cameras:

- Primary imagery – film images used as the primary analysis tools for launch and ascent operations;
- Fall-back imagery – back-up imagery (primarily 35mm and 16mm motion pictures) for use when the primary imagery is unavailable;
- Quick-look imagery – digital imagery (primarily HDTV and SDTV) provided to the image analysis groups shortly after launch for initial assessments; and
- Tracker imagery – imagery used to guide the camera tracking mounts and for analysis when needed.

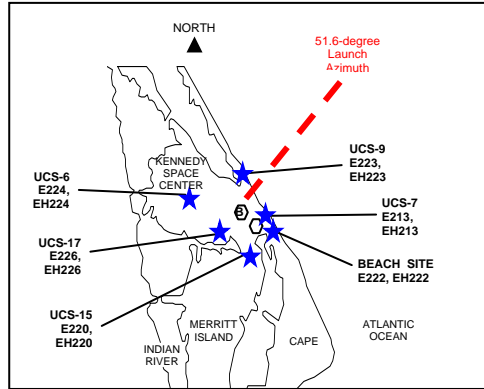
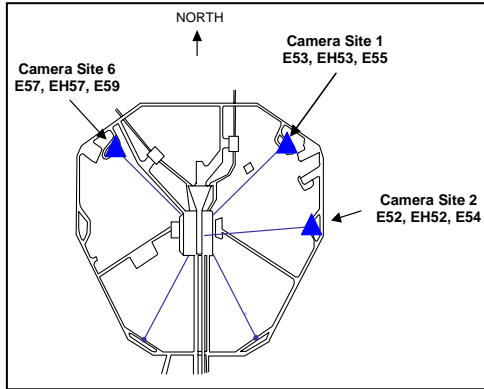
Although ground cameras provide important engineering data for the Space Shuttle, they are not intended to provide the resolution to identify the exact nature of any potential damage to the Orbiter. No real-time repair decisions will be directly based on this ascent imagery data. Instead, any anomalies identified using ground-based imagery assessments will be used to optimize the on-orbit inspections described in Section 3.13 (Recommendation 6.4-1).

For the STS-114 launch, NASA has three short-range camera sites around the perimeter of the launch pad, seven medium-range camera sites, and nine long-range camera sites. Each of the medium- and long-range tracking cameras is independent, ensuring that no single failure can disable all of the trackers. Further, each of the film cameras on the trackers has a backup (fall-back), so no single camera failure eliminates a particular view. The locations of the new cameras and trackers are optimized for 51.6-degree-inclination launches since most, if not all, future Space Shuttle launches will be to the International Space Station. Previously, camera coverage was limited by a generic configuration originally designed for the full range of possible launch inclinations and ascent tracks envisioned early in the Space Shuttle program.

Space Shuttle ascent imagery acquisition is divided into three overlapping periods with different requirements that provide for steps in lens focal lengths to maintain image resolution as the vehicle moves away from each camera location:

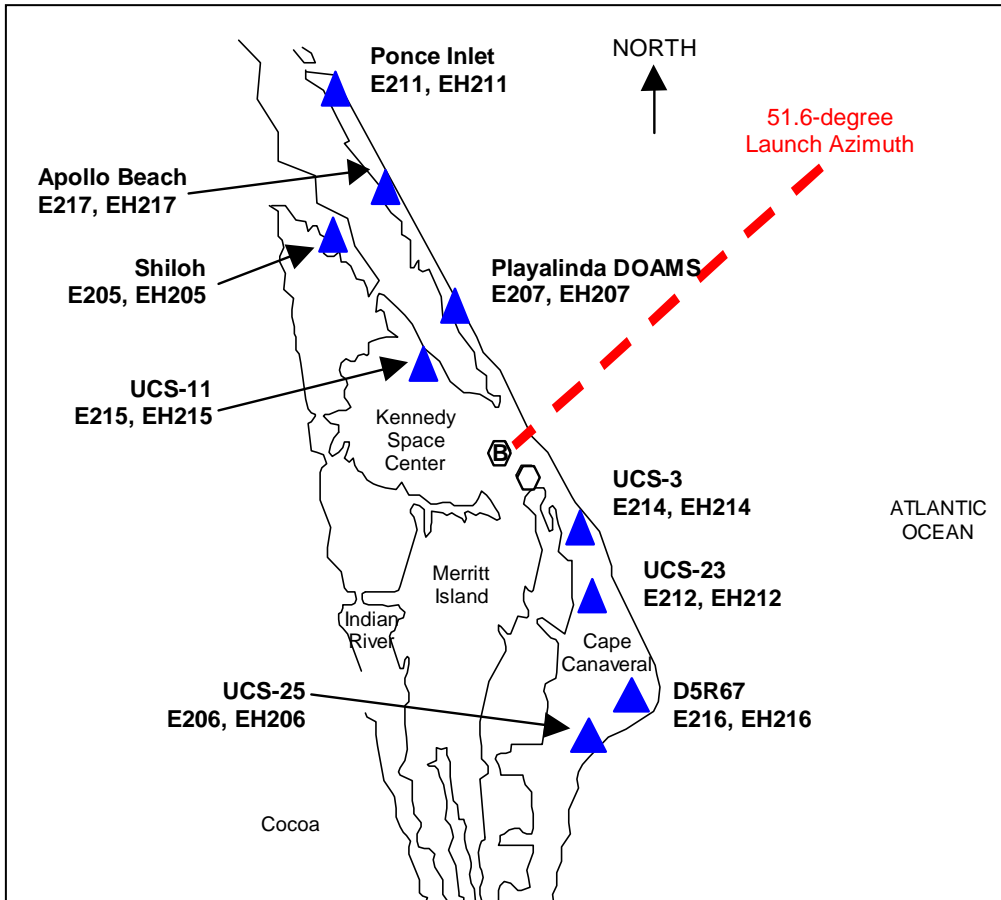
- Short-range images (T-10 seconds through T+57 seconds);
- Medium-range images (T-7 seconds through T+100 seconds); and
- Long-range trackers (T-7 seconds or vehicle acquisition through T+165 seconds).

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Left: Three short-range tracking sites are located around each LC-39 launch pad.

Right: Medium-range tracking sites available for the Space Shuttle Program



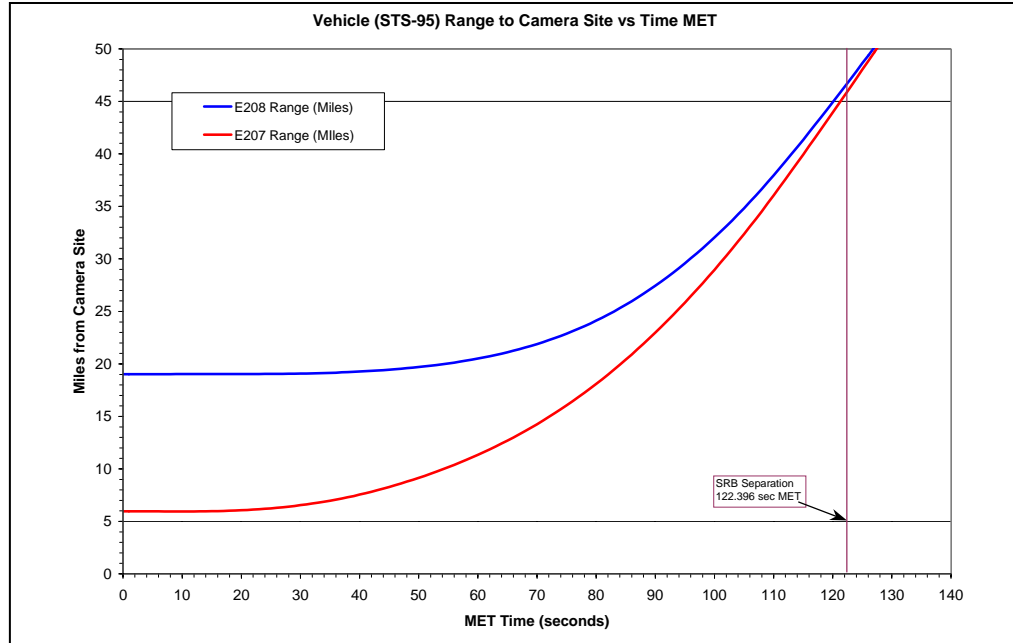
Long-range tracking sites located around the Kennedy Space Center.

Currently, this capability nominally consists of 7.8-, 32-, 150-, and 400-inch focal length lenses. The theoretical limits of the optics under ideal conditions – assuming the object is not obscured by the exhaust plume and depending on orientation of vehicle to plane of film – provide:

- Resolution to 1-inch size and 0.5-foot linear accuracy of debris source and impact location from lift-off to L+30 seconds along any expected azimuth;
- Resolution to 3-inch size and 1-foot linear accuracy of debris source and impact location from L+30 seconds to L+60 seconds along any expected azimuth;

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- Resolution to 8-inch size and 3-foot linear accuracy of debris source and impact location from L+60 seconds to L+90 seconds along any expected azimuth;
- Resolution to 15-inch size and 5-foot linear accuracy of debris source and impact location from L+90 seconds to SRB separation (approximately 122 miles from the launch site) along any expected azimuth.



Range to target versus time for the two DOAMS long-range tracking sites. Only the Playalinda Beach DOAMS (E207) will be used for STS-114. The Cocoa Beach DOAMS (E208) is being moved to a new location at Patrick AFB and will not be used to support the first two launches.

These images will be acquired by a combination of mobile Kineto Tracking Mount (KTM), Intermediate Focal Length Optical Tracking (IFLOT), and Advanced Transportable Optical Tracking System (ATOTS) platforms that can be optimally positioned for each flight based on launch azimuth and other considerations. In addition, the fixed-position Distant Object Attitude Measurement System (DOAMS) site at Playalinda Beach, operated by the Air Force 45th Space Wing, will continue to be used for long-range observation. The “fuzzy” optics in the Cocoa Beach DOAMS noted by the CAIB has been corrected by the vendor, but the Air Force is in the process of moving this fixed installation several miles south to Patrick AFB to avoid high-rise condominiums that have been erected adjacent to the existing site, severely restricting the view of the launch areas; it will not be used to support STS-114.



A DOAMS long-range tracking site.



NASA is continuing to ship 14 existing trackers at the Kennedy Space Center to the White Sands Missile Range for refurbishment. This work will be ongoing until refurbishment of all trackers is complete in 2008. Trackers and optics will be borrowed from other ranges to support launches until the refurbished assets are redelivered. NASA is also procuring

additional cameras to provide increased redundancy and refurbishing existing cameras. NASA has ordered 35 fixed camera lenses to supplement the existing inventory and has purchased two KTM Digital Signal Processing Amplifiers to improve KTM reliability and performance. In addition, NASA has received 24 HDTV cameras to improve quick-look capabilities. Funding has also been approved to procure additional spare mounts, as well as to fund studies on additional capability in the areas of infrared and ultraviolet imagery, adaptive optics, and high-speed digital video.



Long-range trackers at the Kennedy Space Center.

During, and subsequent to, the accident investigation, there was considerable interest in whether video technology had evolved far enough to replace film as the primary imagery for Space Shuttle launches. The NASA Intercenter Photo Working Group (IPWG) compared the image resolution of several different types of image gathering systems and determined their theoretical maximum performance.

Based on this analysis, NASA decided that the primary product for imagery analysis will continue to be film due to its resolution capability and dynamic range. The long-range tracking sites use 70mm cameras to track the Solid Rocket Boosters after separation and to provide “big sky” coverage of any major mishaps. All short- and medium-range tracking sites use 35mm cameras for optimum “resolution-on-media” as their primary imagery. Close-in fixed camera sites use high-speed (400 frames per second) 16mm film motion picture cameras. All short-, medium-, and long-range tracking sites use HDTV for a quick-look capability and as a backup to the primary 35mm or 70mm cameras. SDTV was not chosen as an analysis tool, but it will continue to be used by camera site operators for wide field-of-view target locating. SVHS demonstrated a poor resolution that made it unacceptable as an analysis tool, although budget constraints have forced its use in some limited instances.

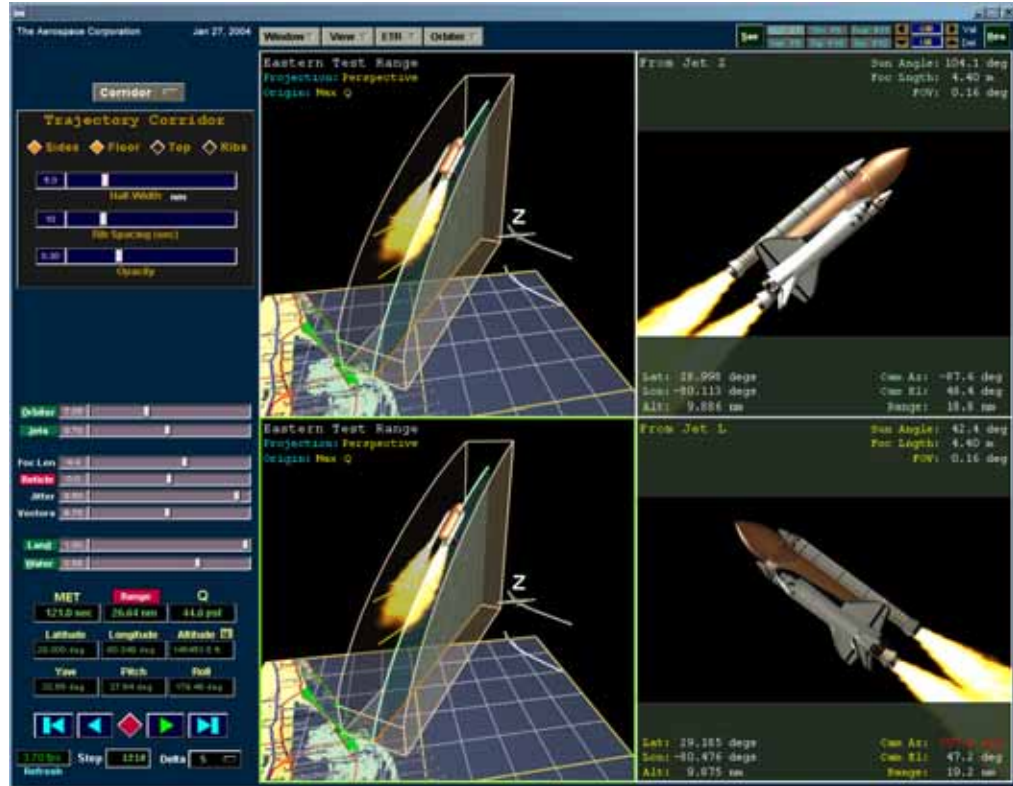
In addition to ground cameras, NASA approved the development and implementation of an aircraft-based imaging system known as the WB-57 Ascent Video Experiment (WAVE) to provide both ascent and entry imagery.



The two NASA high-altitude WB-57F aircraft have been modified with cameras to photograph the Space Shuttle during ascent.

The use of an airborne imaging system will provide opportunities to better observe the vehicle during days of heavier cloud cover and in areas obscured from ground cameras by the exhaust plume following launch. The use of two aircraft flying at an altitude of 60,000 feet will allow a wide range of coverage with each airplane providing imagery over a 400-mile path. A 32-inch diameter ball turret in the nose of each WB-57F houses an optical bench that contains HDTV and infrared camera systems. The optics consists of a 4.2-meter fixed focal length lens that can be operated in both auto track and manual modes.

Computer model showing the views expected from the WB-57 WAVE aircraft.



The WAVE aircraft will be used on an experimental basis during the first two return-to-flight launches (STS-114 and STS-121). Based on an analysis of the system's performance and quality of the products obtained, NASA will make a decision on whether to continue use of this system on future flights. The Critical Design Review for the WAVE was completed on July 1, 2004 and the ball turrets were installed in early 2005. The HALO II Gulfstream aircraft operated for the Missile Defense Agency is available as a backup airborne tracking asset if needed.

NASA also has assessed using ground based radar for identifying and tracking potential debris sources, and new C-band radar on North Merritt Island will be used on STS-114 to complement information obtained from the camera systems.

In addition, NASA is revising the launch requirements and procedures to support an ability to capture three useful views of the Shuttle during ascent. Initially, NASA will limit launches to daylight hours in order to maximize the ability to capture the most useful ground ascent imagery. Camera and tracker operability and readiness to support launch will be supported by a new set of pre-launch equipment and data system checks. In addition to certification at the Flight Readiness Review, the status of the group imagery assets will be reviewed at the MMT Tanking Meeting (approximately L-11 hours) and within one hour of launch. The readiness of the camera sites will be reported to the Launch Director at T-20 minutes that will provide status to the MMT on the capability to capture three useful views.

3.4.4 RTF TG Assessment

The NASA approach to the CAIB recommendation was to provide an integrated package that tied together all three imagery recommendations (R3.4-1, Ground-Based Imagery; R3.4-2, High-Resolution Images of External Tank; and R3.4-3, High-Resolution Images of Orbiter), and moved the on-orbit inspection capabilities to R6.4-1, Thermal Protection System Inspection and Repair. Ultimately, the Task Group decided to consider R3.4-1 and R3.4-2 as standalone packages, while R3.4-3 and the inspection portion of R6.4-1 were tightly coupled and their final assessments were considered together.

NASA has made progress toward achieving an integrated suite of ground cameras to capture high-resolution images of the Space Shuttle during ascent and has significantly increased the number and capability of ground camera sites. Also, the Agency has arranged for airborne assets (WAVE) to mitigate the effects of cloud cover and improve higher altitude resolution, at least for the first two launches. From a hardware asset perspective, these changes should ensure an adequate capability to meet the CAIB intent for three useful views.

The RTF TG believes that NASA is aware of the limitations inherent in its approach to ground imagery. Although the ground cameras provide important engineering data for the Space Shuttle during launch and ascent, they do not have the resolution necessary to definitively establish that the Orbiter has not suffered ascent debris damage. NASA has stated that they will not make any real-time repair decisions directly based on ground imagery data. Rather, the comprehensive assessments of Orbiter impacts and damage necessary to ensure the safety of the vehicle and crew will be conducted using on-orbit inspection and analysis, but focused by ground and ascent imagery.

Numerous fact-finding activities were conducted by the Task Group beginning in October 2003 through the closure meeting on November 30, 2004. This final meeting led the Task Group to conditionally close their assessment during the December 2004 plenary. The conditions included the closure of two requests for information, completing the required safety documentation, complete systems testing and verification, training of the operators on the new cameras and mounts, incorporating the Ground Imagery Project Summary into the overall Program Design Certification Review, completing the Critical Design Review action closeout, and completing the standard readiness review process. In addition, prior to return to flight, NASA stated that they would add a redundant power source to the system that operates the launch pad cameras.

During a further fact-finding meeting held in January 2005, NASA, together with the 45th Space Wing, specified the participants and organizations responsible for certifying mission capability during the launch countdown, the reporting mechanisms to launch management for imagery asset status, and how the usability of imagery assets will be evaluated when weather obstructions exist. The relationship between the Kennedy Space Center and the 45th Space Wing on the Eastern Range was clarified, and the Task Group was satisfied that the correct agreements were in place between these organizations to ensure status reflecting the operability and readiness of assets during the launch countdown.

Despite the significant progress made in installing and refurbishing the cameras around the launch complex, not all of work was able to be completed prior to return-to-flight. NASA informed the Task Group that after the launch of STS-114 they will continue to refurbish the cameras and mounts per their existing plan, fly the WAVE aircraft in support of STS-121, and review the data from WAVE to determine if the concept should continue for future launches. Eventually, all borrowed assets will be replaced with planned procurements.

It should be noted that there is a difference between the NASA implementation and the wording of the CAIB recommendation in how the requirements for the camera systems are documented. The CAIB wrote that “*operational status of these assets should be included in*

the Launch Commit Criteria for future launches.” NASA decided that including these systems in the Launch Commit Criteria document was inappropriate, and instead included the information in the Program Requirements Document with status reporting in the launch countdown procedure. While the Program Requirements Document includes launch support requirements, it, alone, does not require the MMT to consider the ground imagery assets as part of the launch decision process. A small part of the camera power system was included in the Launch Commit Criteria since its status affects multiple camera sites. The Task Group, while expressing some concerns, believed this approach was satisfactory.

The RTF TG assessment of NASA’s actions was completed at the June 8, 2005, meeting. The intent of CAIB Recommendation 3.4-1 has been met.

3.4.5 RTF TG Observations

While the actions NASA has taken, for the most part, meet the letter of the CAIB recommendation, the RTF TG has the following observations:

1. The approach to documenting the requirements provides launch management awareness of the status of these assets. However, it does not require a Launch Commit Criteria waiver to proceed with less than three useful views.
2. The Shuttle should be treated as a developmental vehicle with its performance measured for all missions. Imagery has proven to be a useful tool for assessing the performance of the Space Shuttle during launch and ascent. Since a substantial amount of funds were expended to improve the capability to gather this imagery, NASA should retain these assets for the duration of the Space Shuttle Program.

Workers prepare a WB-57F aircraft at Patrick AFB, Florida. The WAVE provides both ascent and entry imagery and enables better observation of the Space Shuttle on days of heavier cloud cover and areas obscured from ground cameras by the launch exhaust plume. WAVE comprises a 32-inch ball turret system mounted on the nose that houses an optical bench, providing installation of both HDTV and infrared cameras. The system can be operated in both auto track and manual modes.



3.5 CAIB Recommendation 3.4-2 – High-Resolution Images of External Tank

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

3.5.1 RTF TG Interpretation

Engineering quality imagery of the External Tank (ET) taken from *Columbia* after separation would have been of great significance in the accident investigation. High-resolution imagery of the External Tank should be obtained on each flight and downlinked to the ground as soon as practical after achieving orbit.

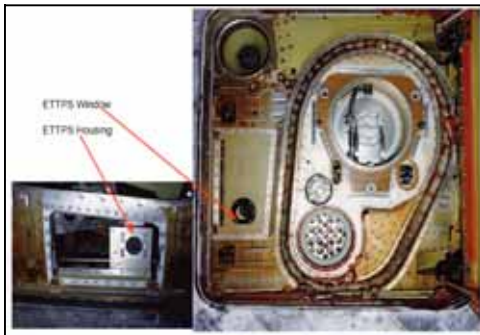
3.5.2 Background

At the time of the *Columbia* accident, the Orbiters had film cameras installed in each umbilical well to provide images of the External Tank following separation. Additionally, after ET separation, the Orbiter would be maneuvered into a position that permitted a crewmember to take images of the ET using a hand-held digital camera. Following landing, the film from the umbilical well cameras was removed and developed for evaluation; the hand-held digital camera was downloaded at the same time. These cameras provided images of sufficient quality and resolution to permit an engineering evaluation of the ET thermal protection system, including foam shedding. Unfortunately, none of these cameras were recovered from the *Columbia* debris. Therefore, no images of the External Tank were available to provide engineering insight into foam shedding and debris during the mission.

3.5.3 NASA Implementation

To provide the capability to downlink images of the External Tank after separation, NASA replaced the 35mm film camera in the Orbiter right umbilical well with a high-resolution digital still camera. This 6 megapixel camera uses a 35mm lens and provides a field-of-view only slightly smaller than the original film camera. Because of technical complexity and limited bandwidth during ascent, the images will not be downlinked in real-time. Rather, once the Orbiter is on-orbit and the laptop network is set up in the crew cabin, the images will be copied from the camera to a laptop computer then downlinked to the Mission Control Center using the existing Orbiter Ku-band link.

In addition, the flight crew will continue to use a handheld digital still camera with a telephoto lens. The Orbiter pitch-over maneuver has been modified to occur sooner after ET separation to provide better images from the crew camera. The location where the camera is stowed in the crew cabin has also been changed to allow easier access by the crew. The data from the digital camera will be transferred to a laptop in the crew cabin and downlinked to Mission Control in the same manner as the umbilical well camera images.



A digital still camera is being carried in the right umbilical well to photograph the External Tank as it separates.

These images will be used for quick-look analysis by the Mission Management Team to determine if any ET anomalies exist that require additional on-orbit inspections (see Section 3.13, Recommendation 6.4-1).

A feasibility study for the Orbiter umbilical well camera was initiated in September 2003 and the design reviews were completed in April 2004. Modifications to *Discovery* to support STS-114 began in May 2004, and the camera system function testing was completed in March 2005. The umbilical well camera was installed during Orbiter processing in early April 2005.

3.5.4 RTF TG Assessment

The NASA approach to the CAIB recommendation was to provide an integrated package that tied together all three imagery recommendations (R3.4-1, Ground-Based Imagery; R3.4-2, High-Resolution Images of External Tank; and 3.4-3, High-Resolution Images of Orbiter), and moved the on-orbit inspection capabilities to R6.4-1, Thermal Protection System Inspection and Repair. Ultimately, the Task Group decided to consider R3.4-1 and R3.4-2 as standalone packages, while R3.4-3 and the inspection portion of R6.4-1 were tightly coupled and their final assessments were considered together.

Fact finding was conducted by the Task Group on February 20, 2004, November 15, 2004, and during the closure meeting on November 30, 2004. This final meeting led the Task Group to close their assessment during the December 2004 plenary.

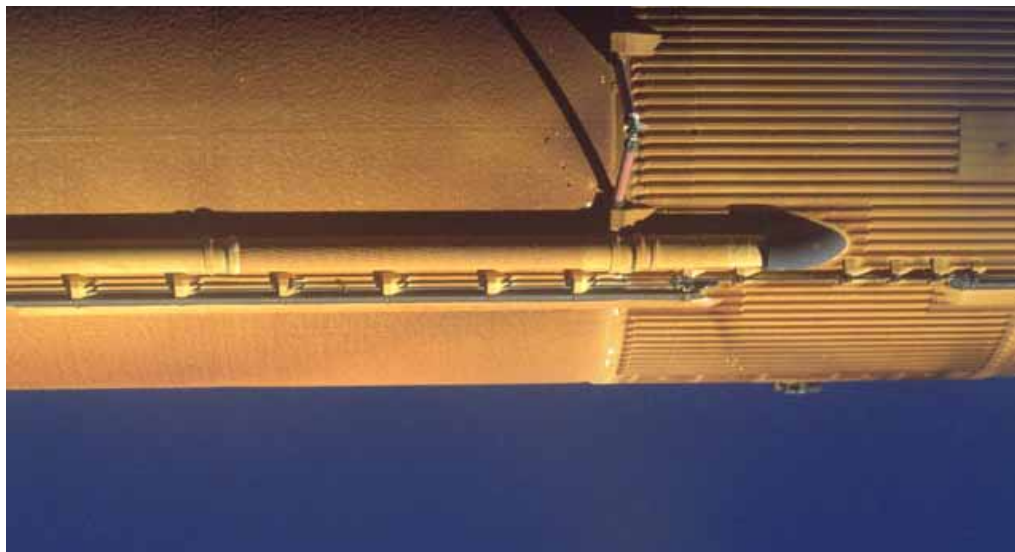
Appropriate cameras have been selected to obtain quality views of the External Tank using both the handheld camera from the Orbiter and the digital umbilical well camera. The STS-114 crew has been trained in use of the hardware, and the digital umbilical well camera was installed before OV-103 rolled-out to the launch pad.

The RTF TG assessment of NASA's actions was completed at the December 16, 2004, meeting. The intent of CAIB Recommendation 3.4-2 has been met.

3.5.5 RTF TG Observation

It is our observation that the addition of the digital umbilical well camera to the overall suite of imagery planned for STS-114 was vital. This camera requires good lighting in order to provide high-quality images during separation. The views obtained from this imagery are, in our opinion, critical for evaluating the state of the modified External Tank.

Image of the STS-106 External Tank taken by the umbilical well film camera after separation. NASA has replaced this camera with a digital camera so that images can be downlinked to the ground during the mission. The bipod ramps that used to be used on the ET are clearly visible.



3.6 CAIB Recommendation 3.4-3 – High-Resolution Images of Orbiter

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.

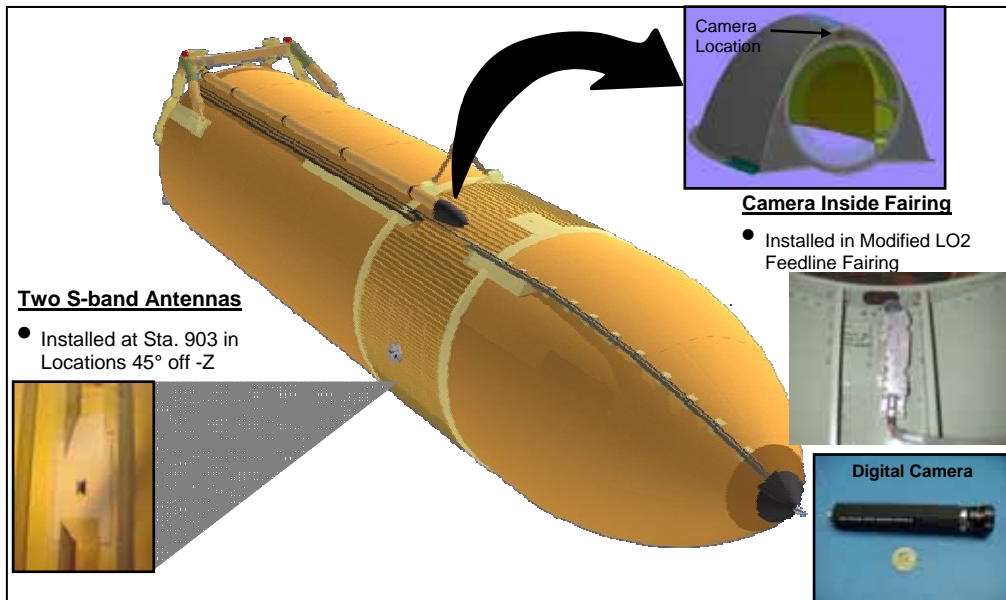
3.6.1 RTF TG Interpretation

The Columbia Accident Investigation Board (CAIB) investigation was hampered by the lack of high-resolution images of the launch ascent trajectory. The only images available were from ground cameras that were inadequate in number, placement, and resolution to permit a meaningful and timely engineering analysis of the External Tank (ET) thermal protection system performance.

3.6.2 Background

The damage to the left wing of *Columbia* occurred shortly after liftoff, but went undetected for the entire mission. Although there was photographic evidence from ground cameras of a debris impact to the wing, the quality of the imagery hampered a thorough analysis of the debris and its potential damage. There was no on-board imagery of the debris strike.

Many expendable launch vehicles carry cameras pointing toward various parts of the vehicle. Usually, these cameras monitor the separation of solid rocket motors, or provide public relations value only. Such a camera was mounted on the ET during STS-112 as an experiment (the so-called "ET-Cam"). The CAIB believed that this type of camera arrangement could provide valuable engineering data if aimed at areas of interest on the Orbiter, such as the main landing gear doors and wing leading edges.



3.6.3 NASA Implementation

For the first few missions after return to flight, NASA will use primarily on-orbit inspections to meet the requirement to assess the health and status of the Orbiter Thermal Protection System. This is because the on-vehicle ascent imagery suite does not provide complete imagery of the underside of the Orbiter or guarantee detection of all potential impacts to the Orbiter. NASA's detailed implementation of high-resolution images of the Orbiter was

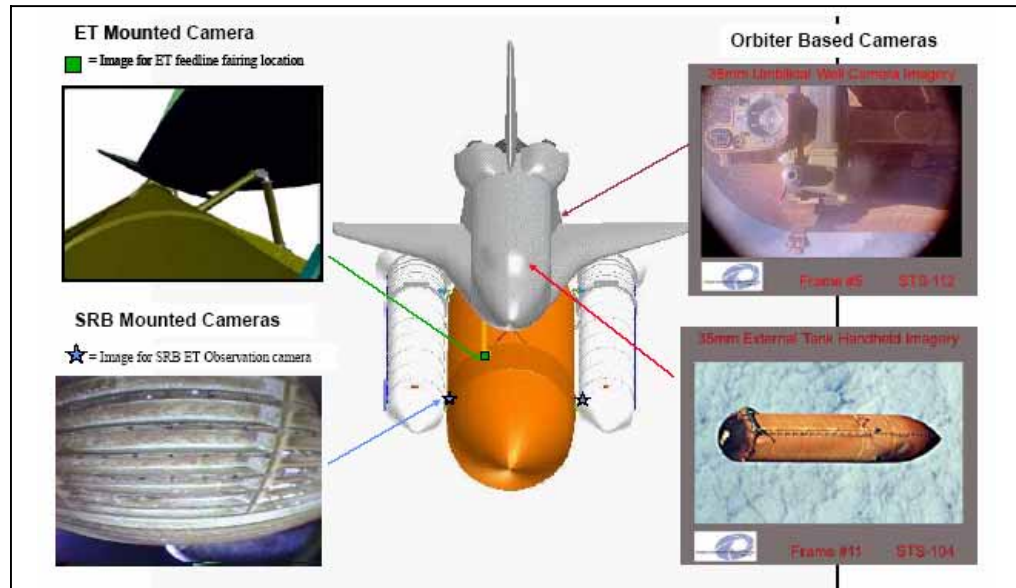
presented with Recommendation 6.4-1. The two primary methods include Orbiter Boom Sensor System (OBSS) and the R-Bar Pitch Maneuver (RPM) imagery; see Section 3.13 (R6.4-1) for a further discussion.

In addition, NASA will have cameras on the External Tank liquid oxygen (LO2) feedline fairing and the forward skirt of each Solid Rocket Booster. The ET LO2 feedline fairing camera will take images of the ET bipod areas and the underside of the Orbiter fuselage and the right wing from liftoff through the first 15 minutes of flight. The new location of the ET camera will reduce the likelihood that its views will be obscured by the booster separation motor plume, a discrepancy observed on STS-112. These images will be transmitted to ground stations in real time.

The SRB forward skirt cameras will take images from 3 seconds to 350 seconds after liftoff. These two cameras will look sideways at the ET intertank. The images from this location will be stored on the Solid Rocket Boosters and will be available after the SRBs are recovered, approximately three days after launch.

Beginning with STS-115 (the third flight), NASA will introduce an additional complement of cameras on the SRBs: aft-looking cameras located on the SRB forward skirt and forward-looking cameras located on the SRB External Tank Attachment Ring. Together, these cameras will provide additional views of the underside of the Orbiter during ascent.

STS-114 and STS-121 will carry cameras in the forward skirt of each Solid Rocket Booster, in the External Tank LO2 feedline fairing, and in the Orbiter umbilical well. In addition, the crew will continue to use hand-held cameras to photograph the ET after separation.



3.6.4 RTF TG Assessment

The NASA approach to the CAIB recommendation was to provide an integrated package that tied together all three imagery recommendations (R3.4-1, Ground-Based Imagery; R3.4-2, High-Resolution Images of External Tank; and 3.4-3, High-Resolution Images of Orbiter), and moved the on-orbit inspection capabilities to R6.4-1, Thermal Protection System Inspection and Repair. Ultimately, the Task Group decided to consider R3.4-1 and R3.4-2 as standalone packages, while R3.4-3 and the inspection portion of R6.4-1 were tightly coupled and their final assessments were considered together.

NASA addressed the Orbiter Boom Sensor System (OBSS) and the R-Bar Pitch Maneuver (RPM) as part of CAIB Recommendation 6.4-1. However, these are the capabilities that provide evidence that this recommendation has been met and are assessed here.



Inside the Orbiter Processing Facility bay 3 at the Kennedy Space Center, *Discovery's* payload bay doors are ready to be closed. Seen in the center (starboard side) and at right are the new Orbiter Boom Sensor System (OBSS) and the Shuttle Remote Manipulator System (SRMS). The black object in the foreground is the Ku-band antenna.

Numerous fact-finding activities were conducted between October 2003 and the closure meeting on November 30, 2004. NASA provided a partial closure package for R3.4-3 concurrently with R3.4-1 and R3.4-2, the other imagery recommendations, and the closure presentation covered all three recommendations. However, since NASA moved their implementation of the OBSS and the R-Bar Pitch Maneuver into R6.4-1, the Task Group did not feel it could close R3.4-3 until the closure package for R6.4-1 was received.

The closure package for R6.4-1 was received on May 26, 2005. Although the Task Group did not feel that the repair portion of the closure package were sufficient to deliberate R6.4-1, the portion of the package concerning inspection was complete and R3.4-3 was deliberated at the June 8, 2005, plenary meeting in Houston.

The closure package showed that the primary tool for imaging the wing leading edge on orbit will be with the Orbiter Boom Sensor System. There are two sensor packages on the OBSS: the laser dynamic range imager (LDRI), which will be used on the lower surface and apex of the wing leading edge, and the laser camera system (LCS), which will be used primarily on the nosecap. The LDRI has demonstrated, under laboratory conditions, the ability to resolve 0.25-inch holes and 0.015-inch cracks, while the LCS has shown the ability to resolve 0.125-inch holes and 0.25-inch coating loss. The Task Group questions whether these resolutions can actually be achieved on orbit, and they do not necessarily correspond to the smallest critical damage the RCC can withstand; nevertheless they are a significant capability.

There are some questions remaining regarding the Orbiter Boom Sensor System, which must be resolved operationally. These include the clearance between the OBSS and the Ku-band antenna in the retracted position, and analysis of LDRI cable clearance with the Orbiter radiator and CMG payload. NASA assures the Task Group that these items will not affect the operation of the OBSS during STS-114.

The primary method for imaging the acreage tiles on the bottom of the Orbiter and the surface insulation on top of the Orbiter will be via photography from the ISS during the R-Bar Pitch Maneuver while the Orbiter is approaching the station to dock. These images provide adequate resolution to initiate a more-focused inspection using the OBSS, if required.

The RTF TG assessment of NASA's actions was completed at the June 8, 2005, meeting.

With the provision that the forward work, described previously, is completed, the Task Group feels that the intent of CAIB Recommendation 3.4-3 has been met.

3.6.5 RTF TG Observation

The Task Group believes that on-vehicle ascent imagery will be a valuable source of engineering, performance, and environment data and will be useful for understanding in-flight anomalies. The new location of the ET camera should reduce the likelihood that the camera will be obscured by the booster separation motor plume. The RTF TG cautions, however, that this on-vehicle ascent imagery suite does not provide complete imagery of the underside of the Orbiter as well as most of the underside tiles.

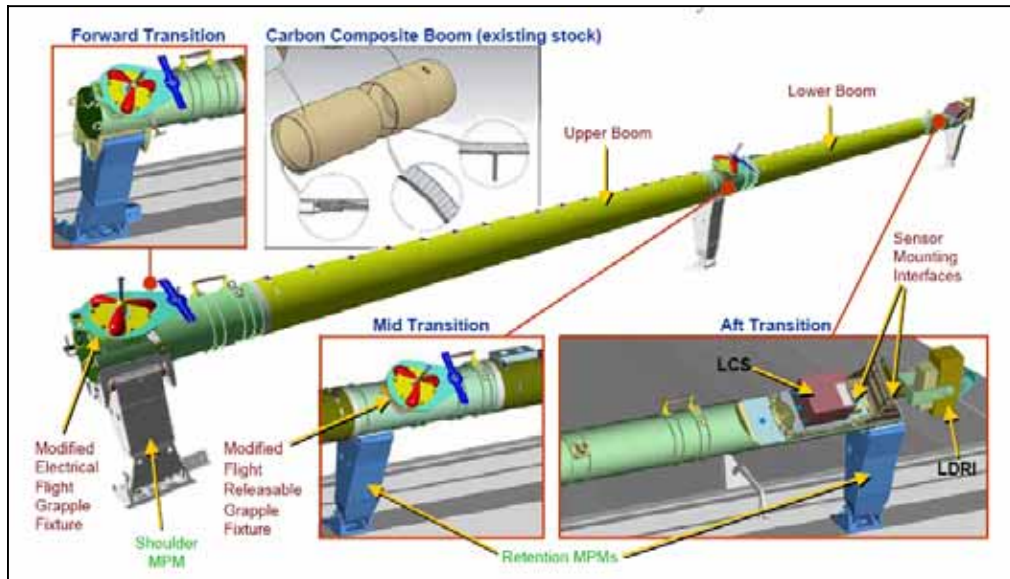
The certified resolution of the OBSS sensor suite does not meet critical damage size criteria.

NASA has committed to retain an on-orbit inspection capability after the OBSS can no longer be flown. The RTF TG strongly endorses that commitment.

The 50-foot long OBSS attaches to the end of the SRMS and provides the capability to inspect all of the RCC on the Orbiter as well as most of the underside tiles.



The OBSS boom is very similar to the standard Remote Manipulator System boom the Orbiter has carried on most of its missions. The RMS attaches to the OBSS and provides power and control to the new boom. Two new imaging systems are located at the end of the OBSS.



3.7 CAIB Recommendation 4.2-1 – Solid Rocket Booster Bolt Catcher

Test and qualify the flight hardware bolt catchers.

3.7.1 RTF TG Interpretation

The meaning of the CAIB recommendation is clear.

3.7.2 Background

A fault tree review conducted for the Columbia Accident Investigation Board (CAIB) uncovered a significant problem with the Solid Rocket Booster (SRB) bolt catchers. Each SRB is connected to the External Tank (ET) by four separation bolts: three at the bottom plus a larger one at the top that weighs approximately 65 pounds. These larger upper (or “forward”) separation bolts (one on each SRB) and their associated bolt catchers on the External Tank were the subject of a great deal of scrutiny by the CAIB.

About two minutes after launch, pyrotechnic charges break each forward separation bolt into two pieces, allowing the spent SRBs to separate from the External Tank. Two “bolt catchers” on the ET each trap the upper half of a fired separation bolt, while the lower half stays attached to the Solid Rocket Booster. As a result, both halves are kept from flying free of the assembly and potentially hitting the Orbiter. Bolt catchers have a domed aluminum cover containing an aluminum honeycomb matrix that absorbs the energy of the fired bolt. The two upper bolt halves and their respective catchers subsequently remain connected to the External Tank, which burns up during reentry, while the lower halves stay with the Solid Rocket Boosters that are recovered from the ocean.

If one of the bolt catchers had failed during STS-107, the resulting debris could have damaged the wing leading edge of *Columbia*. Concerns that the bolt catchers may have failed, causing metal debris to ricochet toward the Orbiter, arose because the configuration of the bolt catchers used on Space Shuttle missions differed in important ways from the design used for the initial qualification tests. Despite the extensive CAIB analyses, the accident board also was not able to determine that the SRB bolt catchers, while an unlikely cause, could be definitively excluded as a potential cause the damage that doomed *Columbia*.

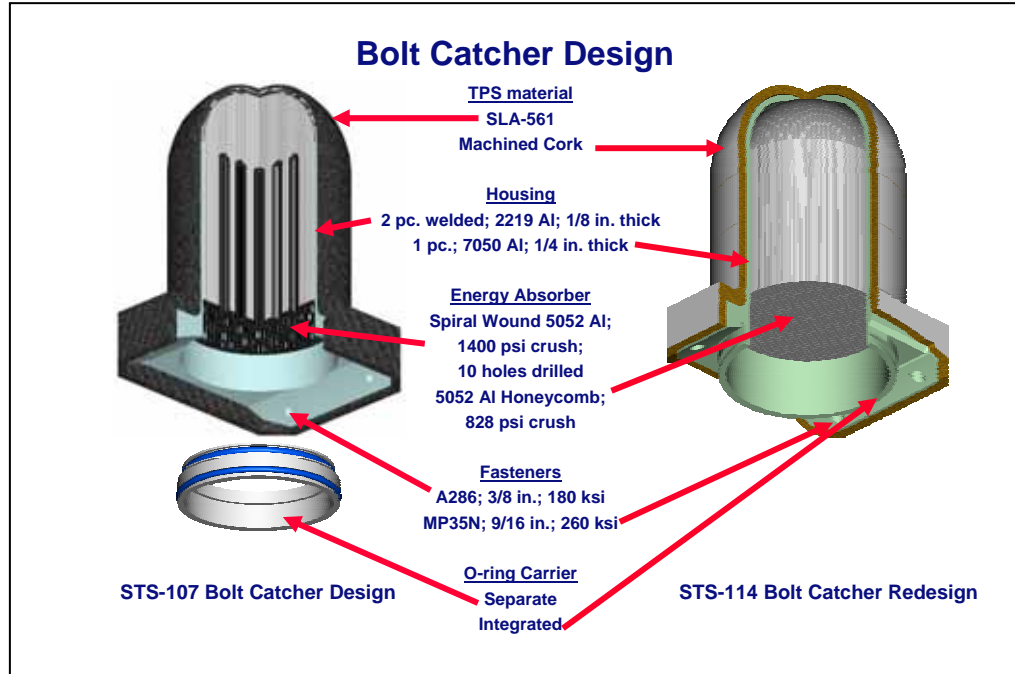
Static and dynamic testing, conducted as a result of the CAIB inquiries, demonstrated that the bolt catchers flown on STS-107 had a factor of safety of 0.956, rather than 1.4 as required by specification. The CAIB and NASA also identified additional reasons to be concerned about the bolt catchers. The bolt catchers did not meet their established requirements; specifically, the thermal protection system for the assembly was not qualified for the separation shock environment; failures of the bolt catcher attach fasteners or inserts could lead to debris; and the ejection effects of the NASA standard initiator (NSI) from its pressure cartridge during bolt firing were not included in the original bolt catcher qualification.

3.7.3 NASA Implementation

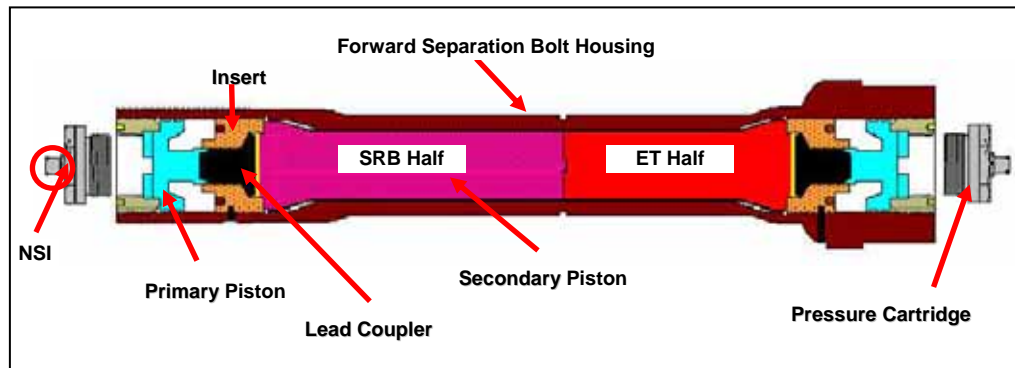
The bolt catcher assembly and related hardware has been redesigned. The bolt catcher housing is now fabricated from a single-piece aluminum forging that removes the weak point at the weld from the original design. The strength of the housing has been increased by doubling the thickness and using a stronger aluminum. Further, NASA has redesigned and resized the bolts and inserts that attach the bolt catcher to the ET, using larger and stronger fasteners. The housing design was enhanced with an integral O-ring carrier design that eliminated a separate carrier and one O-ring. The assembly’s thermal protection system is replaced by machined cork with enhanced adhesion properties to reduce the potential for

debris, and a new honeycomb energy absorber was introduced to reduce the loads. Mandatory government inspection points have been added for the thermal protection system, structure, and energy absorber with 100-percent surveillance of all manufacturing processes during final assembly. This new assembly was qualified by testing as a complete system to demonstrate compliance with NASA factor-of-safety and debris requirements.

The bolt catchers were extensively redesigned after STS-107, and subjected to a full-range of qualification testing.



The forward ET-SRB separation bolt is broken in half when the SRBs are jettisoned. It is the ET half of this bolt that the bolt catchers are intended to capture.



NASA has completed the redesign of the bolt catcher assembly and its associated hardware. Critical Design Reviews were completed for both the bolt catcher and the NSI pressure cartridge in May 2004. Development testing completed to date includes: energy absorber characterization; bolt catcher system drop and firing test; bolt catcher structural tests; bolt catcher attachment fastener prying and bending test; separation bolt velocity determination; NSI pressure cartridge and retention device quick look margin tests; NSI pressure cartridge burst tests; and NSI pin ejection simulations. Thermal protection system qualification testing was completed in August 2004.

Qualification testing of the bolt catcher assembly, to the original specifications, was begun in July 2004. During the final qualification test simulating NSI pin ejection firing, results showed that the actual crush depth was less than the predicted crush depth. (Crush depth is the measurement of the distance the bolt travels into the energy absorber inside the bolt catcher.) The difference between actual and predicted crush depth was determined to be caused by

Polymer Development Laboratories (PDL) foam and the energy absorber counterbore. In order to improve crush depth prediction accuracy, the PDL foam and energy absorber counterbore were eliminated by reducing the length of the energy absorber. Testing shows this reduction in length is acceptable because the longer energy absorber was added before the maximum bolt velocity was established. Subsequent testing proved that the bolts have a lower maximum velocity than the design allows; therefore shortening the energy absorber does not alter the effectiveness of the bolt catcher. However, it does allow for greater predictability of crush depth. Qualification testing was completed in October 2004.



The bolt catchers for ET-120, originally intended for use on STS-114, during their installation at the Kennedy Space Center. The bolt catchers used on ET-121, the tank actually used for STS-114, were identical.

3.7.4 RTF TG Assessment

The RTF TG conducted multiple fact-finding trips in support of the bolt catcher recommendation. The Task Group also supported several design reviews, including the Delta Critical Design Review (CDR) on April 28-30, 2004, and the Design Certification Review on November 22, 2004.

The bolt catcher for the SRB to ET separation bolt has been modified to provide an adequate safety factor, per the original specification. The STS-107 design was a two-piece welded assembly and the new design is based on a one-piece forging. The energy absorber used to attenuate the bolt impact load has been redesigned as well. Additionally, the thermal protection system has been changed from a sprayed-on material to bonded cork. The NASA standard initiator in the pressure cartridge had exhibited an ejection failure mode during several tests which could damage the energy absorber prior to bolt impact. This issue has been addressed by the incorporation of a locking ring assembly to aid in retention of the NSI.

The SRB bolt catcher has successfully completed qualification testing and has demonstrated a minimum structural factor of safety of 1.86. The new assembly was qualified by testing as a complete system to demonstrate compliance with NASA factor-of-safety and debris requirements. Additionally, the NSI retention device has been determined to exhibit a minimum factor of safety of 2.3. The redesigned bolt catcher has successfully completed Level IV DCR.

The RTF TG assessment of NASA's actions was completed at the December 16, 2004 meeting. The intent of CAIB Recommendation 4.2-1 has been met.



Discovery being lifted onto the stack originally intended for use during STS-114. Anomalies with this External Tank forced the eventually switch to the stack planned for use on STS-121.

3.8 CAIB Recommendation 4.2-3 – Two-Person Closeout Inspections

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

3.8.1 RTF TG Interpretation

The Columbia Accident Investigation Board (CAIB) subsequently clarified that this recommendation was intended to apply across the entire Space Shuttle Program for all types of closeouts; although the External Tank (ET) intertank was specifically called out, the recommendation was not intended to be limited to this area. The RTF TG therefore interpreted this recommendation to mean that NASA should review and update all of their process controls to ensure that at least two people observe all final closeout activities in critical areas.

3.8.2 Background

In its report, the CAIB remarked on the Agency's overall success in improving security following September 11, 2001. At that time, NASA embarked upon a comprehensive review of all security procedures in place and all Space Shuttle Program projects and elements cooperated with their host Centers and NASA Headquarters, Office of Security Management and Safeguards, to review NASA and contractor security procedures and implementing a wide array of improvements. This review encompassed the entire scope of security-oriented activities, including hiring procedures, personnel reliability assurance programs, physical site security, specific anti-terrorism measures, and manufacturing and processing procedures.

The CAIB report (pp. 93-94) provides additional detail into the possibility that willful damage contributed to the STS-107 accident. The accident board's investigation determined that this was not a credible potential cause of intertank foam debris.

During this security review, however, the CAIB identified several processes that did not require two people to be present when an area on the flight vehicle was closed-out. Although unlikely, this could allow an individual to sabotage the vehicle without being observed. Equally as important, this was counter to the general policy of "two sets of eyes are better than one" that provides additional technical and safety checks during closeouts.

3.8.3 NASA Implementation

The External Tank Project amended all manufacturing processes and procedures to ensure that at least two employees, and in most cases several more, are present at all manufacturing steps. This includes manual foam applications and all other closeouts, both at Michoud Assembly Facility and the Kennedy Space Center. Furthermore, NASA implemented more-stringent quality assurance requirements and provided additional employee training, certification, and work documentation of inspections and imagery.

In response to additional guidance provided by the RTF TG in April 2004, NASA widened the scope of its corrective measures by issuing additional direction for all major flight hardware and ground processing elements to conduct an audit of their final closeout procedures and protocols. The audit included a review of quality assurance closeout protocols and the protection they offer against willful damage. This audit was completed on April 30, 2004 and the results forwarded to the Task Group shortly afterward.

In the back of the Orbiter Processing Facility bay 3, workers check one of the thermal protection system blanket ground wires to ensure a proper ground between the blanket and the Orbiter Boom Sensor System (OBSS). The installation will conclude TPS closeout prior to installation of the boom in *Discovery*. At least two workers are present for all closeout activities.



3.8.4 RTF TG Assessment

The Task Group conducted several fact-finding activities during early 2004. A closure package was received by the RTF TG in time for this recommendation to be considered at the April 2004 plenary meeting. The Task Group assessed the Agency's implementation of this recommendation and determined that NASA was defining the accident board's intent too narrowly. The Task Group's fact-finding site visits, review of the CAIB report, and correspondence with members of the CAIB, led them to suggest that NASA should widen its perspective to include *all* flight hardware elements, rather than just the External Tank. Nevertheless, sufficient progress had been made for the Task Group to conditionally close their assessment at the April 16, 2004, public meeting.

Accordingly, NASA widened the scope of its corrective effort to conduct a program-wide audit of all final closeouts for major flight hardware elements, both at the manufacturing sites and at the Kennedy Space Center. This audit was completed on April 30, 2004, and all revised requirements were incorporated into the appropriate documentation by January 2005.

The results from this audit were received by the RTF TG on December 8, 2004, and the results presented in the closure package were considered satisfactory. NASA provided data on the documentation that had been updated, also to the Task Group's satisfaction.

The RTF TG assessment of NASA's actions was completed at the December 16, 2004 meeting. The intent of CAIB Recommendation 4.2-3 has been met.

3.9 CAIB Recommendation 4.2-5 – KSC Foreign Object Debris Definition

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

3.9.1 RTF TG Interpretation

During their investigation and interviews with personnel involved with processing the Space Shuttle for flight, the Columbia Accident Investigation Board (CAIB) determined that during January 2001 the Kennedy Space Center (KSC) generated new and non-standard definitions for Foreign Object Debris (FOD) which were fully implemented at KSC in June 2002. The term “processing debris” was applied to debris found during the routine processing of the flight hardware. The term FOD applied only to debris found in flight hardware after final closeout inspections. These definitions were unique to the Space Shuttle Program at the KSC. Because debris of any kind has critical safety implications, these definitions are important. Accordingly, the CAIB wanted the standard, industry-wide definitions reestablished for FOD.

3.9.2 Background

Problems with the Kennedy Space Center and United Space Alliance (USA) Foreign Object Damage Prevention Program, which in the Department of Defense and aviation industry typically falls under the auspices of Quality Assurance, were related to changes made during 2001. In that year, Kennedy Space Center and United Space Alliance redefined the single term “Foreign Object Damage” – an industry-standard term – into two categories: “Processing Debris” and “Foreign Object Debris.”

Processing Debris:

Any material, product, substance, tool or aid generally used during the processing of flight hardware that remains in the work area when not directly in use, or that is left unattended in the work area for any length of time during the processing of tasks, or that is left remaining or forgotten in the work area after the completion of a task or at the end of a work shift. Also any item, material or substance in the work area that should be found and removed as part of standard housekeeping, Hazard Recognition and Inspection Program (HRIP) “walk-downs”, or as part of “Clean As You Go” practices.

Foreign Object Debris:

Processing debris becomes FOD when it poses a potential risk to the Shuttle or any of its components, and only occurs when the debris is found during or subsequent to a final/flight Closeout Inspection, or subsequent to OMI S0007 ET Load SAF/FAC “walk-down.”

These definitions were inconsistent with those of other NASA Centers, the Department of Defense, commercial aviation, and National Aerospace FOD Prevention, Inc., guidelines. Because debris of any kind has critical safety implications, the CAIB believed these definitions were important.

3.9.3 NASA Implementation

The Kennedy Space Center and United Space Alliance have changed work procedures to consider all debris equally important and preventable. Rigorous definitions of FOD that are

the industry standard have been adopted. These new definitions adopted from National Aerospace FOD Prevention, Inc. guidelines and industry standards include Foreign Object Debris, Foreign Object Damage, and Clean-As-You-Go. FOD is redefined as “a substance, debris or article alien to a vehicle or system which would potentially cause damage.”

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 as preventable and with equal importance. Second, it reemphasizes the responsibility and authority for FOD prevention at the operations level. FOD prevention and elimination are stressed and the work force is encouraged to report any and all FOD found by entering the data in the FOD database. This activity is performed with the knowledge that finding and reporting FOD is the goal of the Program and employees will not be penalized for their findings. Third, it elevates the importance of comprehensive independent monitoring by both contractors and the Government.

United Space Alliance 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.



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, post-launch 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.

The implementation of the new program began on July 1, 2004, although many aspects of the plan existed in the previous FOD prevention program in place at KSC. Assessment audits by NASA and United Space Alliance were conducted beginning in October 2004. Corrective Action Plans have been established to address the findings and observations identified during the two audits. Schedules for the verification of the actions taken and for verifying the effectiveness of the corrective actions have been established to ensure the ongoing effectiveness of the FOD prevention program. Continual improvement will be vigorously pursued for the remainder of the life of the Space Shuttle.

3.9.4 RTF TG Assessment

The FOD Program at the Kennedy Space Center was very effective in the past. When the definitions were modified during 2001 to create multiple categories of debris, the workforce was not sufficiently trained to understand the implications. This confusion was expressed to the CAIB members during their interviews with KSC personnel; in response to the CAIB recommendation, KSC reevaluated the entire program. The Task Group concluded fact-

finding during a technical interchange meeting at KSC in May 2004. This complemented previous meetings with KSC quality assurance and United Space Alliance personnel in late 2003 and early 2004.

The Kennedy Space Center and United Space Alliance have changed the definition of “Foreign Object Debris” to be consistent with the recognized and accepted industry standard. Further, they have removed the misleading category of processing debris that caused concern. They have improved the training of the workforce, and obtained buy-in at all levels for both NASA and all contractors. The revised program has implemented several improvements above and beyond the expectations defined in the CAIB recommendation. The FOD database has been made significantly more robust and captures a higher level of reporting detail than existed previously. NASA management has demonstrated their buy-in with participation in “walk-downs” to inspect for FOD.

The RTF TG initial assessment of NASA’s actions was completed at the July 22, 2004, teleconference plenary where the assessment was conditionally closed. After receiving audit results and specified corrective actions from NASA, the assessment was closed at the December 16, 2004, meeting. The intent of CAIB Recommendation 4.2-5 has been met.

3.9.5 RTF TG Observation

It is very important for NASA management to provide positive incentives for the reporting of FOD and to avoid negative sanctions for those who self-report. The Task Group believes management is sufficiently sensitive to this need and will provide the proper positive and negative feedback to the workforce. Metrics defined and tracked by NASA will assure continued compliance with the new improved FOD program.



Discovery during early processing for STS-114. The reinforced carbon-carbon nose cap had been removed and returned to the vendor for testing. Note the open nose landing gear door at the bottom left.



The Crawler-Transporter drives away after delivering *Discovery* on her Mobile Launch Platform to Launch Complex 39B.

3.10 CAIB Recommendation 6.2-1 – Consistency with Resources

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.

3.10.1 RTF TG Interpretation

The Columbia Accident Investigation Board (CAIB) explicitly recognized the legitimate use of schedules to drive a process. They were concerned, however, that the line between “beneficial” schedule pressures and those that become detrimental, cannot be easily defined or measured. In the case of *Columbia*, the CAIB discovered that pressure on the Space Shuttle Program was created by the schedule for construction of the International Space Station. Indeed, the planned February 2004 completion of Node 2 of the International Space Station was being touted as a measure of NASA’s ability to maintain a schedule.

The CAIB further observed that budget constraints inherently intensify the conflicts between schedule and safety. The meaning of the first sentence of the CAIB recommendation is clear: adjust the schedule to fit the available resources.

3.10.2 Background

During the course of the *Columbia* investigation, the CAIB received several unsolicited comments from NASA personnel regarding pressure. Oddly, the pressure was to meet a date more than a year after the launch of STS-107 that seemed etched in stone: February 19, 2004, the scheduled launch of STS-120. This flight was a milestone in the minds of NASA management since it would carry a section of the International Space Station called “Node 2” that would signal “U.S. Core Complete.”

At first glance, the U.S. Core Complete date seemed noteworthy but unrelated to the *Columbia* accident. However, as the investigation continued, it became apparent to the accident board that the political mandates surrounding the International Space Station Program, as well as the Space Shuttle Program management’s responses to them, resulted in pressure to meet an increasingly ambitious launch schedule.

Meeting U.S. Core Complete by February 19, 2004 – a date the CAIB found was promised by NASA management to the White House and Congress – would require launching 10 Space Shuttle missions in less than 16 months. With the focus on retaining political support for the International Space Station Program, little attention was paid to the effects the aggressive Node 2 launch date would have on the Space Shuttle Program. After years of downsizing and budget cuts, this mandate introduced elements of risk, and the high-pressure environments created by NASA Headquarters unquestionably affected *Columbia*, even though it was not flying to the International Space Station.

After considering what they had uncovered during their investigation, the CAIB concluded:

“The agency’s commitment to hold firm to a February 19, 2004, launch date for Node 2 influenced many of decisions in the months leading up to the launch of STS-107, and may well have subtly influenced the way managers handled the STS-112 foam strike and *Columbia*’s as well.

“When a program agrees to spend less money or accelerate a schedule beyond what the engineers and program managers think is reasonable, a small amount of overall

risk is added. These little pieces of risk add up until managers are no longer aware of the total program risk, and are, in fact, gambling. Little by little, NASA was accepting more and more risk in order to stay on schedule.”

3.10.3 NASA Implementation

NASA has strengthened a risk management system that it believes balances technical, schedule, and resource risks to achieve safe and reliable operations. Under this system, safety is ensured by first focusing on the technical risks and taking the time and financial resources necessary to properly resolve them. Once technical risks are reduced to an acceptable level, program managers turn to the management of schedule and resource risks to preserve safety.

Among the activities NASA plans to undertake are more routinely assessing schedule risk, incorporating additional margin into the schedule and manifest to accommodate changes, and revising databases so schedule and risk indicators can be assessed by managers in real-time. KSC and United Space Alliance management use the Equivalent Flow Model (EFM) to plan resources that are consistent with the Space Shuttle flight schedule and available workforce needed to meet the technical requirements. The EFM is a computerized tool that uses a planned manifest and past performance to calculate processing resource requirements. The workforce, a primary input to the EFM tool, comprises fixed resources, supporting core daily operations, and variable resources that fluctuate depending on the manifest. Using past mission timelines and actual hours worked, an “equivalent flow” is developed to establish the required processing hours for a processing flow.

To assess and manage the manifest, NASA has developed a process called the Manifest Assessment System that incorporates all manifest constraints and influences, and allows adequate margin to accommodate a normalized amount of changes. This process entails building in launch margin, cargo and logistics margin, and crew timeline margin while preserving the technical element needed for safe and reliable operations. United Space Alliance is using the Manifest Assessment System to assess the feasibility of proposed technical and manifest changes to determine how changes to facility availability, schedule, or duration of flight production activities affect the overall manifest schedule. This capability enables a more useful way to implement realistic, achievable schedules while successfully balancing technical, schedule, and resource risks to maintain safe and reliable operations.

Policies are also in place to ensure the workforce health at KSC in the face of schedule deadlines. The Maximum Work Time Policy, found in KSC Handbook (KHB) 1710.2, section 3.4 includes daily, weekly, monthly, yearly, and consecutive hours worked limitations. Deviations require senior management approval up to the KSC Center Director and independent of the Space Shuttle Program. KSC work time safeguards ensure that when available resource capacity is approached, the schedule is adjusted to safely accommodate the added work. When possible, launches are planned on Wednesdays or Thursdays to minimize weekend hours and associated costs; repeated launch attempts are scheduled to reduce crew and test team fatigue. Overtime hours and safety hazard data are continually monitored by KSC and Space Shuttle Program management for indications of workforce stress.

3.10.4 RTF TG Assessment

The CAIB explored a number of root causes for the *Columbia* accident; one of these was the desire to maintain a schedule for achieving U.S. Core Complete during construction of the International Space Station. The ISS Program had a long history of cost and schedule overruns and had been the subject of numerous Congressional hearings and independent commissions. NASA was determined to complete construction with as few additional budgetary resources as possible. In this environment, there was a reluctance to expend the resources to investigate obvious problems with the Space Shuttle, among them the shedding of foam from the External Tank (ET). Damage to a Solid Rocket Booster – caused by foam

from the ET – two flights before *Columbia*, prompted a study into the anomaly, but even this was not enough to cause anyone to waiver from the schedule.

Thus CAIB recommended that NASA “Adopt and maintain a Space Shuttle flight schedule that is consistent with available resources...” Recognizing the ongoing nature of this recommendation, the Task Group believes it will take vigilance in the future to maintain the “appropriate” pressure necessary to maintain a schedule for such a complex system without the pressure becoming, for any reason, “undue.”

Recognizing the difficulty in assessing this recommendation, the Task Group undertook several activities in an attempt to evaluate the presence of “undue” schedule pressure and the general availability of resources. The Task Group consistently explored the question of adequacy of resources in virtually every meeting with NASA personnel – from Headquarters staff to the workforce on the floor of the Kennedy Space Center. The answer has always been the same: “...there are sufficient budgetary resources for return to flight.”

Recognizing that any assessment is a snapshot, the Task Group also requested data on overtime and other work rule exceptions. The RTF TG looked at reports on sick leave, employee assistance visits, accidents, and near-accidents (close-calls or “diving catches”), as well as reports of problems with the quality of workmanship being performed. Altogether, these data, compared with previous intervals prior to launch, showed no unusual patterns suggestive of substantial adverse pressure.

During the middle of 2004, press reports claimed NASA personnel were concerned about resources and the possibility of workforce reductions. The RTF TG was not able to confirm these reports and notes most were made prior to the finalization of the Fiscal Year 2005 NASA budget, during a time when exercises were being conducted to assess the impacts of various alternative levels of spending. NASA was one of the few federal agencies to receive full funding, although funding for aeronautics programs was severely cut to fund space initiatives, particularly the Vision for Space Exploration.

The Task Group also had the opportunity to assess the outcome of NASA’s budget requests over the last two years. Last year (FY05), Congress actually added funds to the request to augment return-to-flight activities, and this year has taken actions to help protect resources for NASA in the future. And while NASA has somewhat reduced funding for the Headquarters Office of Safety and Mission Assurance, the Task Group has been assured these reductions will have no effect on return-to-flight activities.

The RTF TG assessment of NASA’s actions was completed at the June 8, 2005, meeting. The intent of CAIB Recommendation 6.2-1 has been met.

3.10.5 RTF TG Observations

Resource sufficiency is also tied to the scheduled retirement date for the Space Shuttle, and any evaluation of whether to keep Space Shuttle in service past 2010 should include a reassessment of actions and upgrades not undertaken, and any long term items already deleted from work and acquisition cycles, including the Service Life Extension Program.

The Task Group also observes that resource constraints will likely pressure future programs, such as the Vision for Space Exploration. There will always be pressure for under-funding and overly-aggressive scheduling that must be recognized and mitigated by senior leadership. Along these lines, NASA must address the size and mixture of its future workforce to accomplish its new missions.

As new NASA space flight programs evolve, the Space Shuttle could well be caught between

competing goals (e.g., the 2010 retirement date, Hubble SM4, and the delays in fielding a new vehicle). NASA will need to exercise great rigor to ensure that competing budgetary requirements do not affect the safety and reliability of Space Shuttle.



Discovery at the beginning of her slow trip to Launch Complex 39B, as seen from inside the Vehicle Assembly Building.

3.11 CAIB Recommendation 6.3-1 – Mission Management Team Improvements

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

3.11.1 RTF TG Interpretation

Mission Management Team (MMT) activities during the flight of *Columbia* have been widely criticized. Many of the additional capabilities embedded in other recommendations from the Columbia Accident Investigation Board (CAIB), such as imagery from various sources, are intended to support MMT activities for the next and subsequent flights. In addition to enhanced training for participants in the MMT, the Agency will need to exercise these many new sources of data and information.

3.11.2 Background

The CAIB report was very clear on the importance the accident investigation board placed on correcting the organizational behaviors which led to the multiple STS-107 MMT decision making failures they identified. Indeed, the CAIB issued 29 findings related to these failures, ranging from lapses in MMT leadership and communication, to the passivity of MMT safety representatives, to the lack of reliance on solid analysis and engineering data, to the absence of effective mechanisms for expressions of concern or dissent.

According to NSTS 07700, Volume VIII, Appendix D, the MMT is “the program decision-making body responsible for making programmatic trades and decisions associated with launch countdown and in-flight activities ... outside the responsibility or authority of the Launch Director or Flight Director.” Throughout STS-107, the CAIB found that the MMT (and its processes and procedures) failed to support or result in timely, informed, or effective critical decisions. In short, the MMT failed in the performance of its mission.

During Space Shuttle missions, the Mission Management Team is responsible for oversight of the launch and flight operations teams. The countdown and flight operations are conducted to rules and procedures approved by program management and are documented in NSTS 07700, Volume VIII. The MMT provides guidance to the operations teams during situations that fall outside normal operations; the MMT also redefines programmatic priorities when in-flight anomalies or off-nominal conditions result in conflicting priorities.

The MMT responsibilities for a specific Space Shuttle mission begin with a scheduled meeting two days prior to a scheduled launch (L-2). The MMT Chair, supported by the entire MMT, is responsible for the final GO/NO-GO decision for launch. MMT activities at the Kennedy Space Center continue through launch and terminate upon the declaration by the Flight Director of “Go for On-Orbit Operations,” approximately 2 hours after launch. At that time, MMT activities transfer to the Johnson Space Center. The flight MMT meets daily during the subsequent on-orbit, entry, and landing phases, and terminates with crew egress from the Orbiter. When the MMT is not in session, all members are on-call and required to support emergency meetings convened because of anomalies or changing flight conditions.

As exhibited during STS-107, the MMT had become somewhat *ad hoc* and informal in nature; there was no clear method to formally present issues in an official forum. Therefore, the concerns of individual engineers, the quality of risk assessments, and the pedigree of engineering assessments were sometimes poorly understood by senior management. In

retrospect, this approach did not adequately sensitize NASA management in general – and the MMT, in particular – to actively seek out potential concerns and issues raised by individuals, support teams, and working groups.

3.11.3 NASA Implementation

As a result of the CAIB findings and recommendations, the Space Shuttle Program began to identify necessary changes to the MMT in May 2003. A Space Shuttle Program Requirements Change Board on September 11, 2003, reviewed the proposed changes and presented a slightly modified set to the Space Flight Leadership Council on November 21, 2003. The changes included expanding the MMT membership, better defining member responsibilities, making the flight MMT meetings more formal, establishing a time reporting process, and establishing a rigorous process for the review and disposition of mission anomalies and issues. In addition, NASA contracted with several external evaluators (experts in training and critical decision making) and several past flight directors, including Gene Kranz and Glynn Lunney, to study the MMT processes and make recommendations to improve communications, decision-making, and operational processes.

NASA established a process for the review and resolution of off-nominal mission events to ensure that all such issues are identified to and resolved by the flight MMT. The Space Shuttle Systems Engineering and Integration Office will maintain and provide an integrated anomaly list at each MMT meeting. All anomalies will be assigned a formal office of primary responsibility (OPR) for technical evaluation and will be subject to an independent risk assessment by Safety and Mission Assurance (SMA). The MMT has one Space Shuttle Program SMA core member and three institutional SMA advisory members from JSC, KSC, and MSFC. In addition, the MMT has added the Space Shuttle System Technical Warrant Holder as a core member; this person represents the NASA Independent Technical Authority as a voting member. The NASA Engineering and Safety Center (NESC) also serves as a formal advisor to the MMT.

The MMT secretary will maintain an action tracking log to ensure all members are adequately informed of the status of all anomalies. Closure of actions associated with each anomaly will require a formal written request that includes a description of the issue (observation and potential consequences), technical analysis details (including databases, employed models, and methodologies), recommended actions and associated mission impacts, and flight closure rationale, if applicable. These steps are designed to eliminate the possibility of critical missteps by the MMT due to incomplete or un-communicated information. NASA has documented these changes in a new 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.

Additional improvements were made to MMT internal processes and procedures, including more clearly defining requirements for MMT meeting frequency and the process for requesting an emergency MMT meeting. The MMT will hold meetings daily beginning at L-2 or L-1 day, depending on the scheduled time of launch. The membership and organization of the preflight and flight MMT are standardized. In addition, the Space Shuttle Program Deputy Manager now chairs both phases of the MMT, preflight and flight.

The MMT member's responsibilities have been clearly defined, and MMT membership and training status for each mission is established by each participating organization in writing at the Flight Readiness Review (FRR). Each MMT member also has clearly defined processes for MMT support and problem reporting.

Procedures for flight MMT meetings are standardized through the use of predefined templates for agenda formats, presentations, action item assignments, and readiness polls. This ensures that the communication and resolution of issues are performed in a consistent, rigorous

manner. Existing Space Shuttle Program meeting support infrastructure and a collaboration tool are used to ensure that critical data are distributed before scheduled meetings and that MMT meeting minutes are quickly distributed following each meeting. In addition, NASA established formal processes for the review of findings from ascent and on-orbit imagery analyses, post-launch hardware inspections, ascent reconstruction, and all other flight data reviews to ensure timely, effective reviews of key data by the MMT.

Using recognized techniques for improving communications for critical decision making, NASA refurbished the Mission Management Team's working space to provide increased seating and improved communications. Other enhancements include a video-teleconferencing capability, a multi-user collaboration tool, and a larger room to allow more subject matter experts and MMT members. A large C-shaped table now seats all members of the MMT and encourages open communication by eliminating a hierarchical seating arrangement. The MMT Command Center has been operational since the November 2004 MMT simulation to give the team time to adapt and learn how to use all of the new tools.



The MMT conference room was refurbished with the addition of a large C-shaped table and multimedia capabilities to better facilitate communications between members.

3.11.3.1 Training

All MMT members, except those serving exclusively in an advisory capacity and the Department of Defense Mission Support representative, are required to complete a minimum set of training requirements to attain initial qualification prior to performing MMT responsibilities. MMT members must also participate in an ongoing training program to maintain qualification status, which is renewed annually. Training records are maintained to ensure compliance with the new requirements.

In addition, to ensure adequate backup personnel are available, at least two people will be trained to fill each MMT core position prior to return to flight. This will protect the integrity of the integrated MMT process against individuals' inability to perform their role for any reason. Verification of each flight specific team will be presented at the appropriate FRR.

The Space Shuttle Program published a formal MMT training plan (NSTS 07700, Volume II, Program Structure and Responsibilities, Book 2, 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. MMT training activities are well under way with several courses/workshops held at various NASA centers and 13 simulations completed, including an end-to-end contingency simulation and a simulation to address MMT actions related to Contingency Shuttle Crew Support (see Section 3.16, SSP-3). These simulations brought together the flight crew, flight control team, launch control team, engineering staff, outside agencies, and ISS and Space Shuttle MMT members to improve communication and teach better problem-recognition and decision-making skills.

Quality assurance processes have been established to help monitor that MMT training requirements are met, sustained, and improved over time. Numerous channels have been opened to allow the real-time expression of concerns or dissent. The support teams, including contractors, have revised their processes to better serve the MMT and have trained to these

new processes. Formal training objectives, evaluation processes, metrics, and a closed-loop lessons-learned system are now a part of MMT training. Independent external evaluators will continue to challenge the integrity of MMT training. The International Space Station and Space Shuttle MMTs have cross-trained and are improving the standardization of processes and communications. The development of NSTS 60540, *STS-114 Operations Integration Plan for Thermal Protection System Assessment* has greatly improved the real-time decision-making process concerning potential Orbiter Thermal Protection System damage (see Section 2.2 of this report for a further discussion of the OIP).

Risk management is now a major consideration at each MMT meeting. Each identified hazard is required to have a clear risk assessment performed and presented to the MMT so the appropriate risk-versus-risk tradeoffs can be discussed and decided upon. Supporting analyses, assumptions, issues, and ramifications are a part of this discussion.

3.11.4 RTF TG Assessment

Because of the central role played by the MMT during the last flight of *Columbia*, the Task Group conducted a great deal of fact-finding regarding this recommendation. Members attended the first “live” simulation on December 3-5, 2003, and additional sims on February 11, 2004, April 2, 2004, November 16-19, 2004, February 28 through March 7, 2005, and May 4, 2005. A variety of meetings, classroom training, assessed evaluations, and training exercises were also attended by the Task Group members and staff. NASA submitted a closure package in November 2004, but after review the Task Group requested additional data and simulations, especially one that exercised consideration of Contingency Shuttle Crew Support. A revised closure package was submitted to the Task Group on March 7, 2005. The Task Group again requested to witness a simulation that demonstrated the complex risk-versus-risk trades involved with the possibility of invoking the CSCS capability; this sim was finally held on May 4, 2005.

NASA has developed a new training plan for the MMT. With the passage of time, the Task Group has been able to witness the implementation of most aspects of the plan. There have also been numerous simulations conducted to date including more than ten involving live, face-to-face exercises of various parts of the next mission.

Some of the training protocols were initially developed without clear objectives and techniques to assess the quality of training. Similarly, the first simulations lacked clear objectives and evaluation criteria. Further, lessons learned from prior simulations were not incorporated in subsequent exercises. With a maturing training program, many of the earlier deficiencies have been corrected and the MMT Training Plan has been updated to reflect formal evaluation requirements. However, not all aspects of the enhanced role of the MMT have been exercised completely, such as the potential use of the CSCS option and a launch-on-need rescue mission (STS-300) and the incorporation of all new sources of data and imagery. The MMT held a special simulation (sim #13) that included consideration of invoking the CSCS capability; most Task Group members in attendance were satisfied with the results.

The various delays in launching STS-114 have allowed the MMT to further refine its procedures and have resulted in continual improvement. The Mission Management Team has made notable progress in addressing the accident board’s concerns, and NASA has demonstrated a commitment to continual MMT improvement.

The RTF TG assessment of NASA’s actions was completed at the June 8, 2005, meeting. The intent of CAIB Recommendation 6.3-1 has been met.

3.11.5 RTF TG Observations

The Task Group recognizes that the notable MMT improvements made to-date are a journey, not an end, and MMT processes and member training need to continue to grow and mature through the remaining missions of the Space Shuttle Program. In addition, NASA needs to ensure that the MMT and its support teams understand and have confidence in their ability to incorporate the latest analytical and engineering information available to them, to include the totally integrated risk assessment of the Space Shuttle system and its knowns, unknowns, limitations, uncertainties, and assumptions. Specific observations of areas that need continual improvement include:

- NASA needs to continually grow and improve a systematic MMT training evaluation system which ensures that MMT training focuses on value, required knowledge, and the “science of learning.” The course content, simulation design and delivery, and self-instruction requirements must be continuously assessed and quality assurance plans rigorously applied. NASA should also consider formal MMT training on new and emerging capabilities, such as inspection, imagery, and CSCS.
- Just as the MMT needs to adjust and improve with each “learning experience” (training or live), all of the documents supporting the MMT need to be continually updated and refined based on experience, need, and the evolving MMT decision-making capabilities.
- The MMT needs to continue to improve and mature their integrated risk-versus-risk identification, assessment, decision making, and trades capabilities based on the latest available information and systems integration capabilities to guide them in their time-sensitive critical decisions. This includes the certainties and uncertainties that exist in the various analytical tools and models used by the MMT. Existing linear (i.e., non-integrated) decision making frameworks and the existing meeting agenda format need to be continually assessed and revised to meet the MMT’s needs.
- In terms of the new, more rigorous training requirements, NASA also should recognize the opportunity to capitalize on the broader test and validation potentials of MMT simulations for other technical and operational capabilities beyond just the training of MMT members.
- Post-*Columbia*, NASA senior leadership have new responsibilities in terms of MMT decision making and, during future MMT simulations need to ensure that MMT processes fully support their new Headquarters roles for time critical decisions and risk-versus-risk trades and periodically exercise them. Specific areas where NASA Headquarters senior leaders have new responsibilities include Safety and Mission Assurance, the Independent Technical Authority, and the potential decision to declare the need to implement the Contingency Shuttle Crew Support capability and its resulting launch-on-need rescue mission.
- As a senior critical decision-making team, the MMT will continue to have unique insight into areas where there are critical information gaps, seams, unknowns, and uncertainties. The MMT can further serve NASA and the program by helping to point out these areas and prioritize them for focused closure.
- Finally, the Task Group observes that NASA should consider formalizing periodic, independent oversight of the MMT to help sustain it as a “continuously

learning” entity for the remainder of the Space Shuttle Program. On at least an annual basis, an external entity should observe, evaluate (audit), and challenge the MMT’s ability to continuously improve, as well as evaluate MMT member certifications and training.

While the Agency’s implementation of this recommendation has been serious and comprehensive, it will, by its very nature, remain a “work in progress” for the remaining missions of the Space Shuttle Program. Many lessons have been learned from the *Columbia* accident over the past 29 months, but with each mission many other lessons will also be learned. As stated previously, the fulfillment of R6.3-1 is a journey, not an end.



The Vehicle Assembly Building (VAB) at the Kennedy Space Center is one of the largest enclosed spaces in the world.

The building was originally constructed as part of the Apollo moon program, and is currently used to stack the Space Shuttle vehicle.

3.12 CAIB Recommendation 6.3-2 – National Imagery and Mapping Agency Memorandum of Agreement

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

3.12.1 RTF TG Interpretation

There was considerable public discussion of the decision during the flight of *Columbia* to forego requesting the assistance of other federal agencies in assessing the condition of the Orbiter. The Columbia Accident Investigation Board (CAIB) wanted the Space Shuttle Program to have the procedures in place to get all possible data to investigate a potential problem. This included having the proper personnel maintain the appropriate security clearances to access data from National assets.

3.12.2 Background

The National Imagery and Mapping Agency (NIMA) was created in 1996 by combining the mapping and imagery analysis efforts of the Central Intelligence Agency (CIA) and Department of Defense (DoD). On November 24, 2003, NIMA changed their name to the National Geospatial-Intelligence Agency (NGA) as dictated by the 2003 Defense Authorization Bill.

National assets were available that potentially could have revealed the damage to *Columbia* while on orbit, but these assets were not used during the flight. NASA has previously used National assets to support the Space Shuttle Program, but the process and procedures to do so were overly complex and obscure.



The CAIB found that the relationships between NASA and other Government agencies that could provide the assessment capabilities needed to be formalized and strengthened. Additionally, they recommended that such assessments should become a part of the standard mission requirements for each Space Shuttle flight, that all decision-makers within the Space Shuttle Program be made aware of the available capabilities, and that a small set of personnel maintain the appropriate security clearances and briefings.

3.12.3 NASA Implementation

The Memorandum of Agreement (MoA) with the National Imagery and Mapping Agency was modified in July 2003 as recommended by the CAIB. NASA has since worked with the full range of supporting agencies to develop an Interface Operations Agreement that maximized the use of available National assets to assist in on-orbit assessments. The NASA Standard Operating Procedures for requesting support from appropriate federal agencies were completed in December 2003 and have been exercised successfully. The capabilities have been, and will continue to be, demonstrated during MMT simulations.

In order to fully comply with the CAIB recommendation, NASA has identified the positions that require access to classified data and will ensure that all NASA personnel involved in human space flight are familiar with the general capabilities available for on-orbit vehicle assessments and the procedures to request and process such assessments. NASA has also put in place secure data transmission systems and procedures for the dissemination of classified information to the NASA Space Operations Mission Directorate field centers.

Final implementation details have been worked out in a lower level memorandum of understanding. Since this action may involve receipt and handling of classified information, the appropriate security safeguards will be observed during its implementation.

Although these actions address the recommendation found in CAIB R6.3-2, NASA has taken additional appropriate actions with other federal agencies to maximize use of National assets for all flight segments. NASA has teamed with the Department of Defense and the intelligence community to develop new agreements and operating procedures to obtain support from the partnering agencies.

3.12.4 RTF TG Assessment

Fact-finding meetings were attended by the Task Group on December 8, 2003, and February 18-19, 2004, where the Memorandum of Agreement with the NGA was discussed. The next lower-level Interface Operating Agreement that details the methods for NASA to obtain information, and how that classified information would be handled within NASA were also discussed. The detailed plans and agreements themselves are classified due to the nature of National assets they discuss.

The Task Group's initial evaluation of NASA's actions was completed at the April 16, 2004, teleconference plenary where the assessment was conditionally closed. The conditions required that NASA present the results of an integrated simulation that exercised the NGA MoA for assessment by the RTF TG. After receiving additional information from NASA, the assessment was closed at the December 16, 2004, plenary meeting. The intent of CAIB Recommendation 6.3-2 has been met.

3.12.5 RTF TG Observations

The Task Group believes that NASA should periodically review the Memorandum of Agreement with the National Geospatial-Intelligence Agency, assess the capabilities of the NGA and other agencies, and ensure that the appropriate security clearances are maintained within NASA to exploit these capabilities as necessary. In addition, this capability should also be periodically exercised during MMT simulations.

Discovery in the Vehicle Assembly Building transfer aisle, ready to be lifted to the vertical position in preparation for mating with the External Tank and Solid Rocket Boosters.



3.13 CAIB Recommendation 6.4-1 – Thermal Protection System Inspection and Repair

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.

3.13.1 RTF TG Interpretation

Based on a majority opinion of the members, the Task Group revised its interpretation of this CAIB recommendation at the June 27, 2005 meeting. The interpretation that the final assessment was based on follows:

CAIB Recommendation 6.4-1 consists of four separate provisions. Although the entire recommendation is labeled Return to Flight, the second and fourth provisions do not apply to STS-114. These provisions are not being considered by NASA or the Task Group. If a non-ISS mission, such as Hubble Space Telescope (HST) Service Mission 4, is added to the flight manifest, the ASAP should review this recommendation.

NASA must define any damage to tile and RCC that poses an unacceptable hazard to the Orbiter and crew during entry, and be able to detect the location and extent of such damage. Assessment of NASA's on-orbit TPS inspection capability is covered in Recommendation 3.4-3

Each of the repair options in the suite of options that constitutes the repair capability must be have completed formal design reviews, ground verification testing, procedure development and an integrated Design Certification Review such that NASA could implement it in an emergency situation with confidence that it would behave as expected

3.13.2 Background

The *Columbia* accident clearly demonstrated that the Orbiter Thermal Protection System, including the reinforced carbon-carbon (RCC) panels and acreage tiles, was vulnerable to impact damage from the existing debris environment. As a result, the Columbia Accident Investigation Board (CAIB) issued recommendations to eliminate debris (R3.2-1), determine the structural integrity of the RCC (R3.3-1), harden the Orbiter (R3.3-2) against impacts, and to develop on-orbit repair capabilities (R6.4-1).

The concept of a "tile repair kit" is hardly new. Such a kit was originally intended to be flown aboard STS-1 and work was undertaken by NASA and its contractors, particularly Martin Marietta. However, as the launch of STS-1 approached, the development effort was cancelled

due to a variety of technical problems and a renewed confidence in the tiles themselves. At the time, the RCC was considered particularly resilient and there was little thought given to a repair capability; as later events demonstrated, this assumption was incorrect.

3.13.3 NASA Implementation

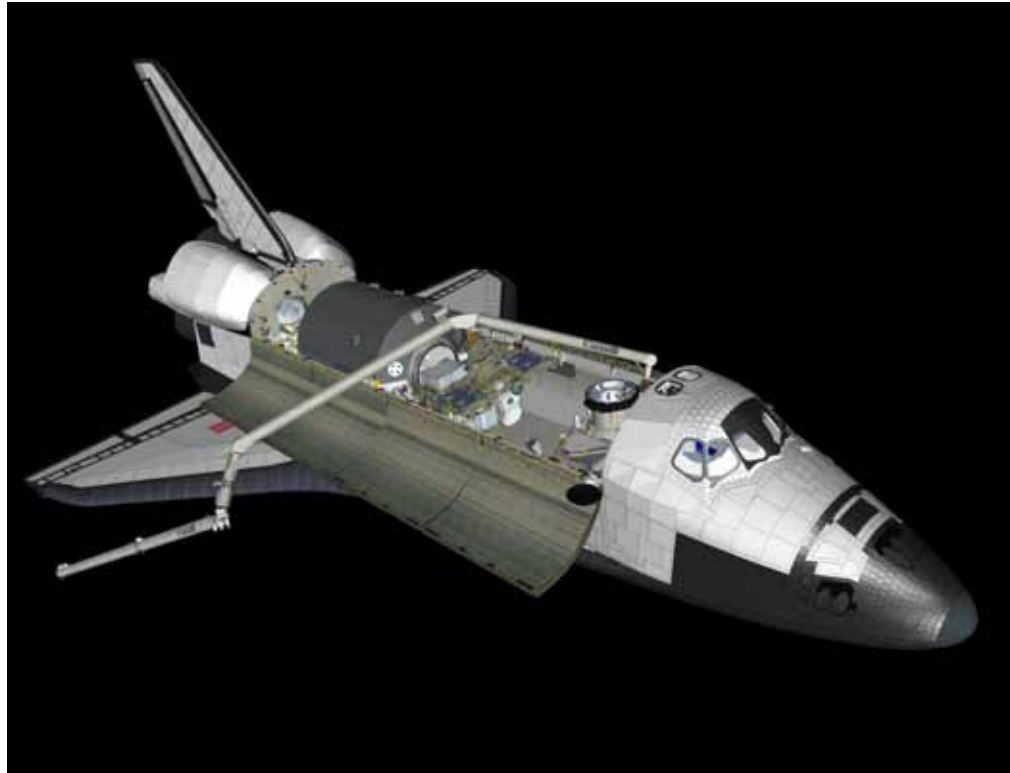
Note: This section refers to inspection and repair during missions to the ISS.

NASA has expanded the capabilities to detect debris liberated during ascent, to locate where debris may have originated, and to identify impact sites on the Orbiter Thermal Protection System for detailed evaluation. Methods to access the Orbiter for possible repair have been evaluated and procedures developed and trained. In addition, five repair techniques have been selected to be carried on STS-114.

These capabilities, paired with NASA's improved insight into the impact and damage tolerance of the Orbiter, will allow the Mission Management Team (MMT) to make informed decisions about whether any impacts sustained represent a threat to mission success or the safety of the crew and the vehicle. They will also help to determine whether any repairs that are attempted are successful.

3.13.3.1 Inspection

NASA will use a combination of Space Shuttle and International Space Station assets to evaluate the Orbiter Thermal Protection System and identify and characterize whether damage was sustained during ascent. These inspection assets and methods include the Orbiter Boom Sensor System (OBSS), the R-Bar Pitch Maneuver, the Shuttle Remote Manipulator System (SRMS), the Space Station Remote Manipulator System (SSRMS), and an experimental wing leading edge impact detection system. Each inspection method provides a piece of information to improve insight into the conditions of the Orbiter Thermal Protection System.



A computer-generated image of the OBSS in operation while attached to the Shuttle Remote Manipulator System. The OBSS is capable of inspecting all of the RCC on the Orbiter, as well as the majority of the tiles on the underside of the vehicle.

3.13.3.1.1 Orbiter Boom Sensor System

The OBSS is an imaging system that consists of two sensor packages on the end of a 50-foot-long boom structure. The boom is carried on the starboard sill of the Orbiter payload bay (which had originally been configured to carry a second remote manipulator system arm if needed) and is used in conjunction with the Shuttle Remote Manipulator System (SRMS) carried on the port sill. The OBSS carries a laser camera system (LCS) and a laser dynamic range imager (LDRI) that downlink data via the Orbiter communications system. The data will be processed and analyzed on the ground as part of the Thermal Protection System assessment process. The OBSS is the primary system used to inspect the wing leading edge and noscap RCC, and also to obtain detailed depth measurements of damaged areas. In addition, the OBSS has the capability to support a crewmember in foot restraints if needed to perform inspection or repair during extra-vehicular activities (EVA).

On flight day 2, prior to docking with the ISS, the crew will use the OBSS to inspect the noscap and the underside and apex of the 22 leading edge RCC panels on each wing. If any evidence of a debris strike exists, the OBSS instruments will be used during flight day 4 for more detailed inspections of specific areas.

3.13.3.1.2 ISS Imagery during the R-bar Pitch Maneuver

The primary method of inspecting the acreage tile on the bottom of the Orbiter consists of imagery taken by the ISS crew as the Orbiter approaches for docking. This approach, called the R-Bar Pitch Maneuver, has been practiced by Space Shuttle flight crews in the simulator. When the Orbiter is 600 feet away from the ISS, it will pause its approach and pitch-over to present its underside to the station. The ISS crew will take overlapping high-resolution digital still images of the acreage tiles and downlink them to the ground. Areas of concern will be re-inspected for more detail (such as damage depth) while the Orbiter is docked to the ISS.

The cameras used during the R-Bar Pitch Maneuver have the capability to detect critical damage in all areas of the Orbiter Thermal Protection System tile. Analysis indicates that the photos taken with a 400mm lens have an analytical resolution of 3 inches on normal surfaces; the 800mm lens provides a 1-inch analytical resolution.

3.13.3.1.3 Other Imagery Assets

Other imagery assets include the cameras on SRMS, the SSRMS, and digital camera assets on board the Orbiter or the ISS. The SRMS and SSRMS can inspect areas of the Orbiter Thermal Protection System within their reach, such as the crew cabin area, forward lower surface, and vertical tail, using their closed circuit television camera systems. Other assets include the still cameras available to EVA crewmembers in the event an EVA inspection is required to do focused inspection of areas that may have suspected damage. These alternate inspection methods are not pre-planned, and will be used as a backup for the other inspection methods.

3.13.3.1.4 Wing Leading Edge Impact Detection System

The wing leading edge impact detection system was developed from an existing technology that had been previously flown as an experiment in the Orbiter aft fuselage. Initially, NASA hoped to include the wing leading edge sensors as a key element to detect damage. However, this system has not been flight-tested in this environment, so its actual capability is yet to be determined. For STS-114, these sensors will be used primarily to “point” to areas of the wing leading edge needing further inspection by the OBSS.

The wing leading edge impact detection system is composed of accelerometer and temperature sensors attached to the wing spar behind the reinforced carbon-carbon panels.

These battery-powered sensors transmit data via RF to receivers in the Orbiter. The data are collected during ascent and downlinked to the ground via the Orbiter communications system once on-orbit to help identify possible debris impact areas on the wing leading edge RCC panels. In the event an impact is detected, engineers can determine the location of the sensor(s) that measured the impact and, through the TPS assessment process, recommend a more focused inspection of the suspect area later in the mission. Due to the limited battery life in the current implementation, there is a finite period of time for collection and transfer of impact data using this system. In the future, the power source will be changed from batteries to the Orbiter's main electrical systems, allowing the sensor system to provide impact detection throughout the mission.

3.13.3.2 Repair

Despite extensive efforts to develop TPS materials and techniques, the state-of-the-art in this area has yielded little technology to support the concept. As a result, continued effort does not hold promise of significant capabilities beyond those in hand. While a vehicle-wide TPS repair capability is not a constraint to the return to flight, STS-114 will carry a limited number of experimental materials and tools to repair minor tile damage and small- to medium-sized RCC damage in an emergency.



A variety of special tools are being carried aboard STS-114 and future flights in case repairs to the reinforced carbon-carbon panels becomes necessary.

To effect repairs, the EVA crew will use either the SRMS or the SSRMS to gain access to locations on the Orbiter; when necessary, they may also use the OBSS. NASA has also devel-

oped a combined SRMS and SSRMS “flip around” operation, called the Orbiter Repair Maneuver (ORM), to allow TPS repairs while the Orbiter is docked to the ISS. The ORM involves turning the Orbiter into a belly-up position that allows the SSRMS to position an EVA crewmember to reach any TPS surface needing repair. The procedure is feasible until later flights when the ISS grapple fixture required to support this maneuver will be blocked, and new TPS repair access techniques will need to be developed.

3.13.3.2.1 *RCC Repair*

NASA has evaluated RCC repair concepts with participation from six NASA Centers, 11 contractors, and the United States Air Force Research Laboratory. The main challenges to repairing RCC are maintaining a bond to the RCC coating during entry heating and meeting stringent aerodynamic requirements for repair patches and fills. NASA is investigating two complementary repair concepts – plug and crack – that together could, in the future, allow the emergency repair of limited RCC damage. Both concepts have limitations in terms of damage characteristics, damage location, and amount of testing and analysis completed to-date.

NOAX

Non-Oxide Adhesive eXperimental sealant (NOAX) is a pre-ceramic polymer sealant intended to repair cracks up to 0.065-inch-wide by 9-inches-long, and small areas (1-inch at the outer mold line and 2-inches at the inner mold line) of coating loss on any Orbiter RCC panel. Curing NOAX requires a heater, adding significant complication to its use on-orbit; however, uncured NOAX has recently passed arc-jet tests, leading to a decision not to use the heater to cure the material. NOAX has been shown to be successful in repairing cracks in ground tests but process controls will be more challenging in the EVA environment. At this time, there is uncertainty concerning the microgravity behavior of the material, and there is limited ground testing on real RCC substrate with realistic damage. This technology will be tested during an EVA development test objective (DTO) on STS-114.

Plug Repair

The plug repair is intended for small to medium-size holes in some areas of the wing leading edge RCC. A flexible carbon-silicon carbide (C-SiC) cover plate is held in place with a SiC-coated TZM toggle bolt and sealed around the edges with NOAX. Each plug cover plate might repair up to a 4-inch-diameter hole (major dimension) with a 1-inch surrounding spalled area. If the existing hole is less than 1-inch diameter, a drill will be used to enlarge the hole in order to insert the toggle bolt. A dozen different cover plates with various curvatures are available and provide coverage for 62-percent of the wing leading edge RCC areas. Although arc-jet testing indicates that the material can withstand entry, there are concerns about the bolt fracturing if the SiC coating is scratched. There are also concerns about drilling through RCC to insert the plug, especially if there is not a preexisting hole. A middeck DTO on the mechanical function of this repair capability, excluding drilling, will be performed on STS-114.

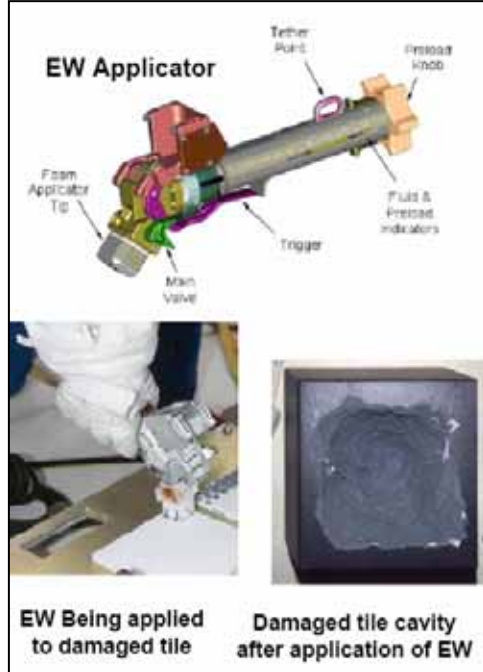


The plug repair starts with either a pre-existing hole in an RCC panel, or with the astronaut drilling a hole. A toggle bolt is inserted through the hole to hold the carbon-silicon carbide cover in place. NOAX is used around the edge as a sealant.

3.13.3.2.2 Tile Repair

A limited tile repair capability will be ready for on-orbit testing on STS-114. On this flight, NASA plans to demonstrate the emittance wash technique during an EVA, fly two Cure-In-Place Ablator (CIPA) applicators (that will not be demonstrated) that could repair tile damage, and fly a mechanical overlay (also not demonstrated) that could potentially repair larger areas of damage in the acreage tiles.

A hand-held extrusion gun is used to apply the emittance wash.

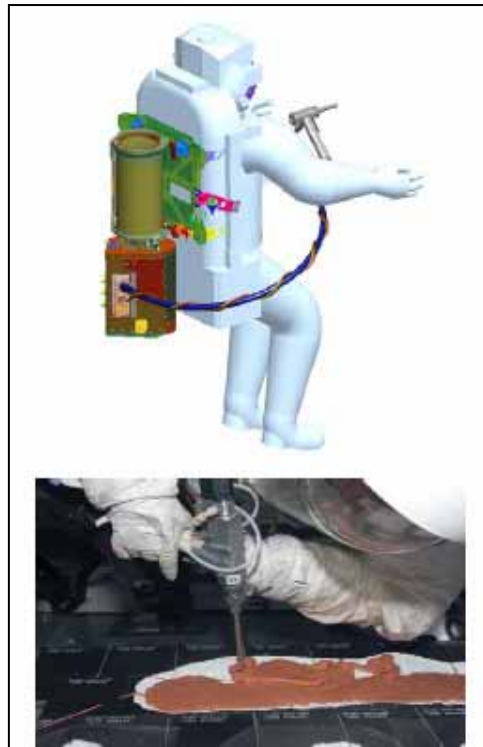


Emittance Wash

Emittance wash, a silicon carbide (SiC) material mixed with a carrier, is expected to be effective for shallow tile damage on any black tile surface. While initially developed as a surface preparation for the CIPA technique, NASA determined the material has a stand-alone repair potential. Emittance wash partially restores the emissivity of damaged tile surface to increase heat rejection through radiation, and is used to prevent small gouges in the tile from becoming deeper holes. The material is applied using an extrusion gun. Arc-jet tests are continuing to gather data on the thermal performance of a repair using this technique; however, thermal performance testing will be limited before STS-114.

Cure-in-Place Ablator (CIPA)

Two CIPA applicators will be carried aboard STS-114, potentially allowing repair of tile damage sites anywhere on the Orbiter except a small number of LI-2200 tiles. The CIPA material, called STA-54, is a two-part room temperature material that is applied with a pneumatic dispenser gun that mixes the two parts within the dispenser. Ancillary tools include emittance wash to prime the surface, gel and foam brushes to clean the surface, stamps to shape the material, a contour gage to measure the material surface relative to the outer mold line, and a durometer to test hardness. The CIPA “goo” is intended for use in deeper tile damage in areas up to 10 by 20 inches. If a CIPA repair is attempted, a second EVA will be required to inspect the repair and test the hardness. This information along with photographs of a dissected “test bead” created at the same time as the repair are required to assess the integrity of the repair for entry. The quality of the repair appears to be highly operator dependent.



The CIPA hardware is much more involved, with most components contained on a backpack that fits over the EVA suit.

There have been multiple technical difficulties in the development of the CIPA materials and application tools. Most significant of these is

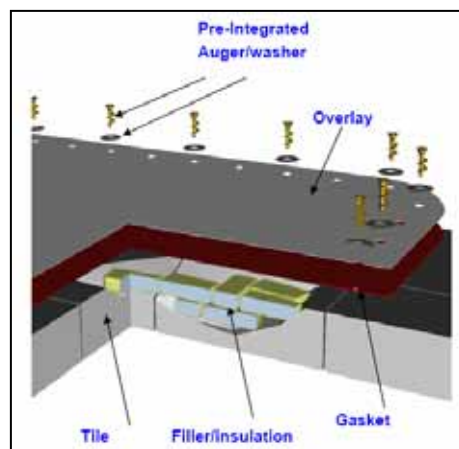
recurrent bubbling in the STA-54. NASA has been unable to determine the root cause of the bubbling, or to adequately and consistently characterize its severity. Additionally, there remain several areas of uncertainty about the material properties of STA-54, including its ability to cure during the thermal cycling of Earth orbit and its adhesion to tile during entry, since tile and STA-54 have different thermal expansion coefficients.

Though somewhat unpredictable, bubbling of the material has been shown in arc-jet testing to be less important in the ability to protect the Orbiter than originally thought, but testing in the actual on-orbit environment is necessary to confirm this finding. Analytical models for CIPA repair assessment are uncorrelated with test data, and if the material is used as an emergency repair on STS-114, formal validation testing to material performance requirements will be limited to real time arc-jets test.

Another issue concerns the level of toxicity of one of the STA-54 components prior to mixing and dispensing. At this time the program is pursuing a triple level of containment – a common toxicity mitigation technique – for STA-54 stowage and is assessing the crew risk during EVA use for the STS-121 development test objective or if needed for tile repair.

Tile Overlay

The mechanical overlay repair is performed by filling the damaged tile cavity with a Saffil batting insulation, then placing a thin C-SiC cover plate and high-temperature gasket seal over the damaged tile area. SiC-coated ceramic augers (screws) with accompanying SiC-coated ceramic washers are screwed into undamaged tiles to attach the overlay. The 12-inch by 25-inch overlay is capable of covering a 10-inch by 20-inch damage area. While this technology is being carried as a contingency on STS-114, its testing is very immature at this time. However, development testing is on a fast track and NASA believes this option appears to be promising.



The tile overlay repair is a metallic sheet that is screwed in place over the damaged tiles after the cavity is filled with Saffil batting insulation.

3.13.3.3 TPS Damage Assessment

The Space Shuttle Program has developed a substantial knowledge-base of the vulnerabilities of both tile and RCC, and the level of damage that testing to date indicates could be sustained without unacceptable risk during entry. This knowledge is essential for decision-making in the event that on-orbit inspection reveals damage to the TPS. Critical damage size has been defined and is highly location dependent. NASA has incorporated the experimental data gleaned over the last year to create a “critical damage map” that reflects the best understanding to date. For RCC, critical damage in the most vulnerable areas is a 0.020-inch-wide crack or a 0.08-inch (major dimension) coating loss. A 1-inch (major dimension) gouge around the main landing gear door seals or ET umbilical door seals, or a 3-inch gouge in acreage tile represents critical tile damage. If damage exceeding these dimensions is detected, reducing Orbiter weight, altering the entry profile, reducing landing sink rate, and other options will be considered, along with or in lieu of repair, to achieve an acceptable condition for entry. The decision to land an Orbiter with an untested repair will require a difficult decision based on models, experimental runs in the arc-jet, and flight history of the thermal environment during the entry. The OIP companion document, NSTS 60540-ANX1 *Orbiter Damage Assessment Process Annex*, describes the teams, tools, and processes that will be used to transform data from the TPS assessment teams into information that can be used about the condition of the TPS at multiple milestones during flight by program leadership to make a timely entry readiness, repair, or Contingency Shuttle Crew Support determination.

3.13.4 RTF TG Assessment

The Orbiter Thermal Protection System was never intended to be repaired on-orbit. Various repair capabilities were explored early during Space Shuttle development and again more recently, but it is highly unlikely that a comprehensive repair capability for all possible damage will become available for the remaining flights of the Space Shuttle Program. Tile and RCC repair have proven to be far more challenging than either the CAIB or NASA understood two years ago. Enormous effort has been expended in search of effective and operationally feasible repair capabilities, and far more is known today than before about the capabilities and vulnerabilities of the Orbiter Thermal Protection System. Nevertheless, the program is far from having a certifiable capability. Several innovative repair solutions for a limited range of potential damage are aggressively being pursued. Five such limited repair options will be carried on STS-114; however, much more testing and evaluation remain to be done. The options proposed by NASA have not yet achieved a level of maturity that the Task Group considers necessary to be defined as a capability and thus the intent of this recommendation has not been met.

3.13.4.1 *Inspection*

The two primary methods to be used on-orbit for critical inspection of Orbiter Thermal Protection System, the OBSS sensor suite and R-Bar Pitch Maneuver have been assessed as part the Task Group's evaluation of CAIB Recommendation 3.4-3, High-Resolution Imagery of Orbiter. That recommendation was closed on June 8, 2005 (see Section 3.6 of this report). Data from the wing leading edge impact detection system will be used as corroborating evidence with imagery data to provide focus for on-orbit inspection. The limited data that will be available due to short battery life, together with the experimental nature of this system, mandate that no critical decisions be based on the data from this system.

The Task Group supports use of numerous other sources of ground and airborne imagery during launch and ascent to provide views of the External Tanks and Orbiter which serve as pointers for focused inspection of the Orbiter by the OBSS. All these capabilities together should assure a comprehensive and successful inspection.

3.13.4.2 *Repair Technologies*

Although NASA has determined, and accepted the risk, that the repair capability called for in CAIB Recommendation 6.4-1 is not a constraint to launch of STS-114, the Space Shuttle Program intends to provide the STS-114 crew with the best available options. An enormous amount of work on both tile and RCC repair has resulted in five experimental repair techniques. None of these techniques will be certified for STS-114; some may never be certified because they are too operator dependent. As NASA stated in the May 2005 version of the *Integrated Risk Acceptance Approach for Return to Flight* – “Until a verifiable, reliable Thermal Protection System repair technique for tile and reinforced carbon-carbon components is in hand, we will have limited, best effort capabilities to apply when needed.”

While it is prudent to manifest repair materials and hardware on STS-114 to be used only if the Orbiter cannot otherwise make a safe entry, extreme caution must be exercised when use of these materials and hardware might further exacerbate the risk to Orbiter and crew beyond the risk due to the initial Thermal Protection System damage. In particular, the RCC plug and tile overlay repairs require additional holes to be bored into the Thermal Protection System, and CIPA and NOAX can each create an additional hazard if the material expands beyond the Orbiter outer mold line. Each option carries its own risks. For STS-114, should a damage situation require use of any repair technique, the Mission Management Team and NASA leadership will confront extremely complex and difficult risk-versus-risk trades given the unknowns and uncertainties within and between inspection, repair, and rescue options.

3.13.4.3 TPS Damage Assessment

The Task Group believes that it is just as important to be able to decide when not to repair as it is when to attempt a repair, especially when the repair capabilities are unproven. The “critical damage maps,” although certified for preflight, continue to evolve to reduce the likelihood of making unnecessary repairs. The NASA Engineering Safety Center (NESC) peer review of critical tile damage models is an important milestone to be achieved prior to STS-114; a preliminary draft was available to the Task Group during this assessment. The addition of the peer review provides added confidence in the accuracy of these models.

The Mission Operations Directorate has defined several alternate scenarios to minimize entry heating that will be available should they be required. A number of procedures in various stages of maturity can be uplinked so that the crew can make these adjustments.

Because they will be collecting significant volumes of data on the condition of the TPS, much of which will be new to the ground operations team, the Task Group fully supports the development of NSTS 6054, *STS-114 Operations Integration Plan for Thermal Protection System Assessment* (the OIP) and its associated *Damage Assessment Annex* to govern the use of all these data in the decision-making process on the health of the Orbiter Thermal Protection System and the potential need to repair damage, execute other operational risk reduction strategies, or fly home with the expectation that the damage is not large enough to be considered critical. See Section 2.2 of this report for a further discussion of the OIP.

3.13.4.4 Conclusion

In the May 2005 *Integrated Risk Assessment Approach for Return to Flight*, NASA acknowledges that External Tank debris allowables currently do not protect against catastrophic damage to the Orbiter Thermal Protection System. Therefore the goal of demonstrating that the Orbiter Thermal Protection System can withstand impact from any debris which may be released from the External Tank or other flight elements has not been met. Nor can the repair options manifested on STS-114, even if they were certified, repair the range of damage that could occur. There is a gap between possible debris liberation and the ability of Orbiter Thermal protection System to withstand impact and to repair damage.

The Task Group has reached the conclusion that the five experimental repair options manifested on STS-114 show promise for future flights, but are contingency measures rather than practicable repair capabilities at this time. Even though all Orbiter Thermal Protection System repair techniques being considered are only for emergency use and cover a limited range of potential damage, they can and should go through a rigorous design and certification process; to date, none of the tile or RCC repair techniques have gone through this process. Therefore, the Task Group does not consider tile and RCC repair techniques sufficiently mature to be a practicable repair capability for STS-114.

As assessed in Section 3.6 (R3.4-3), the inspection techniques planned for STS-114 provide high resolution capability and significantly enhance the ability to view possible damage. Resources available via National assets (R6.3-2) add to this capability. Therefore, NASA has satisfied the inspection portion of this recommendation.

The RTF TG assessment of NASA’s actions was completed at the June 27, 2005, meeting. Despite extensive efforts on the part of the Tile Repair Project and RCC Repair Project to develop a practicable Thermal Protection System repair capability, the majority of the Task Group believes that the intent of CAIB Recommendation 6.4-1 has not been met.

3.13.5 RTF TG Observation

The RTF TG believes that the repair portion of R6.4-1 presented an extreme technical challenge to NASA given the physical characteristics of the Orbiter Thermal Protection System. Repairs to TPS damage of the magnitude suffered by *Columbia* are not considered feasible with current technology; however, modifications to the External Tank should preclude that type of damage from occurring in the future.

3.13.6 RTF TG Minority Opinion on CAIB Recommendation 6.4-1

Much of the discussion among Task Group members has centered on the definition of the words “practicable capability.” While Task Group members agree that a practicable capability must be “feasible, able to be accomplished,” we cannot agree on the level to which a task must be developed before it becomes a “capability.” The minority opinion of the Task Group is that a repair technique is a capability if it can actually be performed on orbit and has been shown to be able to withstand the heat of entry, which is its intended purpose.

There has been further discussion around the accident board’s intent when they used the words “widest possible range of damage.” Multiple conversations with several members of the CAIB, including those most closely associated with the writing of this recommendation indicate a clear intent of those words to be “to the widest possible damage that NASA can accomplish.” Thus, the fact that NASA does not yet have coverage for 100 percent of the Orbiter Thermal Protection System does not preclude compliance with the intent of the recommendation.

While much more testing is necessary to increase the confidence in the repairs and to certify them, the repair capabilities are a far cry from the notion outlined for the CAIB that amounted to stuffing tools and water-filled baggies into the wing leading edge while dangling from a ladder hanging from the payload bay doors (CAIB, Vol. I, p. 173). The use of the crew in the development of the operations associated with the repair techniques, coupled with multiple training sessions using the standard environments to prepare for EVA operations, have resulted in repair techniques that can be put into practice should the need arise. MMT and component simulations have shown a willingness of the community to attempt a repair should one be deemed necessary, and upon successful completion of that repair, evaluated using set criteria, a willingness to bring the Orbiter and crew home rather than commit to a CSCS and attempt to launch a second vehicle.

The minority opinion of the RTF TG is that this is what the CAIB intended when writing Recommendation 6.4-1. Therefore, it is the minority opinion of the Task Group that the intent of CAIB Recommendation 6.4-1 has been met.

Discovery, with Earth as a backdrop, performs the R-bar Pitch Maneuver as she approaches the International Space Station. The crew of the ISS takes high-resolution photographs of the Orbiter during this maneuver to allow ground-based analysts to determine if there is any damage to the Orbiter Thermal Protection System.



3.14 CAIB Recommendation 9.1-1 – Detailed Plan for Organizational Change

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.

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

- *Develop and maintain technical standards for all Space Shuttle Program projects and elements*
- *Be the sole waiver-granting authority for all technical standards*
- *Conduct trend and risk analysis at the 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.

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

R7.5-3 *Reorganize the Space Shuttle Integration Office to make it capable of integrating all elements of the Space Shuttle Program, including the Orbiter.*

3.14.1 RTF TG Interpretation

The Columbia Accident Investigation Board (CAIB) expected NASA to return to flight relatively quickly, and did not want to restrict this activity by requiring major organizational changes. Instead, the CAIB wrote a separate recommendation that NASA produce a detailed plan on how the Agency would implement organizational changes embodied in three other recommendations (R7.5-1, Independent Technical Authority; R7.5-2, Safety and Mission Assurance; and R7.5-3, Systems Engineering and Integration).

However, preparations for the first return-to-flight mission took longer than initially expected, and NASA proceeded to implement the three specific organizational recommendations of the CAIB; the Task Group elected to evaluate the actual changes, although the final assessment was based only on the required plan.

The CAIB used the term “culture” throughout its report, although there was not a specific recommendation (RTF or otherwise) to change NASA culture. Nonetheless, numerous CAIB findings and observations strongly emphasize leadership, managerial, training, and organizational issues that require immediate and serious attention. Within the parameters of the RTF TG charter, the Task Group did not specifically address these CAIB “culture” concerns, and the Task Group did not assess the studies ongoing within NASA pertaining to culture issues. Nonetheless, NASA has elected to implement an Agency-wide response to R9.1-1 through a document entitled “NASA Plan for Implementing Safe and Reliable Operations” (referred to as the “9.1-1 Plan”).

Many of the CAIB organization observations are reflected in R7.5-1. The CAIB observed critical technical requirements were routinely waived and concluded the inherent conflicts of schedule, cost, and safety – the balance for which resided essentially with the Space Shuttle Program Manager – needed to be separated to provide an independent safety consideration.

In regards to R7.5-2, the CAIB observed various parts of NASA were nominally responsible for “safety;” each NASA Center has safety organizations; each NASA program, including the Space Shuttle Program, has designated individuals responsible for safety; and NASA has an Office of Safety and Mission Assurance at Headquarters. This recommendation was intended to create clear lines of authority, responsibility, and communication, and help ensure independence by moving funding from NASA Centers and programs to NASA Headquarters.

The CAIB found several aspects of Space Shuttle operations it believed to be suffering from incomplete integration, prompting them to write R7.5-3. Perhaps the most glaring was the apparent division of responsibility for addressing the separation of foam from the External Tank. Simplistically stated, the Orbiter Project thought it was up to those responsible for the tank to stop the shedding; the External Tank Project assumed the shedding occurring was not injurious to the Orbiter because no one told them otherwise.

3.14.2 Background

The accident board’s independent investigation revealed numerous areas in NASA’s organization and its operations requiring substantial improvement before returning the Space Shuttle to safe and reliable flight operations. The CAIB report specifically called for a detailed plan prior to the return to flight on three fundamental changes that NASA needed to make to improve the safety and reliability of its operations:

- Restore specific engineering technical authority, independent of programmatic decision-making.
- Increase authority, independence, and capability of the Safety and Mission Assurance (SMA) organizations.
- Expand the role of the Space Shuttle Integration Office to address the entire Space Shuttle system, not just propulsive elements.

3.14.3 NASA Implementation

Once a plan for CAIB Recommendation 9.1-1 had been developed, NASA proceeded toward implementation.

3.14.3.1 Independent Technical Authority (R7.5-1)

The NASA Chief Engineer, as the Independent Technical Authority, governs and is accountable for technical decisions affecting safe and reliable operations. The Independent Technical Authority provides technical decisions for safe and reliable operations in support of mission development activities and programs and projects that pose minimum reasonable risk to astronauts, the NASA workforce, and the public. Sound technical requirements necessary for safe and reliable operations will not be compromised by programmatic constraints, including cost and schedule.

The Independent Technical Authority is also working to strengthen the technical conscience throughout the engineering community, that is, personal responsibility to provide safe technical products coupled with an awareness of avenues available to raise and resolve technical concerns. Technical authority and technical conscience represent a renewed culture in NASA governing and upholding sound technical decision-making by personnel who are independent of programmatic processes. This change affects how technical requirements are established and maintained as well as how technical decisions are made, safety considerations being first and foremost in technical decision-making. Five key principles govern the Independent Technical Authority. This authority:

1. Resides in an individual, not an organization;
2. Is clear and unambiguous regarding authority, responsibility, and accountability;
3. Is independent of Program Management;
4. Is executed using credible personnel, technical requirements, and decision-making tools; and
5. Makes and influences technical decisions through prestige, visibility, and the strength of technical requirements and evaluations.

3.14.3.1.1 Warrant System

The Chief Engineer has put technical authority into practice through a system of governing warrants issued to individuals. These Technical Warrant Holders (TWH) are proven subject matter experts with mature judgment who are operating with an Independent Technical Authority budget that is separate from program budgets and program authority. This Independent Technical Authority budget covers the cost of the Technical Warrant Holders and their agents as they execute their responsibility for establishing and maintaining technical requirements, reviewing technical products, and preparing and administering technical processes and policies for disciplines and systems under their purview.

The warrant system provides a disciplined formal procedure that is standardized across the Agency, and a process that is recognized inside and outside NASA in the execution of Independent Technical Authority.

On November 23, 2004, the NASA Administrator issued the policy and requirements to implement Independent Technical Authority through a technical warrant process. This policy was issued under NPD 1240.4 NASA Technical Authority (draft) and NPR 1240.1 Technical Warrant System (draft), and is in accordance with the 9.1-1 Plan. The Chief Engineer has selected Technical Warrant Holders for many critical areas, including all major systems for the Space Shuttle. These Technical Warrant Holders are making technical decisions necessary for safe and reliable operations and are involved in return to flight activities for the Space Shuttle. NASA is selecting additional Technical Warrant Holders to span the full range of

technical disciplines and systems needed across the Agency. The Chief Engineer issued several new warrants in March 2005, including one for Systems Safety Engineering which will help revitalize the conduct of safety analyses (failure mode and effects analysis – FMEA, hazards analysis, reliability engineering, etc.) as part of design and engineering. The Chief Engineer will continue to issue warrants as required.

3.14.3.1.2 Technical Conscience

Technical conscience is personal ownership of the technical product by the individual who is responsible for that product. Committee reviews, supervisory initials, etc., do not relieve these individuals of their obligation for a safe and reliable mission operation if their technical requirements are followed. Technical conscience is also the personal principle for individuals to raise concerns regarding situations that do not “sit right” with the Agency’s mandate for safe and reliable systems and operations. With adoption of the Independent Technical Authority and the warrant system, technical personnel have the means to address and adjudicate technical concerns according to the requirements of the situation. The Independent Technical Authority and Technical Warrant Holders provide the means for independent evaluation and adjudication of any concern raised in exercising technical conscience.

3.14.3.2 Safety and Mission Assurance (R7.5-2)

To address the authority issue raised by the accident board, NASA has strengthened the traditional policy oversight over NASA programs provided by the Office of Safety and Mission Assurance (OSMA) with explicit authority of the Administrator through the Deputy Administrator to enforce those policies. The Chief Safety and Mission Assurance Officer provides leadership, policy direction, functional oversight, assessment, and coordination for the safety, quality, and mission assurance disciplines across the Agency. Operational responsibility for meeting the requirements of these disciplines rests with the Agency’s program and line organizations as an integral part of the NASA mission. To increase OSMA’s “line authority” over field SMA activities, NASA has taken four important steps:

1. The Chief Safety and Mission Assurance Officer now has explicit authority over the selection, relief, and performance evaluation of all Center SMA Directors as well as the lead SMA managers for major programs – including Space Shuttle and International Space Station – and the Director of the Independent Verification and Validation (IV&V) Center.
2. The Chief Safety and Mission Assurance Officer will provide a formal “functional performance evaluation” for each Center Director to their Headquarters Center Executive each year.
3. “Suspension” authority is delegated to the Center Directors and their SMA Directors. This authority applies to any program, project, or operation conducted at the Center or under that Center’s SMA oversight regardless of whether the Center also has programmatic responsibility for that activity.
4. The Safety and Mission Assurance community, through their institutional chain of command up to the Deputy Administrator, now has authority to decide the level of SMA support for the project/program.

NASA safety and mission assurance support for the Space Shuttle Program consists of dedicated program office staff, technical support from the centers, and functional oversight from the Headquarters OSMA. The program’s SMA Manager reports directly to the Space Shuttle Program Manager and is responsible for execution of the safety and quality assurance requirements within the program. The program SMA Office integrates the safety and quality

assurance activities performed by all Centers for various projects and program elements located at those Centers.

The Center SMA Directorates provide technical support to the program's SMA Manager. They also provide independent safety and quality assurance functions in the form of independent assessments, safety, and reliability panel reviews. Finally, they provide a cadre of personnel dedicated to the Headquarters OSMA Independent Assessment function.

3.14.3.2.1 SMA Independence

The CAIB recommendation requires that OSMA be independently funded. After the *Report of the Presidential Commission on the Space Shuttle Challenger Accident*, also known as the Rogers Commission Report, NASA created the Office of Safety, Reliability and Quality Assurance, later renamed OSMA, and specifically set up its reporting and funding to be separate from the Office of the Chief Engineer and any of the programs. At the time of the *Columbia* accident, all funding for OSMA was in the general and administrative (G&A) line, separate from all other program, institutional, and mission support and functional support office funding. All permanent OSMA personnel are dedicated to OSMA and, therefore, independent of program or other mission support and functional support offices. This plan retains independent reporting and funding approach consistent with the CAIB recommendation.

With respect to center-based civil servants and their support contractors performing safety, reliability, and quality assurance tasks, this plan calls for significant change. The 9.1-1 Plan establishes that the institution, not the program, decides SMA resource levels. Under the oversight of Headquarters Center Executives, centers will set up "directed service pools" to allow SMA labor to be applied to programs and projects in the areas and at levels deemed necessary by SMA Directors and their institutional chain of authority. The SMA Directors will pre-coordinate the use of their resources with the programs to foster understanding of how SMA labor will be used. This approach will guarantee both organizational and funding independence from the programs in a way that fully addresses the CAIB findings. Finally, the Headquarters OSMA will, for the first time, be a voting member of the Institutional Committee wherein institutional (including the directed service pool) budget decisions are made for the Agency.

The prior definition of independence focused on organizational independence, and the Space Shuttle program and project managers had approval authority for about 99 percent (based on FY03 estimates) of total SMA funding level for Space Shuttle (including all contractor and Center NASA and support contractor SMA resources). The remaining 1 percent consisted of Center SMA supervisor time (paid by center general and administrative funds) and approximately \$2 million per year of Space Shuttle Independent Assessment activity paid for by Headquarters OSMA.

Under the new definition of independence, which now includes the directed service pool, the Space Shuttle Program has funding approval authority for only about 70 percent of the total SMA funding level. This funding pays for Space Shuttle prime and subcontractor SMA and for the small civil service SMA Management Office in the program. Remaining funding approval is accomplished through the directed service pool, and is therefore independent from the program.

3.14.3.2.2 SMA Capability

To address SMA capability, all centers have reviewed their safety and mission assurance skills and resources for adequacy and added positions as required. Headquarters OSMA has increased significantly its ability to provide functional oversight of all NASA safety and mission assurance programs. Staffing has been increased in the Headquarters office from 48

to 51 people, partly to accommodate increased liaison needs created by the addition of NASA Engineering and Safety Center (NESC), IV&V, and new assurance programs. At the time of the *Columbia* accident, OSMA had a budget of \$6 million per year for Independent Assessments, its primary assurance tool. OSMA will continue to send Independent Assessment funding to the centers for use by SMA Directorates in performing center audits and supporting OSMA audits and assessment of resident programs.

The NASA Engineering and Safety Center (NESC), as a technical resource available to the SMA community, in coordination with the ITA, combined with IV&V and Independent Assessment capabilities, provides an unprecedented increase in the independent assessment, audit, and review capability. This will reinforce the SMA community's role in providing verification and assurance of compliance with technical requirements owned by the Independent Technical Authority, and in technical support for mishap investigations.

The Independent Technical Authority will own all technical requirements, including safety and reliability design and engineering standards and requirements. OSMA will continue to develop and improve generic safety, reliability, and quality process standards, including FMEA, risk, and hazards analysis processes; however, the Independent Technical Authority will specify and approve these analyses and their application in engineering technical products.

NASA is also improving its trend analysis, problem tracking, and lessons learned systems (CAIB Finding F7.4-9, -10, and -11), in a concerted effort to ensure the Independent Technical Authority invokes appropriate technical requirements. In order to improve OSMA insight and reduce the confusion cited in F7.4-13, NASA is formalizing its Prelaunch Assessment Review (PAR) process for the Space Shuttle and International Space Station, and the equivalent processes for expendable launch vehicles and experimental aerospace vehicle flight approvals, called Independent Mission Assurance Reviews (IMAR). Both processes have been standardized into a new NASA-wide review process called Safety and Mission Assurance Readiness Reviews (SMARR).

In addressing the CAIB concern about the lack of mainstreaming and visibility of the system safety discipline (F7.4-4), OSMA has taken two actions, one long term and the other completed. First, the audit plan includes the project and/or line engineering assessment of the OSMA system safety engineering per new NASA policy directives for program management and ITA. Secondly, for some years the senior system safety expert in the Agency was also the OSMA Requirements Division Chief (now Deputy Chief, OSMA). To respond to the CAIB concern, OSMA has brought on a full-time experienced system safety manager who is the Agency's dedicated senior system safety assurance policy expert. In addition, the Chief Engineer will select a Systems Safety Engineering Technical Warrant Holder who will be responsible for establishing systems safety engineering requirements.

The SMA Directorates supporting the Space Shuttle Program are staffed with a combination of civil service and support contractors providing system safety, reliability, and quality expertise and services. Their role is predominantly assurance in nature, providing the program with functional oversight of the compliance with requirements of the contractor engineering and operations. The civil service personnel assigned to work on Space Shuttle are functionally tied to their Center SMA organizations, and although some are collocated with their project or contractor element, their official supervisors are in the Center SMA organization.

The System Safety Review Panel (SSRP) process continues to evolve as the relationship between the ITA, SMA, and the Space Shuttle Program is defined and understood. This plan redefines the SSRP as the Engineering Risk Review Panels (ERRP). The ERRP is designed to improve engagement by the engineering community into the safety process, including the development and maintenance of documentation such as hazard reports.

The organizational structure of the ERRP will consist of Level II (Program) and Level III (Project/Element) functionality. The ERRP structure and process continues to evolve in a phased approach. Until return to flight, the Space Shuttle System Technical Warrant Holder will be represented at all ERRP levels through trusted agents who are assigned to support each ERRP. The trusted agents ensure that the engineering interests of the Independent Technical Authority are represented at all working levels of the ERRP and are reflected in the products resulting from these panels. After return to flight, the Shuttle System Technical Warrant Holder will reassess his/her role in all Space Shuttle Program panels and boards that deal with flight safety issues, including the ERRP.

The Level II Panel will ensure that the safety integration function remains at the Program level. It will have representation by all program elements as well as the Engineering Directorate, ITA, and SMA. The Lead ERRP Manager will also assure that Level III panels operate in accordance with safety program requirements. The Level II Panel exists to oversee and resolve integrated hazards, forwarding them to the System Integration Configuration Board (SICB), and finally to the ITA and the Space Shuttle Program Manager for approval.

The Level III ERRPs will consist of a Johnson Space Center (JSC) Panel dealing with the Orbiter, extravehicular activity, government-furnished equipment, and integration responsibility; a Marshall Space Flight Center (MSFC) Panel that handles the External Tank, Solid Rocket Booster, Reusable Solid Rocket Motor, and Space Shuttle Main Engine; and a Kennedy Space Center (KSC) Panel that deals with ground servicing equipment and ground operations. As presently defined, the Level III Panels will be chaired by the independent SMA Directorates at each center, again with representation by trusted agents at these panels.

The Space Operations Mission Directorate Space Shuttle Certificate of Flight Readiness (CoFR) process is being updated to clearly show the new SMA, Integration, and Independent Technical Authority roles and responsibilities. Part of that will be a requirement for concurrence by the Chief Safety and Mission Assurance Officer on the flight readiness statement as a constraint to mission approval.

3.14.3.3 Integration of the New ITA and SMA (R7.5-1/R7.5-2)

In a practical sense, the people that perform the responsibilities of SMA and the ITA need to be involved within a program or project beginning in the early stages and continuing for the life of the program or project. CAIB Recommendation 7.5-1 defined what activities at the program level must be clearly controlled by the Independent Technical Authority. At the same time, Chapter 7 of the CAIB report makes it clear that the SMA organization must be independent of the program and technically capable to provide proper check-and-balance with the program. Finally, the SMA organization must be able to perform its assurance functions in support of but independent of both program and engineering organizations.

The Independent Technical Authority has delegated fully to responsible individuals who hold warrants for systems and engineering disciplines. Fundamentally, this concept brings a “balance of power” to program management such that the Independent Technical Authority sets technical requirements, the programs execute to that set of technical requirements, and the SMA organization assures the requirements are satisfied. This means that the Independent Technical Authority owns the technical requirements and will be the waiver-granting authority for them.

The principal effect of the foregoing is the clear assignment of responsibility for execution of design and engineering, including the safety functions (FMEA, hazards analysis, reliability engineering, etc.) to engineering with the Independent Technical Authority setting requirements and approving the resulting engineering products. In this context, SMA organizations have the responsibility for independently assuring that delivered products comply with requirements.

3.14.3.4 Systems Engineering and Integration (R7.5-3)

The CAIB found several deficiencies in the organizational approach to program-wide system engineering integration for the Space Shuttle Program. Their Recommendation 7.5-3 calls for a reorganization of the Space Shuttle Integration Office to “make it capable of integrating all elements of the Space Shuttle Program, including the Orbiter.” The CAIB concluded, “...deficiencies in communication ...were a foundation for the *Columbia* accident. These deficiencies are byproducts of a cumbersome, bureaucratic, and highly complex Shuttle Program structure and the absence of authority in two key program areas that are responsible for integrating information across all programs and elements in the Shuttle program.”

3.14.3.4.1 Integration Definition

NASA defines integration as a system engineering function that combines the technical efforts of multiple system elements, functions, and disciplines to perform a higher-level system function in a manner that does not compromise the integrity of either the system or the individual elements. The integration function assesses, defines, and verifies the required characteristics of the interactions that exist between multiple system elements, functions, and disciplines, as these interactions converge to perform a higher-level function.

3.14.3.4.2 Restructured Space Shuttle Systems Engineering and Integration Office

NASA has restructured its Shuttle Integration Office into a Space Shuttle Systems Engineering and Integration Office (SEIO) to include the systems engineering and integration of all elements of the Space Shuttle system. The SEIO Manager now reports directly to the Space Shuttle Program Manager, thereby placing the SEIO at a level in the Space Shuttle organization that establishes the authority and accountability for integration of all Space Shuttle elements. The new SEIO charter clearly establishes that it is responsible for the systems engineering and integration of all Space Shuttle elements. 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 JSC Engineering and Mission Operations Directorates and from outside of NASA. The role of the System Integration Plan (SIP) and the Master Verification Plans (MVP) for all design changes with multi-element impact has been revitalized. The SEIO is now responsible for all SIPs and MVPs, including those developed for all major changes that impact multiple Space Shuttle elements.

3.14.3.4.3 Orbiter Project Office

The Space Shuttle Vehicle Engineering Office is now the Orbiter Project Office, and its charter is amended to clarify that SEIO is now responsible for integrating all flight elements. NASA reorganized and revitalized the Integration Control Board, with the Orbiter Project Office now a mandatory member. The Space Shuttle Flight Software organization was moved from the Orbiter Project into the SEIO. This reflects the fact that the Shuttle Flight Software Office manages multiple flight element software sources besides the Orbiter.

3.14.3.4.4 Integration of Engineering at Centers

All Space Shuttle Program integration functions at JSC, KSC, and MSFC are now coordinated through, and receive technical direction from, the SEIO. The former MSFC Propulsion Systems Integration office is now called the Propulsion Systems Engineering and Integration (PSE&I) office. Agreements between the PSE&I Project Office and the appropriate MSFC engineering organizations are being expanded to enhance anomaly resolution within the Space Shuttle Program.

3.14.3.4.5 Integrated Debris Environments/Certification

The SEIO is also responsible for generation of all natural and induced design environments analyses. Debris is now treated as an integrated induced environment that will result in element design requirements for generation limits and impact tolerance. All flight elements are being reevaluated as potential debris generators. Computations of debris trajectories under a wide variety of conditions define the induced environment due to debris. The risk associated with the Orbiter Thermal Protection System will be reassessed for this debris environment, as will the systems of all flight elements.

3.14.3.5 Summary

The reorganized SEIO now addresses all elements of the Space Shuttle system including the Orbiter. The SEIO manager located at JSC has oversight and control of matrix Systems Engineering and Integration support from KSC and MSFC. SEIO works in compliance with Independent Technical Authority requirements and the SMA organization. SEIO recognizes the Independent Technical Authority as the approval authority for variances to technical requirements, as documented in NSTS 07700, Volume IV. Additionally, SEIO will conduct integrated hazard analyses with the oversight of the Space Shuttle System Technical Warrant Holder. The results of these analyses will be accepted or rejected by the Space Shuttle System Technical Warrant Holder prior to use.

3.14.4 RTF TG Assessment

In support of our assessment of CAIB Recommendation 9.1-1, the RTF TG conducted fact-finding with several former CAIB members, representatives of the NASA-Navy Benchmarking Team, and various senior NASA officials on numerous occasions during the last two years.

CAIB required only a plan to implement the 7.5-series of recommendations before return to flight. The accident board, as did many of the Task Group, assumed that the return-to-flight would not be a two-plus-year endeavor and a plan was all that could be reasonably expected before the launch of STS-114. Thus, strictly speaking, NASA has largely complied with this recommendation.

With the passage of time, however, the NASA Administrator announced his desire to have the elements of R9.1.1 implemented, at least for the Space Shuttle Program, before the return to flight. The Task Group has therefore been able to monitor the implementation of at least some of the plan, gauge early effects, and evaluate whether the individual elements of the 7.5-series of recommendations meet the intent of the CAIB. On that basis, the results are mixed.

3.14.4.1 Recommendation 7.5-1: Independent Technical Authority

The CAIB was concerned with the conflict of interest inherent in the Space Shuttle Program Manager balancing resources, schedule, and safety. In that role, prior to the *Columbia* accident, the program manager was often called upon to approve waivers of technical requirements – waivers that could compromise program safety – sometimes in order to meet schedule or budget constraints.

The road to the current plan was neither straight nor smooth – there was a great deal of resistance from the safety community within NASA as well as from the various NASA centers. Some in the safety community view the current construct as a diminution of authority, with certain standards and waiver authority transferred to the ITA. The original assignment of NESC to SMA and its subsequent movement to the Chief Engineer was also viewed as a further relegation of authority. The NASA centers, maintaining their historical

position, argued that the accident board's recommendation for Headquarters-level ITA was misguided – that centers are better able to manage technical authority.

The Agency's plan for implementing a new agency-wide Independent Technical Authority places waiver-approval in the hands of the Chief Engineer, who is independent of all programs. However, because of internal dissension, the final organizational structure of the Independent Technical Authority was only recently determined and full implementation has not yet been accomplished. The establishment of roles and responsibilities, in addition to technical waivers, is being determined in conjunction with the Office of Safety and Mission Assurance and the Systems Engineering and Integration Office.

The Chief Engineer has chosen to exercise this authority through delegation to a series of Technical Warrant Holders. Each warrant holder is considered to be among the foremost technical experts in his or her field employed by NASA. Warrant holders essentially own the technical standards specified in their warrant and possess the discretion to change the standards and grant waivers to them.

This construct is fully consistent with the intent of the CAIB. However, not all details of implementation have been worked out, especially the roles and responsibilities of the Independent Technical Authority relative to Office of Safety and Mission Assurance and the Systems Engineering and Integration Office. Further, while a number of warrant holders have been designated, not all will be in place before the return to flight.

There also remains resistance within NASA to the totality of the change implied by the Independent Technical Authority concept. Nevertheless, the Agency's implementation of this recommendation is viewed by many in Congress and the public as an indicator of the Agency's willingness to change. Further implementation of the Independent Technical Authority and its durability will be of continued interest long after the return to flight. Ultimately, the sustainability of the Independent Technical Authority will be one measure of NASA's willingness to change critical processes.

3.14.4.2 Recommendation 7.5-2: Safety and Mission Assurance

The CAIB viewed the organization of the Agency's Space Shuttle safety offices as a contributing factor to NASA not being appropriately attuned to minimizing risks. They recommended: "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."

After review, NASA determined it is preferable to keep the Center Directors in the line of authority so they retain some responsibility for safety. Therefore, NASA has chosen not to completely comply with the CAIB recommendation. Instead, they have increased the authority of Headquarters, but are keeping the director of each NASA Center responsible for safety and mission assurance by continuing to have each center's SMA organizations report to the Center Director rather than the Chief Safety and Mission Assurance Officer at Headquarters. As part of these changes, NASA has strengthened the role Headquarters plays in employment and evaluation of safety personnel, and removed decisions for funding safety activities from the Space Shuttle Program.

The Task Group has also noted OSMA efforts to enhance its auditing role – making sure that safety-related processes are adequate and implemented. Expanded auditing can help ensure that the remaining center-centric aspect of managing the safety organizations is not detrimental to the overall agency adoption of adequate safety systems. Like R7.5-1, the success of the implementation of this recommendation will require consistent attention by NASA leadership to ensure survival.

3.14.4.3 Recommendation 7.5-3: Systems Engineering and Integration

The CAIB noted the apparent inability of the Space Shuttle Program to integrate across its various components. In the long history of NASA, integration has been the hallmark of both the challenges and successes of the Agency. In the particular case of the *Columbia* accident, foam from the External Tank inflicted catastrophic damage to the Orbiter. Previous instances of foam debris – including one just two flights prior to STS-107 – had not been taken sufficiently seriously by the managers of either the External Tank Project or the Orbiter Project. It appeared that no one was in charge of monitoring trends between and among flights, and data was generally unable to be shared between NASA Centers and program elements. The Agency’s capabilities for system engineering had atrophied.

In response to the CAIB recommendation, NASA enhanced the reach and responsibilities of the SEIO operation within the Space Shuttle Program. Additional resources and personnel were added and new processes instituted. The integration function was improved and coordination between the program elements is more common. In addition, system analysis has improved; e.g., analytical modeling of debris flow. In strengthening system analysis and integration, the basic intent of R7.5-3 has been partially accomplished.

However, weaknesses remain in the system engineering function and related processes. In many cases unverified and unvalidated analytical modeling is replacing sound engineering rationale as the hallmark of establishing engineering standards, measuring the attainment of technical requirements, and assessing risk.

The Task Group and other outside observers (e.g., The Aerospace Corp. audit and NESC) have faulted NASA for inadequate documentation. Requirements have often been established long after design, testing, or hardware modifications have taken place; e.g., foam debris allowables, or repair material to be flown on the next flight manufactured prior to the completion of the establishment of requirements or formal design reviews. In some cases, such as ice debris from the External Tank, or software to control the bellows heaters, the requirements have yet to be established, as of the June 8, 2005 Task Group’s public meeting.

Further, the SEIO management of the Design Certification Review/Design Verification Review (DCR/DVR) process for the return to flight has been inconsistent – each project has executed these critical processes in different manners, ranging from rigorous reviews to status reports. In many cases, minutes of the meetings were not published and required actions were not tracked. Information is therefore not systematically collected and may be lost or not easily accessible; e.g., the list of actions from the first Program DCR, conducted April 19, 2005, took over three weeks to assemble and consisted of different, non-collated lists contained in over half a dozen non-standardized files.

3.14.4.4 Conclusion

NASA has a mature plan to restructure the organization in response to the CAIB recommendation and therefore satisfies the letter of R9.1-1. Planned implementation of the Independent Technical Authority comports with CAIB intent – it will take some time to see if the process is robust enough to be sustainable. The planned response to R7.5-2 is intentionally not consistent with CAIB intent – NASA simply disagrees that the best organization for SMA is direct reporting to Headquarters. Implementation of R7.5-3 is uneven, with improved integration and system analysis but remaining gaps in system engineering capability.

The RTF TG assessment of NASA’s actions was completed at the June 8, 2005 meeting. The intent of CAIB Recommendation 9.1-1 has been met.

3.14.5 RTF TG Observations

The Task Group observes that the R9.1-1 plan is a first iteration, and the implementations of the 7.5-x recommendations are works in progress. Constant senior leadership vigilance of the implementation will be required to ensure maturity and resolve potential areas of conflict or confusion in terms of roles and responsibilities. The Task Group suggests that the Aerospace Safety Advisory Panel (ASAP) continue to review the ongoing implementation of the 7.5-x recommendations.

Because of a lengthy NASA internal debate over the implementation of Recommendation R7.5-1, planning was not finalized until November 2004, resulting in a major organizational change to the program late in 2004. This resulted in confusion over roles and responsibilities and significant changes to program documentation immediately prior to the then-scheduled return-to-flight launch of STS-114. Of particular importance for NASA leadership is to ensure that the Independent Technical Authority implementation fulfills one of its stated key principles, specifically, “clear and unambiguous ... authority, responsibility, and accountability.”

Although not directly related to any CAIB recommendation, the Task Group applauds NASA’s establishment of the NASA Engineering and Safety Center (NESC) and observed valuable work produced by NESC. Over time, NASA leadership needs to ensure clarity of the NESC role (and more importantly, the NESC authority) in decision making.

With respect to Recommendation R7.5-2, given the NASA alternative to “direct line reporting” and the history from *Challenger* to *Columbia*, the Task Group feels that significant NASA Headquarters leadership attention will be required to ensure SMA “independence” and appropriate authority. Enhancing Headquarters auditing capabilities and performance are critical to ensure this result. NASA Headquarters may wish to develop specific metrics and oversight to periodically ensure the independence and authority of critical SMA functions, including their performance in the Mission Management Team.

Since the Space Shuttle SMA Manager is the voting member of the MMT, constant vigilance will need to be maintained to ensure the independence of the safety function and that close communications are maintained with those SMA directors which possess “suspension authority.”

In regards to recommendation R7.5-3, the Task Group expects that NASA will address the remaining identified weaknesses in the systems engineering function and processes; will demand rigorous documentation that sustains effective systems integration and engineering; and will require improvements in standards for (and standardization of) validation, verification, and certification requirements for the development and use of analytical models.

NASA further needs to assess the impact of its contractual relationships on effective systems engineering and integration. The Task Group was advised very shortly after its formation by Shuttle management that the Space Flight Operations Contract (SFOC) needed revitalization to ensure effective SEIO functions and/or those workforce capabilities reestablished in-house. The SSP needs to ensure that flight-to-flight verification and evolution of SEI databases are continuously updated, documented and appropriately provided for future flight and MMT decision making.

The Task Group also observes that a significant workforce challenge is facing NASA. The Space Shuttle Program long ago transitioned, largely, to an “operations and maintenance” organization, losing the skill set and talents required to do the developmental work that was required post-*Columbia*. The Space Shuttle will remain a “developmental” vehicle until its retirement, and will require a developmental mindset, skill set, and discipline at both the workforce and management levels.

3.15 CAIB Recommendation 10.3-1 – Digitize Closeout Photos

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

3.15.1 RTF TG Interpretation

During the investigation, the Columbia Accident Investigation Board (CAIB) encountered numerous engineering drawings that were inaccurate. Further, they discovered a large number of engineering change orders had not been incorporated into the drawings. Tied in with this, CAIB investigators were not able to access needed closeout photography for several weeks.

3.15.2 Background

Closeout photographs have been archived in a database at the Kennedy Space Center since the beginning of the program. (Closeout photos are pictures taken of Space Shuttle areas before they are sealed for flight.) This database was primarily used by the KSC engineering community and photos were filed based on the work authorization document that originally requested the photograph, making it difficult to search for particular images. A large number of non-standardized cameras were used resulting in arbitrary resolution of critical images. In addition, there were no clear requirements to photograph all critical closeout activities, or to record changes to the vehicle configuration.

In the years since the Space Shuttle was designed, NASA has not updated many of its engineering drawings or converted to computer-aided drafting systems. The accident board's review of those engineering drawings revealed numerous inaccuracies; in particular, the drawings do not incorporate many engineering changes made in the last two decades. Equally troubling was the difficulty in obtaining the drawings, accurate or not: some took up to four weeks to receive. Although some close-out photography was available as a substitute, these images took up to six weeks to obtain. The Aerospace Safety Advisory Panel noted similar difficulties in its 2001 and 2002 reports.

3.15.3 NASA Implementation

The Space Shuttle Program 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. Kennedy Space Center (KSC) closeout photography includes the Orbiter, External Tank, Solid Rocket Boosters, and Space Shuttle Main Engines, based on project requirements. The Photo Closeout Team divided the CAIB recommendation 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.

Led by the Photo Closeout Team, the Space Shuttle Program completed an extensive review of existing closeout photo requirements. This team systematically identified the deficiencies of the current system and assembled and prioritized improvements for all elements. These priorities were distilled into a set of revised requirements that has been incorporated into program documentation. NASA also added a formal photography step for KSC-generated documentation and mandated that photography of all Material Review Board (MRB) reports be archived in the Shuttle Image Management System (SIMS) database. These MRB problem reports provide 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, the Kennedy Space Center established a baseline for photographic equipment and quality standards, initiated a training and certification program to ensure all operators understand and can meet these requirements, and improved the SIMS. To verify the quality of photographs taken and archived, NASA has developed an ongoing process that calls for SIMS administrators to continually audit the photos being submitted for archiving in the SIMS. Photographers who fail to meet the photo requirements will lose their certification pending further training. Additionally, to ensure the robustness of the archive, poor-quality photos will not be archived.

The Nikon D100 digital camera provides a resolution of 6.1 megapixels.



NASA determined the minimum resolution for closeout photography should be 6.1 megapixels to provide the necessary clarity and detail. KSC has procured 36 Nikon D100 6.1 megapixel cameras and completed a test program in cooperation with Nikon to ensure the cameras meet the Agency's requirements.

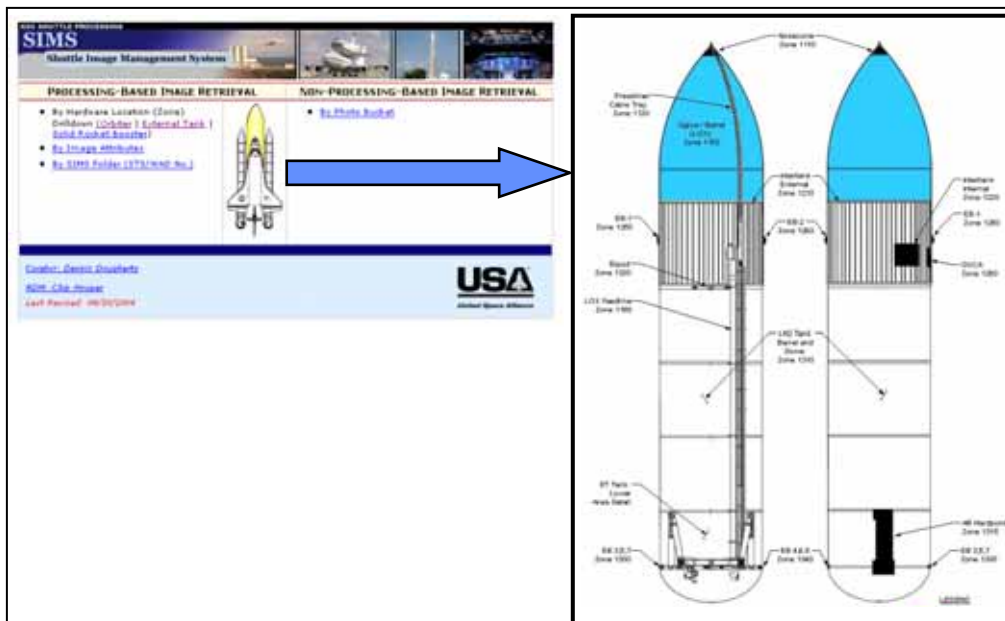
To improve the accessibility of the SIMS database, NASA developed a web-based graphical interface. Users can easily view the desired Space Shuttle elements and systems and quickly drill down to specific components, as well as select photos from specific Orbiters and missions. SIMS also includes hardware reference drawings to help users identify

hardware locations by zones. These enhancements will enable Mission Evaluation Room and Mission Management Team personnel to quickly and intuitively access relevant photos without lengthy searches, improving their ability to respond to contingencies.

The Shuttle Image Management System (SIMS) database features a graphical interface.

NASA has revised the Operation and Maintenance Requirements System to mandate that general closeout photography be performed at the time of 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 photography of visible MRB conditions be entered into the

SIMS closeout photography database. This requirement ensures 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.



Each Space Shuttle element is represented in the SIMS database.

Training for critical personnel is complete, and will be ongoing to ensure the broadest possible dissemination within the user community. Photographer training is complete and associated classes are taught on a regular basis. SIMS computer-based training has been developed and released. Use of SIMS has been successfully demonstrated in a launch countdown simulation at KSC, which included participation from the KSC Launch Team, JSC Flight Control Team, Mission Evaluation Room, MSFC Huntsville Operations and Support Center, and the Systems Engineering and Integration Office.

3.15.4 RTF TG Assessment

The Task Group conducted numerous fact-finding activities during 2004 concerning closeout photography and the SIMS database. These efforts complemented earlier meetings with KSC staff and their contractors to review their response to the CAIB recommendation in December 2003. New standardized 6.1 megapixel cameras have been acquired and are now being used in closeout and configuration photography. Generic and return to flight-specific closeout photo requirements have been established by program elements and documented. Photography of areas already closed has been deemed adequate. NASA identified enhancements to the SIMS and the necessary upgrades are complete. Updated training material has been developed for users of the SIMS database and users have received training at the Kennedy Space Center, Johnson Space Center, and Marshall Space Flight Center from local trainers. Through several integrated launch countdown simulations, the Space Shuttle Program staff has confirmed that the modifications to the SIMS database satisfy their needs.

When the accident board wrote their recommendations, they assumed that the Space Shuttle Program would continue for the long term, and indicated digital photography could provide an interim solution pending the digitizing and updating of all Space Shuttle engineering drawings (R10.3-2). However, based on the National Policy decision to retire the Space Shuttle no later than 2010, the Task Group concurs with the NASA decision that it does not make economic sense to expend the resources to make major changes to the drawings. The digital closeout photography provides an adequate solution until the end of the program.

However, if the Space Shuttle Program is extended past 2010, or if a Shuttle-Derived Launch Vehicle (SDLV) is selected as a future booster, this decision should be reevaluated.

The RTF TG initial assessment of NASA's actions was completed at the July 22, 2004, teleconference plenary where the assessment was conditionally closed. After receiving additional information from NASA, the assessment was fully closed at the December 16, 2004, meeting. The intent of CAIB Recommendation 10.3-1 has been met.

3.15.5 RTF TG Observation

If the Space Shuttle Program is extended past 2010, or a Shuttle-Derived Launch Vehicle (SDLV) is selected as a future booster, the decision concerning updating the Space Shuttle engineering drawings should be reevaluated.

Actual photographs from the SIMS database of STS-114. On the left, a photo of the liquid oxygen feedline where it comes out of the External Tank; on the right, a shot of the inside of a piece of the reinforced carbon-carbon wing leading edge panel.



More photographs from SIMS. At left is a turbopump impeller on a Space Shuttle Main Engine; at right, the bolts around a field joint of a Solid Rocket Booster.



More from the SIMS database. At left, the forward Orbiter-External Tank attach point; at right, the left main landing gear of *Discovery*.



3.16 Raising the Bar Action SSP-3 – Contingency Shuttle Crew Support

NASA Implementation Plan: *NASA will evaluate the feasibility of providing contingency life support on board the International Space Station (ISS) to stranded Shuttle crew members until repair or rescue can be accomplished.*

3.16.1 RTF TG Interpretation

Space Shuttle Program Action 3 (SSP-3) addresses Contingency Shuttle Crew Support (CSCS), the capability to harbor Space Shuttle crewmembers aboard the International Space Station (ISS) until a damaged Orbiter can be repaired or the crew rescued. The Columbia Accident Investigation Board (CAIB) did not make a specific recommendation with regard to CSCS, but Section 9.1 of the CAIB report listed the exploration of “all options for survival, such as provisions for...safe havens” as one of several necessary measures for safe flight. Section 6.4 of the CAIB report also assesses the possibility of rescuing a crew by launching another Space Shuttle.

3.16.2 Background

In the aftermath of the *Columbia* accident, NASA responded with a set of corrective actions characterized as “raising the bar” – not required by the CAIB for returning to flight, but self-imposed by the Space Shuttle Program. These actions are documented in the *NASA Implementation Plan*. One of these actions resulted in NASA examining options for providing a capability to sustain a Space Shuttle crew on the ISS should the Orbiter become unfit for entry. NASA chose to pursue CSCS as a functional emergency capability that is not certified, similar to how NASA addresses other emergency plans. Thus 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. Finally, NASA committed to ensuring that a rescue Space Shuttle will be available for at least its next two flights. In fact, NASA leadership committed to the delay launch of STS-114 and STS-121, if necessary, until a rescue vehicle can be ready within the projected CSCS window.

The Task Group chose to assess SSP-3 because NASA uses the CSCS capability as part of its launch rationale, and because NASA considers the ability to launch a rescue vehicle within estimated CSCS duration to be a constraint to launch for the first two return-to-flight missions. The CSCS capability bears on the safety and operational readiness of STS-114 and therefore falls within the purview of the Task Group to evaluate.

3.16.3 NASA Implementation

On June 9, 2004, the Space Flight Leadership Council approved pursuing the CSCS concept as an emergency capability for the first two return-to-flight missions, STS-114 and STS-121. NASA will revisit the feasibility and need for continued CSCS capability following STS-121.

The CSCS capability will not be fault tolerant, and imposes no additional requirements for fault tolerance other than those that already exist. The capability is built on the presumption that, if necessary, all ISS consumables and Orbiter reserves will be depleted to support the combined crews aboard the ISS until a rescue mission can be launched. In the most extreme CSCS scenarios, it is possible that the ISS crew will need to return to Earth following the rescue of the Space Shuttle crew until consumables margins can be reestablished and a favorable safety review is completed.

For the first two flights, NASA will ensure the capability to launch a rescue mission is available within the time period the International Space Station can reasonably sustain the

combined crews of the ISS and the stricken Orbiter. This includes allowing sufficient time to evacuate the ISS following departure of the rescue Space Shuttle, if necessary. This time period, referred to as the International Space Station engineering estimate of supportable CSCS duration, represents a point between worst- and best-case scenarios based on operational experience and engineering judgment. The ISS Program will provide this estimate in advance of the first two return-to-flight missions as a part of the flight preparation process.

To arrive at the engineering estimate, the ISS Program analyzed the impacts of maintaining seven additional people on the ISS in the event of CSCS. Their analyses indicate that at current operating levels, and with conservative assumptions of system viability, the combined crews can be supported long enough to allow the launch of a rescue mission. As consumables aboard the International Space Station are used by the normal crew prior to the launch of STS-114, the CSCS engineering estimate will change. The engineering estimate will be updated at specific milestones during the STS-114 mission planning process.

As part of the CSCS concept, NASA will have a second Space Shuttle, designated STS-300 for STS-114 and STS-301 for STS-121, ready for launch on short notice. The Space Flight Leadership Council has directed the ability to launch a rescue mission within the ISS Program engineering estimate will be a constraint to launch for the first two missions.

Should a rescue mission become necessary, it would be subject to the same requirements as any other Space Shuttle mission, but processed on an accelerated schedule. The rescue Orbiter would be reconfigured with additional accommodations, including seating, for the crew of the stricken Orbiter.



The International Space Station (ISS) could provide a safe haven for the crew of a damaged Orbiter using the Contingency Shuttle Crew Support capability described in SSP-3.

The rescue Orbiter, *Atlantis* for STS-300 and *Discovery* for STS-301, would be crewed by four astronauts. Following launch, the rescue Orbiter would dock with the ISS using standard rendezvous and approach procedures. Any extra consumables would be transferred to the ISS. The stranded Orbiter crew would board the rescue Orbiter and return to Earth with the four rescue astronauts. If evacuation of ISS becomes necessary, the ISS crew would return to Earth via the Soyuz spacecraft docked at the ISS.

Since, as currently configured, the ISS can only dock one Orbiter at a time, the stricken Orbiter must be undocked prior to arrival of the rescue Orbiter. NASA has developed procedures for undocking an unmanned Orbiter from the station, separating to a safe distance, then conducting a deorbit burn that will cause the Orbiter to enter and burn-up over an uninhabited oceanic area. These procedures have been developed in detail through the ISS Safe Haven Joint Operations Panel, and have been simulated in a joint integrated simulation involving flight controllers and flight crews from both the International Space Station Program and the Space Shuttle Program.

The decision to implement CSCS would result in extremely serious consequences, including: exposure of the stricken Orbiter crew to a severe survival situation presenting the distinct possibility of loss of life; exposure of the rescue Orbiter crew to flying a vehicle possibly vulnerable to the same failure(s) that stranded the first Orbiter; the loss of an irreplaceable National asset (the stricken Orbiter); possible depletion of ISS resources to a level requiring evacuation of ISS; and the likely termination of all future Space Shuttle missions, significantly restricting the United State's human access to space and utilization of the International Space Station.

Given these extreme consequences of implementing CSCS, the Space Flight Leadership Council has made it clear that the Mission Management Team (MMT) will be responsible for orchestrating a recommendation to implement CSCS only upon clear evidence of catastrophic Thermal Protection System damage that cannot be satisfactorily repaired. Such a recommendation would be accompanied by an assessment of the risk of repeating the failure(s) that damaged the first Orbiter. This would be aided by the enhancements to the ascent and on-orbit imagery collection and analysis made since the *Columbia* accident. The MMT would make its recommendation through the Deputy Associate Administrator for International Space Station and Space Shuttle Programs to the Associate Administrator for Space Operations. The final risk-versus-risk trade and decision to implement CSCS, or not, would be made at the Agency level with appropriate notification to National Authorities.

3.16.4 RTF TG Assessment

Since the CSCS capability was not a CAIB recommendation, the Task Group had no predefined criteria to evaluate the capability against. Instead, the RTF TG established five conditions that it believed constituted an adequate CSCS contingency capability:

1. Clear articulation of the role CSCS plays in NASA's risk management framework for damage to the Orbiter Thermal Protection System from debris.
2. Development of a dynamic, rigorous analytic process for estimating the number of days the ISS could sustain the seven crew stranded by a damaged Orbiter in addition to its two crewmembers.
3. Development and demonstration of a robust plan for launching a rescue Orbiter, including safely undocking and de-orbiting a damaged Space Shuttle.
4. Integration of CSCS plans and estimates into the pre-launch decision process and relevant documents.

5. Integration of the CSCS capability into the Mission Management Team (MMT) decision-making process, including a demonstration of its ability to consider the risk-versus-risk trades inherent in invoking CSCS, to make informed decisions in the face of these risks, and to implement CSCS procedures.

This assessment is based on information that emerged from various fact-finding activities. Most prominent among these were a series of meetings between the RTF TG Operations Panel and NASA representatives, beginning on July 8, 2004. The objective of this meeting was to help the Operations Panel obtain a high-level understanding of the NASA Thermal Protection System risk reduction framework, the role of CSCS in that framework, and the extent to which NASA intended to develop the CSCS capability. The second meeting took place on August 10, 2004, to help understand the analytic approach by which NASA will estimate possible CSCS duration. Of particular concern was the health, stability, and resilience of the ISS habitat under the stress of nine people.

In March, 2005, the Task Group observed the performance of the MMT during a simulation (sim #12), the objectives of which included analysis of tile damage and decision-making with regard to repair and the possibility of CSCS. Subsequently, a third fact-finding meeting occurred on March 22, 2005, to discern the extent to which the MMT had exercised the CSCS decision process. The fourth fact-finding meeting was on April 7, 2005, primarily to ascertain the NASA simulation supervisors' assessment of the MMT ability to make decisions regarding CSCS, as demonstrated in various simulations. The fifth meeting took place on April 8 where the NASA simulation supervisors reviewed the training strategy for an additional MMT simulation (sim #13) targeted at the MMT decision-making process regarding repair, entry, and CSCS. Finally, on May 4, 2005, the Task Group observed the simulation in which the MMT was confronted with the choice between entry on an uncertified tile repair or the declaration of CSCS.

The outcomes of these meetings, coupled with additional discussions, review of documentation, and the responses NASA provided to thirteen requests for information, form the basis for the Task group's assessment of SSP-3. Overall, the RTF TG finds that NASA set a Raising the Bar action for themselves and exceeded it by a significant margin. The Task Group commends NASA for its excellent work on SSP-3. This conclusion is derived from the following assessments against the five conditions specified above for successful SSP-3 implementation.

3.16.4.1 Condition 1: Risk Reduction

The NASA return-to-flight approach is founded on a framework for TPS risk reduction that has five hierarchically interrelated components: elimination of critical debris, impact detection during ascent, on-orbit damage detection, TPS repair, and crew rescue.¹ The Agency's core risk management strategy has been to eliminate critical debris sources. Despite these efforts, there remains some probability that debris could cause catastrophic damage, although NASA expects to be able to generate an accepted risk rationale. To reduce this residual risk enough to accept it and provide adequate flight rationale, NASA intends to rely on a set of strategies and capabilities first to detect damage to the Orbiter through sensing, imaging, and on-orbit inspection, and then to either effect repair or rescue the crew with another Space Shuttle.

Each of these capabilities faces technical challenges that create uncertainty about its viability and utility. Crew rescue also involves uncertainties associated with providing life support for the Space Shuttle and Space Station crews aboard ISS, undocking and de-orbiting the damaged Orbiter, and the launch of a rescue vehicle into a risk environment where damage,

¹ This approach is documented in *The Integrated Risk Acceptance Approach for Return to Flight*, May 2005.

potentially from unknown or not-well-understood causes, has already occurred. Furthermore, CSCS itself exposes the crews aboard the ISS to the risks inherent in operating in a survival mode. Finally, CSCS may deplete ISS consumables and systems to the point that the ISS must be evacuated. In sum, a decision to invoke CSCS poses a severe threat to the future of the Space Shuttle Program and the International Space Station Program.

These concerns prompted the RTF TG to query NASA about assessments of these uncertainties and risks, and of other unintended consequences that may result from CSCS. NASA reports that the Space Flight Leadership Council (SFLC) has discussed these risks and consequences “at various forums,” although they did not provide documentation of those discussions. They admitted that “no formal preflight assessment has been performed,” and intend to make a real-time assessment of the risk of rescue versus the risk of repair versus the risk of entry, should TPS damage occur. It is the sense of the RTF TG that while NASA recognizes these risks and the magnitude of potential consequences, they have not systematically developed a mature appreciation of this trade space.

Nonetheless, it is conceivable the aggregate benefits of these capabilities to crew survival will outweigh these risks, therefore providing sufficient justification for NASA to accept the residual risk of damage to TPS that remains after mitigation of critical debris. NASA has appropriately developed CSCS as a viable but limited contingency capability to be invoked only under particular circumstances of extreme emergency. These circumstances are confined to Orbiter TPS anomalies only (and not to other system failures), and further to cases where Orbiter TPS has suffered damage that cannot be repaired adequately to permit safe entry, and therefore the lives of the Space Shuttle crew are in jeopardy. In other words, CSCS is a last resort in the event of a catastrophic damage scenario. Since most of the mitigation for risk associated with critical debris is based on the efforts to reduce the foam shedding of the External Tank, the major burden of risk mitigation is not required of the CSCS capability. Thus, NASA has chosen not to make CSCS a “certified” contingency. This is a choice that the RTF TG endorses, since it would require extreme efforts to balance logistic resources and manage ground-breaking international agreements – efforts disproportionate given the probability of a CSCS declaration. The CSCS capability is, nonetheless, an integral component of NASA’s TPS risk management strategy that, in conjunction with other capabilities, can help NASA accept the residual risk that remains despite efforts to mitigate all sources of critical debris. To be a viable component of overall risk reduction, though, CSCS must be a capability that can be reasonably executed in a survival mode, therefore a vigorous analysis is required to determine ISS duration estimates that exceed the time necessary to launch a rescue mission.

3.16.4.2 Condition 2: Engineering Analysis

The centerpiece of CSCS is an engineering analysis that supports ISS habitability for nine people for a predicted duration; therefore this analysis must thoroughly address issues such as consumables, ISS Environmental Control and Life Support System (ECLSS) functionality, systemic ISS biosphere stability, stowage, crew protocols for food and exercise, and impacts from changes to launch schedules and vehicle manifests. NASA understands this need, and has developed an excellent engineering assessment process that provides an estimate of possible CSCS duration.

The International Space Station Program completed a study of the ability to support a one fault tolerant CSCS capability, and presented these recommendations to the Space Flight Leadership Council on June 9, 2004. The ISS Program has defined the following ECLSS functions as critical: carbon dioxide (CO₂) control and disposal, oxygen (O₂) generation and supply, water supply and recovery, and waste management.² The ISS Program’s June study

² ISS Contingency Crew Support (in support of STS TPS Anomaly) Status presentation to the SFLC,

concluded the ISS will be unable to meet one-fault tolerance in several important areas. Thus the CSCS capability is considered zero-fault tolerant overall, although some systems (e.g. temperature/humidity control and trace contaminant control) are as much as two-fault tolerant. Nonetheless, CSCS will not be a certified capability, since the ISS is only certified for a crew of six on a temporary basis and a crew of three on a permanent basis (without Space Shuttle support). Also, NASA is assuming that “STS-114 will require no newly developed Shuttle or ISS performance capabilities to enable CSCS.”³

It is also important to recognize that NASA is scoping CSCS possibilities “in-house,” and will not coordinate formally with the Russian Federal Space Agency (FKA) to extend FKA commitments beyond their current levels. The FKA has explicitly stated that it does not endorse the CSCS concept. The basis of the FKA position is an operational philosophy – advanced by the United States – that rejects having any more crew aboard ISS than there are “lifeboat” seats available for. The FKA did not comment on the adequacy of ISS consumables to support the CSCS plan. Furthermore, through informal discussions, NASA analysts are aware that their Russians counterparts believe there is unexploited margin in the estimated performance of their systems.

NASA published an L-1-month assessment that included an estimated CSCS duration for STS-114 of 43 days, given a May 15, 2005 launch.⁴ NASA will revise this analysis as the status of systems and consumables aboard the ISS, Progress schedules, and STS-114 launch date vary. The engineering duration estimate is not, however, a stable figure; it can fluctuate as a result of changes in several conditions to which it is particularly sensitive, including:

- Progress [Russian ISS supply vehicle] schedule, which directly affects the levels of consumables aboard the ISS;
- Space Shuttle launch schedule, which likewise drives consumable levels and requirements;
- Current operational status of all environmental systems aboard the ISS, and the occurrence of failures in these systems;
- Plans for and assumptions about crew consumption; and
- Plans for, and assumptions about, Space Shuttle manifests, particularly regarding spares and consumables.

The fluidity inherent in the engineering estimate is mitigated to some extent by the fact that the prediction rests as much as possible on U.S. systems, and makes very conservative estimates about the performance of Russian systems (or omits them from consideration altogether). Moreover, the duration estimate could likely be extended through power-downs, resource-saving measures, and additional supplies/spares. Regardless, the stability and validity of the engineering estimate depends on good coordination and information flow between the International Space Station Program and the Space Shuttle Program.

June 9, 2004.

³ NASA’s *Implementation Plan for Space Shuttle Return to Flight and Beyond*, (Tenth Edition, June 3, 2005, p. 2-6).

⁴ According to NASA, “ISS ECLS engineering team has evaluated all of the critical ISS ECLS systems. Based on the current system status, past history, and current on-orbit consumables, the limiting system is oxygen supply, which can provide a 43-day CSCS TPS duration support.” (“STS-114 (LF-1) L-1 Month Duration Report of the Environmental Control and Life Support Systems (ECLSS) Contingency Shuttle Crew Support (CSCS) for Thermal Protection System (TPS) Failure,” March 2005, p. 24.)

Overall, the RTF TG believes that CSCS protocols must rest on a thorough engineering analysis that specifies the parameters under which CSCS is likely to be technically possible. It is our assessment that NASA has developed and demonstrated a sound approach to such an analysis.

3.16.4.3 Condition 3: Rescue Space Shuttle

Invocation of CSCS necessitates a rescue mission. For STS-114 and STS-121, the Space Flight Leadership Council has mandated that the Space Shuttle Program be able to launch a rescue mission within the ISS engineering estimate of CSCS duration. In the event of CSCS, NASA has developed a plan for launching a rescue Space Shuttle that would have a crew of four, and would return with the stranded Orbiter crew within the duration defined by the ISS Program. If evacuating the ISS becomes necessary as a result of depletion of ISS systems and consumables, the ISS crew would return via the Soyuz spacecraft already docked at the ISS.

Since only one Orbiter can dock to ISS, safe undock and de-orbit procedures for the damaged Orbiter are also necessary. The JSC Mission Operations Directorate has developed procedures for undocking an unmanned Orbiter from the ISS, separating to a safe distance, and then conducting a de-orbit burn to dispose the damaged Orbiter into an uninhabited oceanic area. These procedures have been exercised successfully in a joint integrated simulation involving flight controllers and flight crews from both the ISS Program and the Space Shuttle Program.

The Task Group's assessment is that NASA understands these processes well, and the RTF TG has confidence in their capability to execute them. The prominent concern associated with the launch of a rescue Space Shuttle is that it requires exposing the rescue Orbiter to the same potential for sustaining damage as that which stranded the primary vehicle. NASA is aware of this risk, although, as noted above, no formal assessment of this risk can be performed until the specific cause of the damage to the primary vehicle has been determined.

3.16.4.4 Condition 4: Launch Decision Process

The requirement to launch a rescue Space Shuttle imposes a need for NASA to address CSCS in its launch decision process, because it will have to specify the timeframe within which STS-300 must be ready to launch and CSCS requires coordination between the Space Shuttle Program and the International Space Station Program. CSCS processes are documented in a Memorandum of Agreement between the programs, which jointly analyze and report CSCS capabilities at L-6 months, L-3 months, L-1 month, and the L-2 week Flight Readiness Review. Updates to the estimate will be provided at the L-2-day and L-1-day MMT meetings, the L-9 hour pre-tanking meeting, and final go/no-go poll during the T-9 minute hold. If failures are reported during any of these updates, the MMT will assess their impact, and decide whether to continue or scrub the launch. NASA does not intend to write launch commit criteria to automatically abort a launch for late ISS failures which might create a gap in CSCS capability.

It is the RTF TG's assessment that the process for reporting and updating CSCS capability in the period before launch is appropriate.

3.16.4.5 Condition 5: MMT Capability

NASA asserts it will implement CSCS only upon clear evidence of catastrophic TPS damage that cannot be repaired. It has also determined that a CSCS decision will be made at the agency level, supported by MMT recommendations. The decision process by which the MMT would arrive at a CSCS recommendation is extremely difficult, and the potential consequences of CSCS implementation are momentous. Thus, invocation of CSCS requires complex risk-versus-risk assessments regarding whether to repair, entry, or launch a rescue

Space Shuttle that are fraught with uncertainty and ambiguity. To reduce uncertainty, these decisions will require the rapid assessment of data from multiple sources. To reduce ambiguity, these decisions will require close collaboration among MMT members to develop a common view of the severity of the risks.

Given how central these decisions about repair, entry, CSCS, and rescue are to the NASA risk architecture, and how challenging this decision process would be, the RTF TG believed that it was important for the MMT to exercise and demonstrate this decision-making and analytic process prior to flight. The RTF TG asked NASA to “demonstrate the MMT process to weigh and evaluate the risk of CSCS relative to other options in an integrated simulation; demonstrate how the MMT will build a rationale for launching the rescue vehicle; and demonstrate the MMT, MER, and FCT process to evaluate and consider unintended consequences resulting from calling CSCS.”

NASA believed they had fulfilled the RTF TG request during an MMT simulation held in early March, 2005 (sim #12). According to the simulation supervisor, the objectives of the sim included analysis of tile damage and decision-making with regard to repair and the possibility of CSCS. The simulation supervisor was satisfied with the MMT performance relative to this stated intent. Likewise, the chair of the MMT believed the MMT thought carefully about the implications of repairing the TPS versus invoking CSCS. While MMT sim #12 was a very important exercise that did appear to enhance the capacity of the MMT overall, RTF TG observers present during the simulation witnessed little systematic discussion with regard to CSCS specifically, and believed that NASA failed to fully confront – and ultimately make – the central, difficult risk-risk choices given circumstances where damage cannot be fully assessed, repairs may not be reliable, and a rescue launch may sustain similar debilitating damage. The minutes from the MMT meetings during the simulation also revealed little such discussion. Furthermore, the RTF TG discovered that the ISS team contribution to the MMT sim #12 scenario was relatively static, so that little discussion of the impacts on CSCS of the extra consumables used during the planned tile repair was possible.

Based in part on these concerns, NASA subsequently added another MMT simulation (sim #13) to the schedule, with the objective of completing the scenario that was started in MMT sim #12. Making the critical choice of whether or not to ride a repair to the ground, and performing the risk-versus-risk analysis in the process, were the driving goals for this simulation. In the end, the MMT did review pertinent risk for the major options, and did a greatly improved job of evaluating the CSCS/LON option. Critical factors related to CSCS duration were discussed, and the view of CSCS as a last-resort option was appropriately held by the MMT members. In the end, the MMT unanimously decided to attempt the return from orbit with the uncertified tile repair, but the rationale for this decision was logically and thoroughly discussed.

3.16.4.6 Conclusion

While the RTF TG believes weaknesses remain in NASA’s demonstration of their capacity to handle a CSCS decision, the MMT clearly has made important progress since the loss of *Columbia*, and its overall decision-making ability is much improved. The RTF TG believes the MMT is capable of addressing a CSCS decision appropriately.

The Task Group’s assessment of NASA’s actions was completed at the June 8, 2005, meeting. The RTF TG commends the Agency for its excellent work on SSP-3, and believes that NASA set a raising the bar goal for itself and exceeded that goal by a significant margin.

3.16.5 RTF TG Observation

RTF TG Observations concerning the MMT role in CSCS are provided in Section 3.11.

4 TRANSITION TO THE ASAP

The Aerospace Safety Advisory Panel (ASAP) is a senior advisory committee that reports to the NASA Administrator and Congress. The Panel was established by Congress after the Apollo 204 Command Module (“Apollo 1”) spacecraft fire in January 1967 to advise NASA on the safety of operations, facilities, and personnel.

The statutory duties of the ASAP, as prescribed in Section 6 of the NASA Authorization Act of 1968, Public Law 90-67, as amended, 42 U.S.C. 2477, are:

“The Panel shall review safety studies and operations plans that are referred to it and shall make reports thereon, shall advise the Administrator with respect to the hazards of proposed operations and with respect to the adequacy of proposed or existing safety standards, and shall perform such other duties as the Administrator may request.”

The ASAP consists of nine members appointed to two year terms, reaffirmed annually, by the NASA Administrator. The NASA Chief Safety and Mission Assurance Officer participates as an *ex-officio* member in Panel activities. The ASAP meets as a group four times per year, and conducts independent fact-finding as needed.

Given that the ASAP meets only quarterly, and has no full-time investigative staff, the RTF TG recognizes that this volume of forward work may be beyond the resources of the ASAP. It is possible that ASAP may be assisted by other independent entities to assess the Agency’s performance of the tasks described in the subsequent sections. For example, the ASAP could make arrangements with the NASA Engineering and Safety Center (NESC), the Independent Technical Authority (ITA), the National Research Council, the National Academies, or other independent organizations to assist in its evaluations.

4.1 Conditions for Transition

It became clear early-on that the ASAP would ultimately become involved with monitoring the NASA implementation of the Columbia Accident Investigation Board (CAIB) recommendations. The RTF TG was responsible for assessing only the CAIB recommendations marked “return to flight,” and the Task Group limited itself to this subset of 15 items. The remaining 14 (non-return to flight) CAIB recommendations, as well as other findings, observations, and NASA “raising the bar” actions would need to be assessed by another organization, such as the ASAP. CAIB believed that all 29 of their recommendations captured “thinking on what changes are necessary to operate the Shuttle and future spacecraft safely in the mid- to long-term.” While the RTF TG, by charter, focused solely on CAIB return-to-flight recommendations, the CAIB report focused more broadly on the needs of the Space Shuttle and future program needs.

As the RTF TG completed their assessments, it also became apparent that some of the return-to-flight implementations contained forward work that would require monitoring by another organization, and the RTF TG negotiated a Memorandum of Agreement with the ASAP to continue this work. In the case of the return-to-flight recommendations, the RTF TG only assessed those portions of the NASA implementation that was specifically intended for STS-114 – any future work was largely outside the scope of the Task Group. The conditions that predicated a need to transition a CAIB recommendation to the ASAP were:

1. A CAIB recommendation had a phased implementation approach, some being implemented before return-to-flight and some planned for implementation afterwards. For those phases of implementation not planned for STS-114, the ASAP will need to monitor and evaluate the future implementation.

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2. The implementation of a CAIB recommendation will be available for the return-to-flight, but the implementation needs to be demonstrated in the flight environment. An example includes the reduction of debris shedding from the External Tank. Since the RTF TG completed its assessments prior to STS-114, the ASAP will have to assess the results of the flight data to verify the performance is as expected.
3. A CAIB recommendation has a temporary implementation for STS-114 which cannot be used on a specific later flight, such as the proposed Hubble servicing mission. While the RTF TG has assessed the STS-114 implementation, the ASAP will need to monitor and evaluate the final implementation.

May 17, 2005


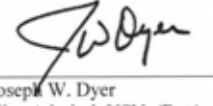
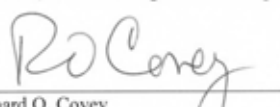
MEMORANDUM OF AGREEMENT

Members of the Return to Flight (RTF) Task Group and the Aerospace Safety Advisory Panel (ASAP) met on September 14, 2004, to discuss ideas to ensure a smooth transition between the panels after the Space Shuttle returns to flight. The focus of this transition effort was to capture knowledge and ensure continuity on critical safety issues as the RTF Task Group concludes. Followup activity on RTF issues and actions will be incorporated into the ASAP's working plan.

The following are essential elements of the agreement:

1. The RTF Task Group will deliver its final report before return to flight and will conclude its assessment, fact-finding, and reporting.
2. RTF Task Group Members will continue to be administratively available to support the ASAP, as requested, until their charter is terminated sometime after the STS-114 launch.
3. The RTF Task Group Co-Chairs will be available as spokespersons for the Task Group, if required, during the duration of the return to flight launch. In addition, Dr. Dan Crippen and Dr. Amy Donahue, who are members of both the RTF Task Group and the ASAP, will have authority to speak for the RTF Task Group on matters of interpretation of the RTF Task Group's final report.
4. Copies of required RTF Task Group electronic and paper records will be transferred to the ASAP.
5. After delivery of the RTF Task Group's final report, RTF Task Group panel leads will meet with ASAP members to conduct a transition briefing, identifying specific areas that the ASAP may consider for further observation.

We believe the proposed actions will ensure a smooth transition between the RTF Task Group and the ASAP.

 Thomas P. Stafford Lieutenant General, USAF, (Ret.) Co-Chair, Return to Flight Task Group	 Joseph W. Dyer Vice Admiral, USN, (Ret.) Chair, Aerospace Safety Advisory Panel
 Richard O. Covey Co-Chair, Return to Flight Task Group	

To assist in the turnover of activities from the RTF TG to the ASAP, several ASAP members were invited to observe the final two plenary meetings of the Task Group and witnessed at least one Mission Management Team (MMT) simulation. The turnover is also assisted by the fact that two Task Group members (Dr. Dan L. Crippen and Dr. Amy K. Donahue) are also members of the ASAP.

4.2 Items to be Transitioned

Several of the CAIB return-to-flight recommendations contain items the RTF TG believes the ASAP should continue to monitor. In addition, the Task Group has several items – not related to specific recommendations – that it believes require future monitoring or assessment. The ASAP might also wish to review the “RTF TG Observation” portion of each assessment.

4.2.1 Integrated Vehicle

The *STS-114 Operations Integrated Plan for Thermal Protection System Assessment* (or simply, the OIP) and its *Damage Assessment Annex* greatly enhanced the ability of the Space Shuttle Program to perform an integrated vehicle external damage assessment in support of decision-making, primarily within the MMT. The RTF TG believes that NASA should continue to develop the OIP and its Annex for all future flights, not just for STS-114. The information, understanding, and experience gained from producing the document for STS-114 will be invaluable for future mission data integration. The ASAP should monitor the continued development of the OIP and its Annex, as well as how the processes and timelines described in the documents are used for decision-making within the MMT and other groups.

4.2.2 CAIB Recommendation 3.2-1, External Tank Debris Shedding

Debris from the External Tank was the physical cause of the *Columbia* accident, and NASA has gone to tremendous lengths in their attempts to cure the problem. According to the NASA May 2005 document *The Integrated Risk Assessment Approach for Return to Flight*, “... The External Tank debris allowable requirements currently do not protect against catastrophic damage of the Orbiter Thermal Protection System.” NASA developed a three-phase approach to correcting the flaws in the External Tank; Phase 1 was implemented for return-to-flight and Phase 3 has been deferred because of the pending 2010 retirement date for the Space Shuttle. Phase 2 is currently slated as post-return-to-flight work, and the RTF TG believes the ASAP should closely monitor the implementation of these changes.

In addition, each of the tanks being used on the first eight launches was substantially completed prior to 2003 and has been modified – at least in the details – differently. Therefore, each is somewhat unique in its configuration. Although NASA plans to use data from the STS-114 flight to further characterize debris from the ET, it is possible that these differences will require additional data collection from future missions.

The RTF TG believes the results of analyses conducted after the STS-114 launch should be closely monitored, as well the applicability of any anomalies to the tanks scheduled for future missions. The ASAP should continue to track the Program’s efforts to eliminate critical debris by aggressively working off the limitations documented in NSTS 60555, *Verification Limitations for the External Tank Thermal Protection System*.

The Task Group suggests the ASAP monitor the continued use of the labor-intensive thermal protection system application processes enacted for the return-to-flight.

4.2.3 CAIB Recommendation 3.3-1, Reinforced Carbon-Carbon Non-Destructive Inspection

Understanding the condition of the RCC panels used on the Orbiter is essential for safe flight operations. NASA has identified future work including finishing the documentation of flight-to-flight inspections in the Operations and Maintenance Requirements Document (OMRSD) and competing the development of applicable non-destructive inspection standards.

The RTF TG believes the ASAP should monitor the Agency’s progress toward finishing the

documentation, and also ensure that meaningful non-destructive inspections continue for the remainder of the Space Shuttle Program. The Task Group is also concerned that NASA has only a single ship-set of spare RCC panels in inventory; something made troublesome by the long lead-times involved in manufacturing additional panels.

4.2.4 CAIB Recommendation 3.3-2, Orbiter Hardening

NASA decided to implement this recommendation in three phases. The first phase of changes to the Orbiters has been completed in time for STS-114. The second phase consists of two changes which could not be completed in time for the return to flight. They are the completion of the remaining “sneak flow” protection changes on RCC panels 1-4 and 14-22, and main landing gear door perimeter tile material change. The risk analysis of the tile damage tolerance indicated that the main landing gear door is one of the critical areas with which to deal. According of the NASA May 2005 document, *The Integrated Risk Assessment Approach for Return to Flight* (p. 11), their “... goal was to demonstrate that the capability of the Orbiter greater than the expected debris environment; however, we fell short in a number of cases.”

It is important for the ASAP to monitor the progress of the BRI-18 tile material certification and the completion of this change on all three Orbiters. The third phase involves more extensive changes to the Orbiters, but these are being reconsidered in light of the scheduled 2010 end of the program.

Future work that NASA has identified includes continuing the verification of the analytical models used in determining the impact resistance of the Orbiter, as well as the continuing refinement of the definition for “critical debris.” The RTF TG believes the ASAP should monitor the progress of each of these items, with particular attention on model verification and configuration management. Abandoning future upgrades to the Orbiter may be appropriate given the limited number of missions expected to be flown, but an independent assessment of this approach should be carried out. ASAP should review the correlation of the remaining risk of damage to potential future Orbiter hardening concepts.

4.2.5 CAIB Recommendation 3.4-1, Ground-Based Imagery

Future work that NASA has identified for this recommendation includes the continued refurbishment and procurement of imagery assets at the Kennedy Space Center and the Eastern Range. The RTF TG believes that the ASAP should continue to assess the availability of adequate imagery assets to ensure there are three useful views of the Space Shuttle available for all future launches.

4.2.6 CAIB Recommendation 3.4-2, High-Resolution Images of External Tank

Future work that NASA identified for this recommendation includes installing additional cameras on the External Tank and Solid Rocket Boosters to provide better imagery of the Orbiter and its environment during ascent. The RTF TG believes that the ASAP should assess the implementation of the ET attach ring and SRB forward skirt cameras, along with the SRB solid-state recorders, planned for STS-115 and subsequent flights.

4.2.7 CAIB Recommendation 3.4-3, High-Resolution Images of Orbiter

NASA has predicated much of its return-to-flight planning on conducting detailed inspections of the Orbiter once it is on orbit. These inspections are accomplished, for the most part, using the Orbiter Boom Sensor System (OBSS) installed in the payload bay and photography from the International Space Station.

The RTF TG believes that the ASAP should continue to assess what constitutes “adequate resolution” as the Orbiter critical damage size evolves. Also, NASA only plans to use the OBSS for a limited number of flights; the ASAP should review the plan to discontinue its use and ensure that other adequate means exist to acquire the necessary imagery.

4.2.8 CAIB Recommendation 4.2-1, Solid Rocket Booster Bolt Catcher

The implementation of this item was straight-forward and has been completed. The RTF TG is satisfied that no ASAP involvement is needed.

4.2.9 CAIB Recommendation 4.2-3, Closeout Inspection

Ensuring that at least two people observe the final close-out of all Space Shuttle flight hardware provided additional assurances that processes were accomplished correctly. The NASA implementation of this recommendation seems complete and appropriate. However, the RTF TG believes that the ASAP should sponsor periodic monitoring to ensure the process is still being followed across the program, particularly as the program winds down.

4.2.10 CAIB Recommendation 4.2-5, Kennedy Space Center Foreign Object Debris Definition

The implementation of this item was straight-forward and has been completed. The RTF TG is satisfied that no ASAP involvement is needed.

4.2.11 CAIB Recommendation 6.2-1, Consistency with Resources

The RTF TG believes that NASA should devote continued attention to ensure undue schedule pressure does not arise. The Task Group further believes that the ASAP should monitor the NASA budget and workforce metrics to ensure sufficient resources are available to meet the Space Shuttle mission manifest, especially given the likely resource requirements of the new Vision for Space Exploration.

4.2.12 CAIB Recommendation 6.3-1, Mission Management Team Improvements

The Task Group believes that the ASAP should observe selected MMT simulations, with particular emphasis on team performance and the MMT processes and tools necessary to effect integrated time-sensitive critical risk-versus-risk trades and decisions.

4.2.13 CAIB Recommendation 6.3-2, National Imagery and Mapping Agency Memorandum of Agreement

The implementation of this item was straight-forward and has been completed. The RTF TG is satisfied that no ASAP involvement is needed.

4.2.14 CAIB Recommendation 6.4-1, Thermal Protection System Inspection and Repair

The ASAP should review the development of comprehensive autonomous (independent of ISS) inspection and repair capabilities; this is particularly important for non-ISS missions (i.e., Hubble Space Telescope Servicing Mission 4), but also protects against the possibility that an ISS mission fails to achieve the correct orbit, fails to dock successfully, or is damaged during or after undocking. Even for nominal ISS missions, NASA has work remaining in the inspection and repair areas; the Task Group believes that the ASAP should closely monitor these efforts. With the suspension of CSCS and rescue missions after the first few flights, the issue of a certified and operational inspection and repair capability must be addressed. The

Task Group feels that the ASAP should make this a high priority when reviewing the Space Shuttle Program.

As the Task Group currently understands the situation, the Space Shuttle Program intends to discontinue the use of OBSS three or four flight after STS-114. In the view of the Task Group, this would require that other methods of detecting damage – such as the wing leading edge sensors – would have to be elevated from “Criticality 3” status to “Criticality 1.”

The Task Group feels that ASAP should assess progress with respect to selecting, developing, and certifying long-term RCC and tile repair capabilities.

4.2.15 CAIB Recommendation 9.1-1, Detailed Plan for Organizational Change

While the CAIB did not make specific “cultural” change recommendations (other than three specific recommendations to be included in the plan required for R9.1-1), they provided numerous pages of text, findings, and observations to underscore their concerns in this area. To their credit and in response, over the past 29 months, NASA revised some pre-*Columbia* initiatives and undertook many other new initiatives (both for the Space Shuttle Program and NASA wide) to address the CAIB concerns. As the scope of these initiatives were beyond the RTF TG charter, the Task Group recommends that ASAP might wish to discern how these varied initiatives fit into an integrated senior leadership plan or vision. For the future, it is critical that NASA establish a foundation that can carry its vision forward.

4.2.15.1 CAIB Recommendation 7.5-1, Independent Technical Authority

The ASAP should monitor the progress toward completing the establishment of the ITA and its Technical Warrant Holders, whether the ITA is working as CAIB intended, whether the CAIB organizational concept is workable, and whether the “independent” funding sources are working. Additionally, the ASAP should monitor the process by which NASA grants waivers to technical requirements to ensure it meets the intent of the CAIB recommendations

4.2.15.2 CAIB Recommendation 7.5-2, Safety and Mission Assurance

ASAP should monitor to ensure SMA continues to be an “independent” voice, and the Agency’s alternative implementation of “direct line authority” will require continued ASAP oversight. Since the Space Shuttle Program SMA Manager is a voting member on the MMT (but does not possess “suspension authority”), further ASAP monitoring might be prudent to verify that those Center and SMA Directors with “suspension authority” recognize their responsibility and authority and are willing to use it if needed. In addition, ASAP needs to be cognizant of the historical trend to diminish the SMA role. Over time, without continued Headquarters leadership emphasis on the importance of the SMA role (including Quality Assurance), NASA history unfortunately portends that SMA roles become diminished.

4.2.15.3 CAIB Recommendation 7.5-3, Systems Engineering and Integration

The ASAP should assess the progress toward establishing a truly effective Systems Engineering and Integration Office. Items remaining include demanding rigorous documentation that sustains effective systems integration and engineering, and requiring improvements in standards for (and standardization of) validation, verification, and certification requirements for the development and use of analytical models.

4.2.16 CAIB Recommendation 10.3-1, Digitize Closeout Photos

The implementation of this item was straight-forward and has been completed. However, the RTF TG believes that, periodically, the ASAP should evaluate the digital imagery database

and closeout photography procedures at the Kennedy Space Center and other NASA installations to ensure its continued effectiveness. Should the Shuttle Program be extended past 2010, the decision for no further non-critical updates to the drawings should also be reconsidered.

4.2.17 SSP-3, Contingency Shuttle Crew Support

Because of the risks entailed, and the most-likely negative programmatic effects, the Task Group believes that CSCS should never be relied upon to overcome risks that could have been mitigated by other actions. The CSCS capability should be used only in the most extreme emergency where there is no other viable option for saving the crew of a stricken Orbiter.

The Task Group believes the ASAP should conduct an independent evaluation of the desirability of maintaining a CSCS capability for flights after STS-121. If the capability does continue into the future, the ASAP should ensure that it does not become a “crutch” for the program and lead to a tendency toward negative changes to the flight rules and operations.



Discovery sitting at LC-39B.



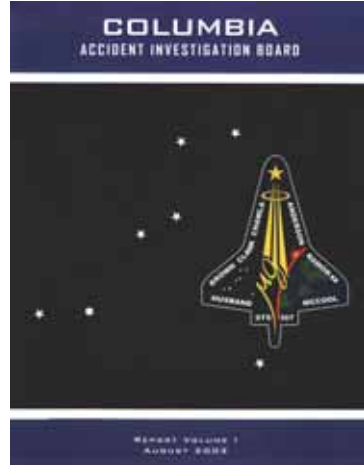
Discovery hangs in the VAB as it is being removed from its original External Tank in the Vehicle Assembly Building at KSC. The Orbiter was later mated with ET-121 prior to the launch of STS-114.

5 THE RETURN TO FLIGHT TASK GROUP

On February 1, 2003, the Space Shuttle *Columbia* disintegrated while returning to Earth during the STS-107 mission, killing the crew of seven. Within hours, the independent Columbia Accident Investigation Board (CAIB) was appointed to determine the cause of the accident. What followed was, perhaps, the most far-reaching accident investigation ever conducted. The CAIB released the first volume of their final report on August 26, 2003, containing 29 specific recommendations for changes to the vehicle, the Space Shuttle Program, and to NASA in general. Among those recommendations were 15 that the accident board believed should be implemented prior to returning the Space Shuttle fleet to flight.

On April 14, 2003, then-NASA-Administrator Sean O’Keefe wrote Lt. Gen. Thomas P. Stafford, U.S. Air Force (Ret.), requesting that the Stafford Task Force on International Space Station Operational Readiness initiate an assessment of NASA’s plans to return the Space Shuttle to flight. The Stafford Task Force is a standing group chartered by the NASA Advisory Council, an independent advisory group to the NASA Administrator.

One month later Lt. Gen. Stafford responded to the Administrator with a plan to activate a sub-organization with Col. Richard O. Covey, U.S. Air Force (Ret.), leading the day-to-day effort of conducting an independent assessment of the 15 CAIB return-to-flight recommendations. As a result, on July 18, 2003, a Return to Flight Task Group (RTF TG) was chartered under the Federal Advisory Committee Act with Lt. Gen. Stafford and Col. Covey as co-chairs.



The Columbia Accident Investigation Board final report was issued on August 26, 2003.

Over the course of the past two years, using expertise from the aerospace industry, federal government, academia, and the military, the RTF TG assessed the actions taken by NASA to implement the CAIB return-to-flight recommendations. During this time the Task Group conducted fact-finding activities, reviewed documentation, held public meetings, reported their assessments to the Space Flight Leadership Council, and released three interim reports on the progress toward launching the first Space Shuttle mission since the *Columbia* accident, designated STS-114. The assessments of the Task Group, although based primarily on data provided by the Space Shuttle Program, are independent of that program and are intended to provide the NASA Administrator an evaluation of the progress NASA has made toward meeting the intent of the 15 CAIB return-to-flight recommendations.

As the Task Group delivers this final report to the NASA Administrator, Congress, and the American public, we take this opportunity to reemphasize that this report is strictly advisory and is not a prerequisite for returning to flight. Only NASA can make the determination if the vehicle, supporting infrastructure, and organization are sufficiently robust to resume flying.

5.1 Federal Advisory Committee Act

NASA is among several federal agencies that access the insights and experiences of accomplished citizens by establishing advisory committees. The Federal Advisory Committee Act (FACA – Public Law 92-463 as amended; 5 U.S.C. App. §§1 *et seq*) governs the creation, management, and termination of such advisory committees when they report directly to federal officials. The General Services Administration provides government-wide administrative guidance for FACA, while the Office of Government Ethics oversees “conflict of interest” matters associated with the designation and conduct of advisory committee members.

For the purposes of the FACA, the RTF TG was composed of two voting Co-Chairs and multiple voting members. In addition, the Task Group had one non-voting *ex-officio* member – the NASA Deputy Chief Safety and Mission Assurance Officer. The Executive Secretary of the Task Group was a Civil Service employee who performed as the Designated Federal Official required by the FACA.

None of the voting members were NASA employees. However, the Co-Chairs and some members were appointed as Special Government Employees under the federal personnel system. All members were reimbursed for travel expenses in accordance with normal government policy.

Under the FACA, the members can not have any vested interest in the outcome of the assessment. The NASA General Counsel determined that the members of the RTF TG had no interest that would prevent them from exercising individual or representative judgment.

5.2 Purpose and Duties of the Task Group

The RTF TG was chartered to perform an independent assessment of NASA's actions to implement the CAIB return-to-flight recommendations. However, this assessment is strictly advisory, and NASA remains responsible for the overall safety and operational readiness of STS-114 and all subsequent Space Shuttle missions. Perhaps as important as what the Task Group was asked to do, is what it was not asked to do:

1. The Task Group was not asked to pass judgment on the appropriateness or validity of the CAIB recommendations.
2. The Task Group was not asked to pass judgment on the methods chosen by NASA to implement the recommendations (i.e., were the selected methods the best); we were only asked to assess whether the selected methods met the intent of the CAIB recommendation.
3. Other than assessing the return-to-flight schedules for “undue pressure,” the Task Group was not asked to pass judgment on when the return-to-flight mission should occur.

To fully understand the intent of the accident board, the RTF TG conducted fact-finding interviews with former members and staff from the CAIB. The Task Group did not, however, attempt to assess the adequacy or appropriateness of the CAIB recommendations.

The Task Group has also made several independent observations on safety and operational readiness that it believes are appropriate.

The RTF TG relied on the expertise of its members and other sources to provide this assessment. Fact-finding was accomplished using written data and briefings supplied by NASA and its contractors, meetings with other persons and organizations as deemed appropriate, and site visits to NASA and contractor facilities. In carrying out its responsibilities, the Task Group:

- Focused on the Agency's actions to implement the 15 CAIB return-to-flight recommendations as related to the safety and operational readiness of STS-114.
- Used, as it deemed appropriate, the Space Shuttle Program Office and Space Shuttle Return to Flight Planning Team, working groups, and supporting facilities to conduct the assessment. These included staff advisors, as required, for expertise in such areas as engineering, public affairs, law, and security.

- Analyzed the facts and opinions considered relevant in the CAIB final report and reviewed the supporting documents and databases as needed.

- Documented and reported RTF TG assessment findings in public meetings, three interim reports, and a final report.

In addition to the 15 return-to-flight recommendations made by the CAIB, after the April 2004 plenary meeting the Task Group notified NASA of its intention to assess one additional “raising the bar” action that NASA assigned itself as part of its return to flight efforts. This task, called SSP-3, Contingency Shuttle Crew Support, is documented in *NASA’s Implementation Plan for the Space Shuttle Return to Flight and Beyond*. Essentially, this “raising the bar” action addresses the use of the International Space Station as a safe haven for a Space Shuttle crew in case an Orbiter is damaged and deemed unsafe for entry. Because of the potential for this being a mitigating or supportive capability for return to flight, the Task Group felt the need to formally assess NASA’s actions relative to establishing the capability.

The CAIB had indicated that NASA need only develop a detailed plan to change certain aspects of its organization prior to return-to-flight. However, because the return-to-flight activities have taken much longer than the CAIB anticipated, NASA has had the opportunity to begin implementing the planned reorganization. Therefore, in addition to R9.1-1 (which the CAIB marked as a return-to-flight item), the Task Group is assessing the progress made on the three organizational recommendations (R7.5-1, R7.5-2, and R7.5-3). These three CAIB recommendations are assessed within the context of the R9.1-1 planning recommendation and may be found in that section of this report.

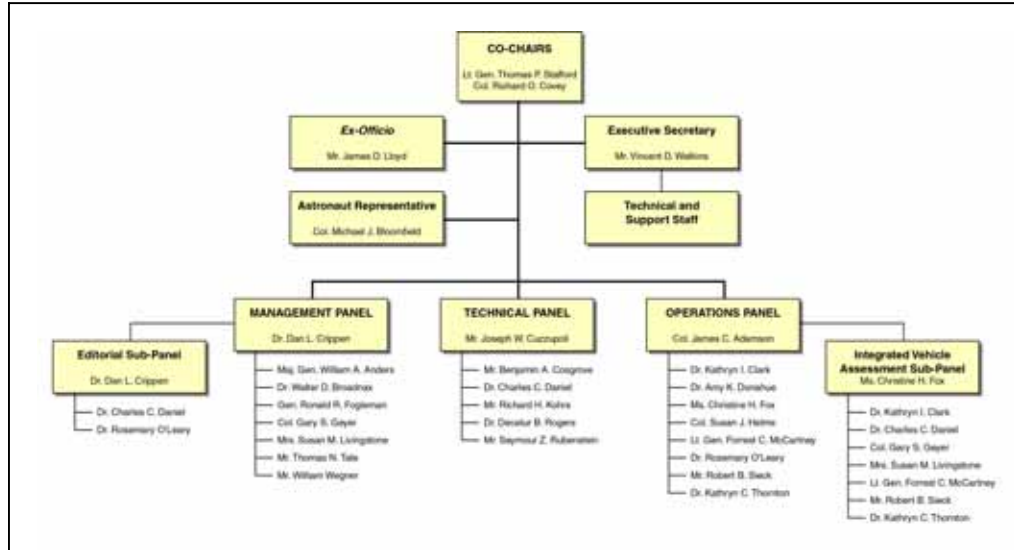
Aside from the one non-CAIB-recommendation noted above, the RTF TG did not assess any other Space Shuttle Program hardware, software, processes, organizations, or procedures. For instance, the Task Group did not evaluate the readiness or safety of the Space Shuttle Main Engines, Solid Rocket Boosters, auxiliary power units, fuel cells, or other element hardware. Nor did the Task Group assess the PASS or BFS flight software. It is NASA, and NASA alone, that can adequately evaluate the Space Shuttle Program as a whole and determine its readiness to resume flying.

5.3 Organization of the Task Group

The RTF TG membership consisted of select representatives from the Stafford Task Force on International Space Station Operational Readiness, under which it was chartered, and additional members selected by the Co-Chairs and appointed by the NASA Administrator. These members provided a knowledge base appropriate to the assessment of NASA’s implementation of the CAIB return-to-flight recommendations.

After reviewing the nature of the CAIB recommendations, the RTF TG organized itself into three panels: the Management Panel, Operations Panel, and Technical Panel. Subsequently, an Integrated Vehicle Assessment Sub-Panel and Editorial Sub-Panel were established for specific tasks. Each of the Panels was responsible for leading the assessment of specific CAIB recommendations, and prepared a final presentation for the assembled Task Group to detail NASA’s implementation of each recommendation in preparation for the final deliberations and vote.

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5.3.1 Management Panel

The Management Panel focused on the NASA compliance with the CAIB recommendations concerning Space Shuttle Program management, the return-to-flight integrated schedule, program/project risk management, and public safety policy. This assessment included CAIB recommendations:

- R6.2-1 Consistency with Resources
- R6.3-1 Mission Management Team Improvements
- R6.3-2 National Imaging and Mapping Agency Memorandum of Agreement
- R9.1-1 Detailed Plan for Organizational Change, including:
 - R7.5-1 Independent Technical Engineering Authority
 - R7.5-2 Safety and Mission Assurance Organization
 - R7.5-3 Space Shuttle Integration Office Reorganization

5.3.2 Operations Panel

The Operations Panel focused on the NASA compliance with the CAIB findings and recommendations concerning Space Shuttle Program crew and controller operations, processing and launch operations, and procedures to support operations. This assessment included CAIB Recommendations:

- R3.4-1 Ground-Based Imagery
- R3.4-2 High-Resolution Images of External Tank
- R3.4-3 High-Resolution Images of Orbiter
- R4.2-5 Kennedy Space Center Foreign Object Debris Definition
- R6.4-1 Thermal Protection System Inspection and Repair (operations only)
- R10.3-1 Digitize Closeout Photos
- SSP-3 Space Shuttle Program Action – Contingency Shuttle Crew Support

5.3.3 Technical Panel

The Technical Panel focused on the NASA compliance with the CAIB recommendations concerning the material condition of the Space Shuttle. This included the development of and compliance with technical requirements, vehicle engineering, hardware and software development/verification, and overall vehicle certification status. This assessment included CAIB recommendations:

- R3.2-1 External Tank Debris Shedding
- R3.3-1 Reinforced Carbon-Carbon Non-Destructive Inspection
- R3.3-2 Orbiter Hardening
- R4.2-1 Solid Rocket Booster Bolt Catcher
- R4.2-3 Closeout Inspection
- R6.4-1 Thermal Protection System Inspection and Repair (system hardware development only)

5.3.4 Integrated Vehicle Assessment Sub-Panel

The Integrated Vehicle Assessment Sub-Panel combined insights from the Management, Operations, and Technical Panels to assess the ability of NASA to perform an integrated vehicle external damage assessment, based on a variety of imagery and sensor sources in support of decision-making during launch and flight.

This sub-panel focused on cross-cutting vehicle assessment actions, specifically including an assessment of the Orbiter Thermal Protection System. The sub-panel assessment considered the broad interactions of allowable debris, critical damage size, damage detection and assessment via imagery and sensors, as well as the development of the Mission Management Team improvements needed to support real-time operations. This assessment included CAIB recommendations:

- R3.2-1 External Tank Debris Shedding
- R3.3-2 Orbiter Hardening
- R3.4-1 Ground-Based Imagery
- R3.4-2 High-Resolution Images of External Tank
- R3.4-3 High-Resolution Images of Orbiter
- R6.3-2 National Imaging and Mapping Agency Memorandum of Agreement
- R6.4-1 Thermal Protection System Inspection and Repair (integrated data flow only)
- R6.3-1 Mission Management Team Improvements
- SSP-3 Space Shuttle Program Action – Contingency Shuttle Crew Support

5.3.5 Editorial Sub-Panel

The Editorial Sub-Panel coordinated the preparation of the RTF TG interim and final reports.

5.3.6 Staff and Other Personnel

The Task Group maintained offices outside the Johnson Space Center in Houston, Texas, for use by the permanent staff and visiting members. The members generally worked out of their home offices except when on fact-finding trips or attending Task Group plenary and public meetings.

The Executive Secretary performed as the Designated Federal Official (DFO) per FACA regulations by fulfilling all functions required by statute, including recordkeeping and compliance with FACA procedures. The DFO served as the Government's agent for all matters related to RTF TG activities.

Support personnel facilitated the Task Group fact-finding activities and were assigned to each panel and sub-panel. A NASA General Counsel was provided by the Johnson Space Center and was available for legal advice and interpretations concerning technical and programmatic issues relevant to the NASA implementation of the CAIB findings and recommendations. A NASA Public Affairs Officer from the Marshall Space Flight Center provided support to the Task Group and served as an interface with the news media and the public. Specialists,

contractors, consultants, and other personnel were provided to the RTF TG as needed during its assessment activities. Administrative, travel, and secretarial support was provided at the Houston office. Valador, Inc., of Herndon, Virginia, was retained as the Task Group support-contractor to provide consultants, maintain the RTF TG web site, and other duties as needed.

5.3.7 Personnel Changes

As with any group that operates over a long period of time, personnel changes on the RTF TG were inevitable. In June 2003, as the Task Group was initially being organized, there were 20 members of the Task Group; all except the *ex-officio* were voting members:

Lt. Gen. Thomas P. Stafford, U.S. Air Force (Ret.), *Co-Chair*
Col. Richard O. Covey, U.S. Air Force (Ret.), *Co-Chair*
Col. James C. Adamson, U.S. Army (Ret.)
Maj. Gen. William A. Anders, U.S. Air Force Reserve (Ret.)
RADM Walter H. Cantrell, U.S. Navy (Ret.)
Mr. Benjamin A. Cosgrove
Dr. Dan L. Crippen
Mr. Joseph W. Cuzzupoli
Dr. Charles C. Daniel
Dr. Richard Danzig
Gen. Ronald R. Fogleman, U.S. Air Force (Ret.)
Col. Gary S. Geyer, U.S. Air Force (Ret.)
Maj. Gen. Ralph H. Jacobson, U.S. Air Force (Ret.)
Mr. Richard H. Kohrs
Mr. James D. Lloyd, *ex-officio*
Lt. Gen. Forrest C. McCartney, U.S. Air Force (Ret.)
Mr. David Raspet
Mr. Seymour Z. Rubenstein
Mr. Robert B. Sieck
Mr. William Wegner

By the end of July 2003, seven additional voting members who brought specific expertise had been added to the Task Group:

Dr. Walter D. Broadnax
Dr. Kathryn I. Clark
Dr. Amy K. Donahue
Ms. Susan M. Livingstone
Dr. Rosemary O'Leary
Dr. Decatur B. Rogers
Mr. Thomas N. Tate

On September 12, 2003, it was announced that three new voting members had been added to the Task Group, bringing the total to 29 voting members and 1 *ex-officio*.

Ms. Christine H. Fox
Col. Susan J. Helms, U.S. Air Force
Dr. Kathryn C. Thornton

However, later during September 2003, two members resigned from the Task Group for personal reasons:

Maj. Gen. Ralph H. Jacobson, U.S. Air Force (Ret.)
Mr. David Raspet

Since the Task Group still had a sufficiently broad cross-section of necessary skills, these members were not replaced. At this time, Dr. Dan L. Crippen took the Lead of the Management Panel formerly held by Maj. Gen. Jacobson.

On May 3, 2004, NASA Headquarters reassigned the Task Group Executive Secretary, Mr. David Lengyel, to the Office of the Chief Engineer at Headquarters because it was felt his skills and expertise were needed in that office. Mr. Vincent D. Watkins, from the Johnson Space Center, succeeded him as Executive Secretary.

In June 2004, RADM Walter H. Cantrell, U.S. Navy (Ret.) left the Task Group to become Deputy Chief Engineer for NASA's new Independent Technical Authority. Since the Co-Chairs felt that the Task Group still had sufficient membership, no successor was named for RADM Cantrell. Dr. Charles Daniel replaced RADM Cantrell on the Integrated Vehicle Assessment Sub-Panel and Editorial Sub-Panel.

In September 2004, Dr. Richard Danzig left the Task Group because "the press of other activities involving national security problems has left me without time to perform as a member of the Group." Since the Task Group believed it was close to completing its activities, no successor was selected.

The first representative from the Astronaut Office, Lt. Col. Carlos L. Noriega, U.S. Marine Corps (Ret.), left the Task Group after he received a flight assignment on STS-121 in December, 2003. Lt. Col. Noriega is currently the Manager of the Exploration Systems Engineering Office at the Johnson Space Center. He was replaced on the Task Group by Col. Michael J. Bloomfield, U.S. Air Force.

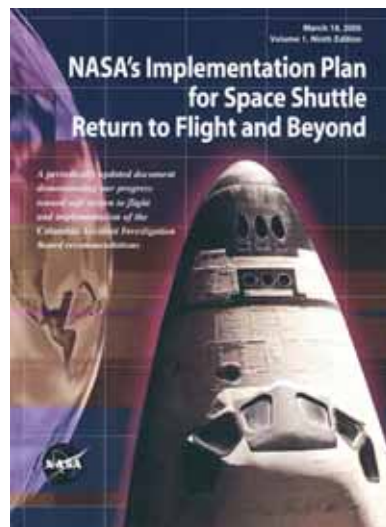
Participation of at least 51 percent of the voting members was required to constitute a quorum of the Task Group.

5.4 Relationship to the NASA Implementation Plan

At the same time that the CAIB was conducting its investigation, NASA began pursuing an Agency-wide effort to improve human space flight. Part of this effort was taking a fresh look at all aspects of the Space Shuttle Program, from technical requirements to managerial processes. The outcome was a set of NASA-generated actions that complement the CAIB recommendations. These are documented in *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond*. (For brevity, the RTF TG generally called this the *NASA Implementation Plan*.)

The *NASA Implementation Plan* integrates both the CAIB recommendations and NASA-generated actions into a single document. Many of the NASA-generated actions "raise the bar" beyond what the CAIB recommended. With a single exception, the RTF TG did not assess these raising-the-bar actions – that exception is SSP-3, Contingency Shuttle Crew Support. It should be noted that some of the raise-the-bar items in the *NASA Implementation Plan* overlapped various CAIB requirements, but the RTF TG assessed the CAIB requirements as written.

In general, the *NASA Implementation Plan* provides high-level description of the steps taken by NASA to implement the CAIB recommendations and the NASA-generated actions. The implementation plan is revised



periodically, with the latest version being the Tenth Edition on June 3, 2005. The *NASA Implementation Plan* went from its December 3, 2004, “Revision C” to the March 18, 2005, “Ninth Edition.” This was explained to the Task Group as an attempt to correct the previous system of revisions that did not track intermediate releases (e.g., 1.1); there had been eight releases prior to March 2005, so this version was called the Ninth Edition.

The RTF TG has not independently verified or validated any information contained in *NASA’s Implementation Plan for Space Shuttle Return to Flight and Beyond*.

5.5 Conduct of the Assessment

The diverse nature of the CAIB recommendations required a unique approach to the assessment of each item. This was a result of the presence of process enhancements, hardware modifications, organizational changes, and documentation revisions, often in a single item. In general, the lead panel conducted fact-finding through field trips to relevant sites, meetings with NASA personnel, discussions with contractors, issuing formal Requests for Information (RFI) to NASA, and consultations with other experts.

5.5.1 Coordination with NASA

NASA provided primary points-of-contact to manage the flow of information between the Task Group and the NASA community. Requests for fact-finding meetings, supporting data via Requests for Information (detailed in the next section) and coordination of schedules and product deliveries was filtered through these contacts. These NASA representatives also developed and provided the official input to the RTF TG for each recommendation in a closure package (this process is discussed further in Section 6.6). Meetings between NASA and the Task Group included formal briefings directly to the members and those where Task Group members were simply part of the audience of a regularly-scheduled meeting.

All material provided to the RTF TG became a part of the permanent Task Group record. Some of this material will not be made available to the public because it contains data restricted under the International Traffic in Arms Regulations (ITAR, 22 CFR Parts 120-130) or company-proprietary information that the contractors have a right to protect under their existing agreements with NASA. All data not restricted by security, ITAR, or company-proprietary considerations were entered into the Process-Based Mission Assurance (PBMA) database to facilitate sharing among Task Group personnel. These data will be archived at the National Archives and Records Administration.

5.5.2 Requests for Information

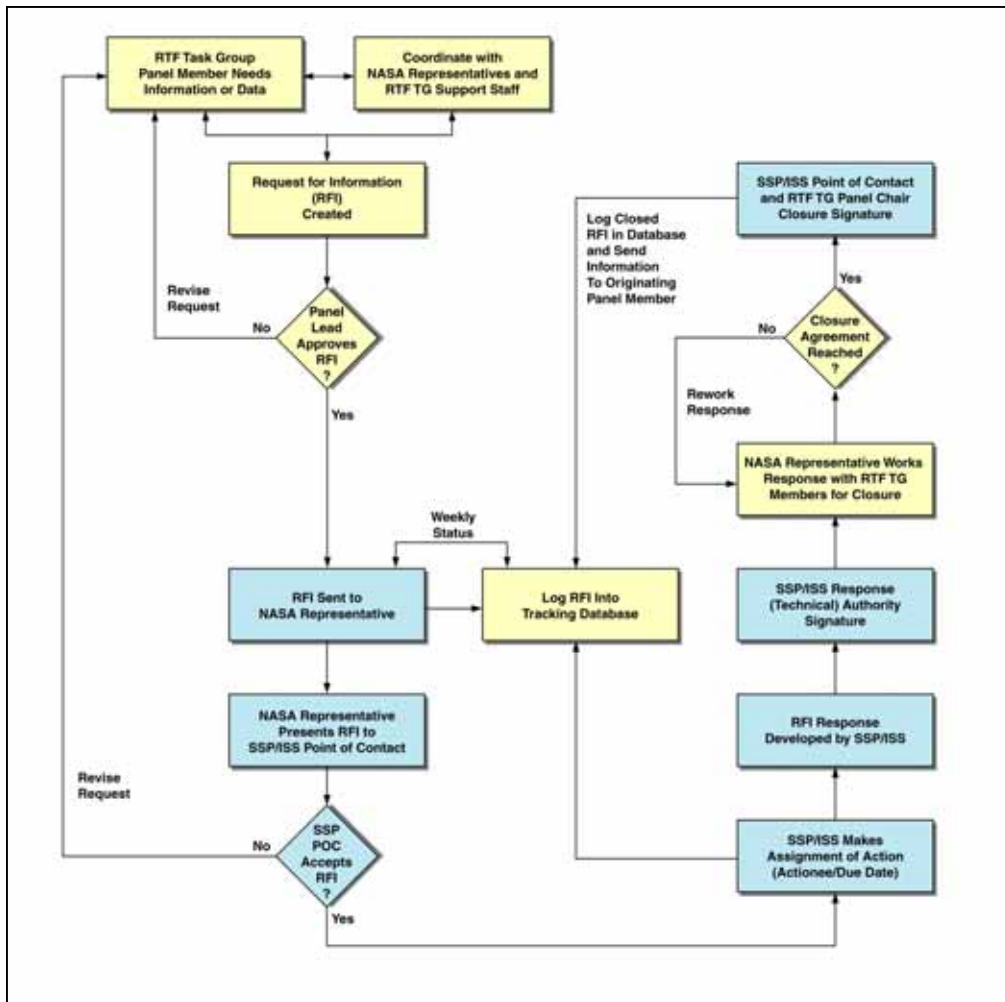
The primary means of requesting and transmitting information between the Program Office and the Task Group was called a “Request for Information” form. This process was similar to that used by the CAIB to request data. An RFI could be a simple request for existing facts or a complex inquiry on operations. In response to an RFI, NASA could provide information, or make specific make presentations to the Task Group. The RTF TG intended that all RFIs be completed prior to final deliberations on individual return-to-flight recommendation assessments.

When a Task Group member needed information, the member or staff completed an RFI form. This form detailed the information required, along with a date by which the information was needed. After the RFI was approved by the appropriate Panel Lead, it was logged into an RTF TG database. The RFI was then sent to the NASA point-of-contact via the NASA representative to the RTG TG. The NASA point-of-contact had the authority to accept or reject the RFI. Rejection was usually caused by the RFI being too broad and placing too great a burden on the NASA organization that was already working to implement the required

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return-to-flight changes. If the NASA point-of-contact rejected an RFI, they worked with the Task Group member to revise the request, which was then resubmitted through the process. Once the NASA point-of-contact accepted the RFI, the request was transferred to the appropriate NASA organization. This information was then fed back to the RTF TG staff to update the tracking database.

The assigned NASA organization developed a response that was then reviewed and approved by a process within NASA. A response to an RFI was only considered official when it was signed by designated officials of the Space Shuttle Program Office. At this point, the NASA point-of-contact sent the data to the RTF TG. If the information was deemed acceptable, the NASA point-of-contact and the RTF TG Panel Lead signed the RFI form for official closure. The RFI form and associated response was then uploaded into PBMA and the RTF TG tracking database was updated.



5.6 Assessment Closure Process

While the Task Group was conducting fact-finding activities, NASA was developing and implementing plans to satisfy the CAIB recommendations. When NASA was satisfied with its implementation, the Agency presented a Return to Flight Action Closure Package and its supporting documentation to the Task Group. These were auditable documents that chronicled NASA's implementation of each CAIB return-to-flight recommendation. Each Return to Flight Action Closure Package contained, at a minimum, the following elements:

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1. Signature sheet, including:
 - a. Relevant element or project manager(s)
 - b. Space Shuttle Program Manager
 - c. Deputy Associate Administrator for International Space Station and Space Shuttle Programs
 - d. Chief Safety and Mission Assurance Officer
 - e. Space Flight Leadership Council Co-Chairs
2. Transmittal letter from the Space Flight Leadership Council Co-Chairs to the RTF TG Co-Chairs
3. Executive Summary, including:
 - a. Background information (including assumptions and interpretation of the CAIB recommendation)
 - b. Corrective measures and results
 - c. Open issues
 - d. Verification
4. Presentation package for the RTF TG (including back-up charts)

During the plenary meeting in April 2004, the Task Group had the opportunity to exercise this process for the first time. Although deemed generally successful, the process was further refined with the following changes:

1. The definition of tasks, requirements, and results would be developed from the most recent release of the *NASA Implementation Plan*.
2. The metrics and audit trail specified above would include the use of the current Space Shuttle Program Office configuration management system to provide tracking on any required:
 - a. Test plans, results and reports
 - b. Design data and documentation
 - c. Programmatic documentation, including Directives, Actions, and Change Requests
 - d. Documentation and documentation traceability, starting with the programmatic documentation, NSTS 07700
 - e. Detailed audit trail and plan for these activities, but not the completion of activities prior to submittal for approval
3. Agreements on the appropriate level at which to track, verify, and certify the activities to be included in the closure package.

After being received, the Return to Flight Action Closure Package was evaluated by the appropriate RTF TG Panel(s). When the Panel(s) was satisfied that the package was complete, it reported to the full Task Group. While the presentation by NASA to the Panel was usually by teleconference, the Panel's reporting to the full Task Group could be either by teleconference or during a face-to-face plenary. The process was the same regardless of the forum.

At the conclusion of the deliberations, the RTF TG formally notified the Space Flight Leadership Council of the Task Group's determination via correspondence; the assessment could be considered "closed" or "conditionally closed," or it could remain open. If an

assessment was “conditionally closed,” the Task Group identified in the same correspondence what action or documentation was required for full closure.

As the Task Group completed its activities, however, it was eventually recognized that this nomenclature was misleading. Both NASA and the press had interpreted the term “closed” as applying to the recommendation itself; the Task Group had no power, nor intent, to “close” a CAIB recommendation. Rather, it was the assessment being conducted by the Task Group that was either “open” or “closed.” In this context, “closed” meant that the Task Group’s assessment was complete.

Although the three interim reports used different terminology, this final report uses a more appropriate nomenclature. By definition, all the Task Group’s assessments are now “closed” since the RTF TG has disbanded at the end of its charter. In each case, the determination is that the NASA implementation met the intent of the CAIB recommendation or that it did not meet the intent.

5.7 Summary of Interim Reports

The first two interim reports were prepared by the Editorial Sub-Panel, consisting of Dr. Dan Crippen, RADM Walt Cantrell, and Dr. Rosemary O’Leary. For the third interim report, RADM Cantrell was replaced by Dr. Charles Daniel. The Technical, Management, and Operations panels provided the primary substance of the reports. The reports were submitted for comments to the entire Task Group, and to NASA for technical review only. Co-Chair Col. Richard Covey approved the final version of each interim report prior to its release.

The first interim report was released on January 20, 2004. This report presented the assessment status of each CAIB return-to-flight recommendation as of early 2004. All of the assessments were still open at this point in time.

The second interim report was released on May 19, 2004, and it updated the assessment status of each recommendation. NASA had submitted closure packages for R3.3-1, R4.2-3, and R6.3-2, and the Task Group’s assessments of these recommendations were conditionally closed. The Task Group felt that there had been substantial progress across the board relative to all of the return-to-flight recommendations. To support this conclusion, the second interim report noted that several other recommendations were far enough along that the assessments could likely be closed at an anticipated August plenary.

The third interim report was released on January 28, 2005, and it again updated the assessment status of each recommendation. The report noted that the assessment of R3.3-1, which had been conditionally closed in the second interim report, had not changed status. NASA had submitted five new closure packages, resulting in the assessments of R3.4-2, R4.2-1, R4.2-5, and R10.3-1 being fully closed and R3.4-1 being conditionally closed. NASA supplied additional data for R4.2-3 and R6.3-2, which had been conditionally closed in the second interim report, so the Task Group revised the status of its assessment in these cases to fully closed.

At the conclusion of its final plenary meeting on June 27, 2005, the Task Group delivered a copy of the Executive Summary only to the NASA Administrator, and copies were transmitted to Congress and the White House. The Executive Summary was also posted to the Task Group’s web site for public distribution. The Executive Summary contained at the beginning of this Final Report is a slightly edited revision of the version released on July 27 – the edits were minor in nature and did not change the content.



The American flag on the Vehicle Assembly Building at the Kennedy Space Center, Florida.

6 SUMMARY OF THE RTF TG PLENARY MEETINGS

Over the course of two years, the Return to Flight Task Group held 11 plenary meetings to discuss its assessment of NASA's implementation of the Columbia Accident Investigation Board (CAIB) return-to-flight recommendations. Nine of these meetings were conducted face-to-face, and two were via teleconference. All of these included fact-finding sessions among the members, and eight included public meetings to deliberate results. The minutes of the public meetings are public record, and video and/or audio of the meetings is available on the RTF TG website.

Three of the following summaries were previously published in the interim reports that were issued immediately after the meetings, and are provided here mostly verbatim (only minor editorial corrections). For that reason, they are written in the present tense, even though the events they discuss are long past. All of these descriptions discuss the events as they were presented at the time; many things have changed over the course of the Task Group's work and the descriptions presented here do not necessarily reflect the current or final status.

6.1 Summary of August 2003 Plenary

This plenary was held August 5-7, 2003, at the Kennedy Space Center, Florida. This meeting was largely administrative in nature as the Task Group received briefings and developed operating procedures, plans, and schedules. During fact-finding, the Task Group received briefings from the Space Shuttle Program regarding its organization, vehicle processing, and the Certificate of Flight Readiness (CoFR) process. The Task Group received a presentation on the coatings used on the launch pad structures and their effects on the reinforced carbon-carbon wing leading edge. NASA also provided a briefing on ascent imagery and the Agency's preliminary plans regarding how to implement the CAIB imagery recommendations. The Space Shuttle Program Manager and his staff made a presentation explaining the purpose and scope of *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* [Revision 1 was current when this plenary was held] and NASA's current schedule for implementing the CAIB recommendations. Following the fact-finding, the Task Group held its first public meeting. This event was covered by the news media and the Task Group introduced itself and discussed its roles and responsibilities.



From the beginning, the Return to Flight Task Group was in the public eye. Here the news media, both print and broadcast, cover the Task Group's first public meeting at the Debus Center, Kennedy Space Center Visitor Complex August 7, 2003. The RTF TG was at KSC to conduct organizational activities, tour Space Shuttle facilities, and receive briefings on Space Shuttle-related topics.

6.2 Summary of September 2003 Plenary

This plenary was held September 9-11, 2003, in Houston, Texas. Again, this fact-finding meeting was partly administrative in nature, with the members receiving a briefing on the Freedom of Information Act (FOIA) and a presentation by the NASA Inspector General. In addition, NASA briefed the Task Group on the current status of *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* [Revision 1.1 was current when this plenary was held], and a discussion of each CAIB return-to-flight recommendation followed. NASA officials then provided a top-level overview of the approach they were using for return-to-flight planning. The core objective was to eliminate critical debris from the External Tank, with a long-term goal of eliminating all debris. Additional efforts centered on imagery, inspection, and repair. The Task Group also discussed the roles and responsibilities of the three panels along with which assessment each panel would lead. Splinter fact-finding meetings dedicated to each panel occupied the remainder of the plenary. Since there were no items to deliberate, the Task Group did not hold a public meeting. However, members of the media were briefed during a teleconference.

6.3 Summary of December 2003 Plenary

This plenary was held December 9-11, 2003, in Houston, Texas. This meeting began, in earnest, the long road to assessing NASA's implementation of the CAIB return-to-flight recommendations.

The CAIB uncovered some very specific conditions that led to the demise of the *Columbia* along with process and management failures that contributed to the accident. In a sense, the loss of the *Columbia* was caused primarily by two faulty assumptions:

Foam shed from the External Tank would be "transported" around the leading edge of the wing by the aerodynamics of the Orbiter; and,

The foam was not substantial enough to develop a ballistic moment capable of puncturing the reinforced carbon-carbon on the wing leading edge.



Return to Flight Task Group members participate in fact-finding meeting in Houston September 10, 2003.

It turns out that both assumptions – long-held and widely shared within NASA – were wrong, despite previous launches in which foam was shed and little damage was done, seemingly validating the assumptions. Thus, the “conditioned” response of senior managers to more junior members, who questioned these assumptions after the *Columbia* launched, was one of discouraging dissent and of comfort with established technical and operational assumption. The problem was exacerbated by systemic failures that prevented critical information getting to the right people at the right time.

In this light, the technical and operational challenges for NASA are to rectify the consequences of these faulty assumptions by, for example, removing debris sources, enhancing photography, improving on-orbit inspections, and developing on-orbit Thermal Protection System repair. The primary challenge for the Agency’s management is to devise an organization with embedded processes to identify other faulty assumptions.

The Return to Flight Task Group is charged with assessing the implementation of the CAIB recommendations. The RTF TG is not in the business of suggesting specific remedies. As one member put it, the Task Group is in the position of an umpire calling balls and strikes in a zone defined by the CAIB recommendations. The RTF TG is not in the position of evaluating the overall readiness or safety of the next flight, just the implementation of the CAIB return-to-flight recommendations.

Because of the substantial changes to the foam insulation and inspection techniques for the External Tank, and the current lack of understanding of the foam shedding phenomena, the STS-114 ascent must be considered a test flight. As such, the RTF TG expects NASA to capture as much test data as possible during ascent, particularly in regard to the imaging recommendations of the CAIB.

NASA has responded to all the recommendations the CAIB identified as necessary for accomplishment before the next Space Shuttle flight in *NASA’s Implementation Plan for Space Shuttle Return to Flight and Beyond* [Revision 1.1 was current when this plenary was held]. Not surprisingly, progress on the many recommendations has been uneven. Several of the technical responses to specific recommendations have indicated substantial progress, although none have been completed. Others, such as preparation of a detailed plan for the implementation of an Independent Technical Authority, are still in planning and some time away from implementation and a long time away from evaluation.

While the tone of this interim report is justifiably positive, progress should not be mistaken for accomplishment. As time passes and the next scheduled flight approaches, the enormity of the remaining task looms. Detailed plans for many of the recommendations have not been forthcoming. NASA has not been timely in some of its responses to Task Group requests for information. And while some of the most critical organizational issues raised by the CAIB require only a “detailed plan” before return-to-flight, the RTF TG will be looking for plans and processes that will stand the test of time – not just suffice for the first launch – much as the hardware redesigns are expected to serve the life of the Space Shuttle. It is still much too soon to predict either the success of implementation or the timing of the next flight.

A public meeting was held after this plenary and members of the media were briefed during a press conference.

6.4 Summary of April 2004 Plenary

This plenary was held April 12-16, 2004, in Houston, Texas. There had been several changes in NASA’s return to flight effort since the previous plenary meeting in December 2003. First, and most immediately, the schedule for the next launch was moved from September 2004 to March-April 2005. This schedule change was prompted by three developments:

1. Additional testing of the susceptibility of the Orbiter Thermal Protection System to damage, especially the reinforced carbon-carbon, coupled with advanced analysis of the airflows around the Orbiter, External Tank, and Solid Rocket Boosters, indicated that the foam on a larger area of the ET should be reassessed;
2. Several rudder speed brake actuators were discovered to have been incorrectly assembled during the original manufacture over 20 years ago. Further, the gears in the actuators have generally suffered minor damage with use and time. Therefore, all the actuators are being replaced or refurbished; and
3. Delays in the design and manufacture of a new camera/laser boom that will be used by the Orbiter's robotic arm to inspect for possible damage while on orbit.

This change in schedule means that NASA will have additional time to implement the CAIB recommendations before return to flight. In many cases this change also allows expected plans to be at least partially implemented. For example, the CAIB called for a detailed plan to, among other things, establish an Independent Technical Authority. It is expected that plan will now be implemented, at least for the Space Operations Mission Directorate [called the Office of Space Flight at the time], before next year.

The expanded period before the next launch also allows NASA additional time to select and perfect methods to implement technical solutions, such as inspecting the Orbiter Thermal Protection System for damage. Since the loss of *Columbia*, NASA has been engaged in a wide-ranging search for corrective and preventive measures of all types. In some cases, the time is approaching when decisions must be made as to the most promising alternatives and resources focused on this smaller set of possibilities – the garden must be thinned. In this sense, the additional time until launch can be seductive and leadership will need to be exercised to sort the many options under consideration.

The second major change since December is the announcement of President Bush's vision for the future of space exploration, particularly the human space flight component. The President proposed to use the Space Shuttle to complete the construction of the International Space Station and then retire the Space Shuttle no later than 2010. In its place would be continued reliance on international partners to service the International Space Station as well as the possibility of private sector development of launch vehicles. During the next decade, NASA would also begin to develop the capability to return astronauts to the moon, establish a lunar presence, and begin the efforts to explore Mars.

While the President's vision has obvious implications for the long-term use of the Space Shuttle, its effects on the current efforts have not been fully examined. However, no matter how long the Space Shuttle is used, it must first be safely returned to flight. Therefore, except for potential competition for human and financial resources, the new program should have minimal impact on the actual return to flight activities and the implementation of CAIB recommendations.

Third, the Task Group determined that the contingency of using the International Space Station as a safe haven in the event of potentially catastrophic vehicle damage is becoming increasingly important in NASA's decision-making for return to flight. Therefore, the Task Group formally notified NASA of its intent to assess the Contingency Shuttle Crew Support capability ("raising the bar" action SSP-3 in the *NASA Implementation Plan*) much as if it were a CAIB recommendation.

The Task Group is encouraged by NASA's progress since its last plenary in December 2003. Throughout the organization, the people of NASA are engaged and dedicated to correcting the deficiencies that led to the demise of *Columbia*.

The RTF TG is conditionally closing its assessment of three CAIB recommendations. "Closing" an assessment means that NASA provided sufficient information concerning the Agency's implementation of a specific CAIB return-to-flight recommendation; "conditionally" means that closing is dependent on the delivery of final documentation. The three assessments being conditionally closed with this second interim report are: R3.3-1, Reinforced Carbon-Carbon Non-Destructive Inspection; R4.2-3, Closeout Inspection; and R6.3-2, National Imagery and Mapping Agency Memorandum of Agreement. The Task Group will continue to monitor the implementation of these recommendations, and NASA has agreed to notify the Task Group if there is any material change in status.

There has been progress on virtually all of the 12 remaining return-to-flight recommendations. It is anticipated that several more recommendations will be substantially met by the time of the next RTF TG plenary in the summer.

One universal concern of the Task Group is the personnel requirements to meet the CAIB recommendations and other return-to-flight activities. The various new organizations, such as the NASA Engineering and Safety Center, the Independent Technical Authority, and the System Engineering and Integration Office, all require talented staff drawn largely from the current NASA and contractor pool. At some point, the ability of the Space Shuttle Program to carry out its mission may be hampered by personnel shortages.

The most important work remains efforts to eliminate critical ascent debris. If it could be guaranteed that no critical debris would come from the External Tank, the immediate cause of the loss of *Columbia* would be rectified. But such a guarantee is impossible short of extensive flight testing. Analyses and simulation will allow a level of comfort before launch, and advances in non-destructive inspection techniques may add to confidence. However, statistically significant results verifying ET debris conditions may not be accomplished even by the end of the Space Shuttle Program.

As such, on-orbit inspection and repair remain necessary to reduce the risk to future flights. Should one or both of these capabilities not be fully developed by the anticipated date of return to flight, the ability for the crew to await a rescue mission at the International Space Station will become an important consideration for the next launch.

A public meeting was held after this plenary and members of the media were briefed during a press conference.

6.5 Summary of July 2004 Plenary

This plenary was held on July 22, 2004, by teleconference since scheduling issues prevented the members from gathering in a common location. Final fact-finding activities were conducted via fax, email, and telephone prior to the public meeting. The public meeting was primarily to deliberate closing two Task Group assessments: R4.2-5, KSC Foreign Object Debris Definition, and R10.3-1, Digitize Closeout Photos.

NASA had submitted closure packages for these recommendations on June 15 (R10.3-1) and July 15 (R4.2-5), and the Task Group evaluated the closure packages and conducted fact-finding to verify the status of each recommendation. After deliberating, the Task Group voted to conditionally close its assessment of each recommendation pending the delivery of final data from NASA. In each case, the Task Group felt the Agency met the intent of the CAIB.

6.6 Summary of September 2004 Plenary

This plenary was held September 14-16, 2004, in Houston, Texas. Even before the plenary convened, the public meeting scheduled for September 16, 2004, was postponed. Several

members of the Task Group lived in the path of Hurricane Ivan and needed to secure their property. Nevertheless, available members of the Task Group met to continue their fact-finding activities. There were no assessments being considered for closure during the planned meeting.

During fact-finding, Lt. Gen. Stafford reviewed the previous week's Congressional testimony by himself and NASA Administrator Sean O'Keefe. Afterwards, there was a brief discussion of the hurricane damage to the Kennedy Space Center and the possible impacts on return-to-flight. At this point the Agency was still expecting a March 2005 launch of STS-114, and believed that data for most, if not all, of the open assessments would be provided in time for the December 2004 plenary. NASA explained that the events for return-to-flight were "milestone driven," not "schedule driven."

An apparent change within NASA was discussed, in which the Agency seemed to be choosing a "best effort" path instead of the more formal certification process. Several members of the Task Group expressed their opinion that NASA should continue the certification process instead of reverting to the less rigorous best effort concept. This plenary was where the Space Shuttle Program first introduced the "capability over environment" (C/E) concept to the Task Group. A long discussion followed about Recommendation R6.4-1, Thermal Protection System Inspection and Repair, attempting to better understand the intent of the CAIB.

Behavioral Science Technology, Inc. (BST) presented a status of its study of the Agency's cultural change initiative. Representatives from BST previewed their conclusions: NASA leadership is committed to making changes in the culture; the safety climate remains very strong; the process has begun on the harder, longer-term job of changing the culture; and if present activities and trends continue, it is likely that NASA will be successful in transforming its culture. BST cautioned, however, that while the commitment is strong at the Space Flight Leadership Council level, it seems less so at the program management level. BST described an important distinction between culture and climate. Culture comprises the common values that drive organizational performance; it is deeply embedded and changes slowly. Climate is much more transient; it is a reflection of current pressures and interests. BST and NASA officials described the initial phases of the NASA initiative to change its culture, as well as less-detailed plans for future phases.

The Space Shuttle Program provided a status of the NASA return-to-flight plans. There were assurances that a limited tile repair capability would be certified prior to the launch of STS-114, along with a certification of the External Tank, although it was cautioned that some uncertainties would remain. It was noted that many certifications were in the yellow (accepted risk) category. The program stated that the non-ET debris allowables were zero; in other words, other elements were not allowed to generate any debris. The ET was treated differently, and there were specific requirements stated for allowable debris. The program provided a status on testing various Orbiter components to determine their ability to withstand debris impacts. It had already been determined through testing at the Glenn Research Center that certain Orbiter windows needed to be replaced with thicker glass. Testing of the tile and reinforced carbon-carbon continued. NASA also provided a status report for ground and flight cameras and on the proposed reorganization to meet CAIB R9.1-1 and its three subordinate recommendations. The Mission Management Team was the subject for a long discussion between Task Group members and NASA representatives. After this the program provided an update on Contingency Shuttle Crew Support, and answered a myriad of questions from the Task Group.

6.7 Summary of December 2004 Plenary

This plenary was held December 14-16, 2004, in Huntsville, Alabama. At the public meeting following two days of fact-finding, it was determined that NASA has made considerable

Final Report of the Return to Flight Task Group

progress on meeting the CAIB recommendations for return to flight. The panels recommended, and the assembled Task Group approved, the complete closure of six assessments and the conditional closure of one additional assessment.

However, considerable work remains. Eight items remain open, including some of the toughest technological challenges the recommendations present: shedding of debris, strengthening the reinforced carbon-carbon, hardening the Orbiter, and repair of the Thermal Protection System. Most of the operational issues have been addressed, with the largest remaining concern involving the ability to detect and repair damage to the Space Shuttle while on orbit. Some planning remains to be accomplished before the International Space Station can potentially be used as a “safe haven” for the crew of a damaged Orbiter while they await the launch of a rescue mission. NASA has also made substantial progress on the various management issues the CAIB cited as “half” the cause of the demise of *Columbia*, but sufficient detail of plans, exercise of new capabilities and responsibilities, and adequate documentation remain open issues.

Several of the CAIB return-to-flight recommendations involve enhanced imagery of the Space Shuttle during ascent and while on orbit. NASA has made sufficient progress on imagery to allow the RTF TG to fully or conditionally close three assessments (R3.4-1, R3.4-2, R6.3-2) and note substantial progress on a fourth (R3.4-3, which will be formally considered as part of R6.4-1, Thermal Protection System Inspection and Repair).

Taken together, the changes in the capability to observe and examine the Space Shuttle during ascent will allow a more complete evaluation of the adequacy of the design and process changes made to the External Tank in the reduction of critical debris. The enhanced imagery will also contribute to the ability to conduct on-orbit inspections. There will undoubtedly be foam shed from the External Tank during the next and subsequent launches. The questions will be: how large are the pieces, where on the tank did the shedding occur, and where did the debris impact? The ascent imagery will help answer these questions.



The Return to Flight Task Group co-chair and panel leads brief the news media following the December 16, 2004 public meeting in Huntsville, Alabama. From left to right: Mr. Joseph W. Cuzzupoli, Col. James C. Adamson, Dr. Dan L. Crippen, and Col. Richard O. Covey. At the far right is the Task Group's Public Affairs Officer, Mr. David B. Drachlis.

Some months ago, it became clear that the immense amount of new data, much in the form of imagery, would require a new approach to integration. In response, NASA formed a development team that has produced a Thermal Protection System Operations Integration Plan intended to allow the Mission Management Team to make a timely entry readiness,

repair, or safe haven determination. The latest version of the plan, though still needing further simulation and testing, is very robust and a potential model for other integration activities within the Space Shuttle Program, as well as the Agency.

Two assessments affecting closeout procedures (R4.2-3 and R10.3-1) were moved from conditionally closed to fully closed at the plenary. "Closeout" refers to the process of finalizing work on the vehicle, often in an area that is then sealed from further view or inspection. The requirement for two-person closeouts is simply intended to add an additional pair of eyes to the evaluation of the completed work before the area is sealed for flight. The requirement for digitized closeout photos is intended to yield an adequate ability to both examine work after closeouts and the ability to easily recall the images, particularly while the Space Shuttle is on-orbit.

During the course of its investigation, the CAIB uncovered a technical deficiency in the bolt catcher, a device that prevents the explosive bolts used to mate the Solid Rocket Boosters to the External Tank from becoming debris that might impact the Orbiter. Although determined not to have contributed to the *Columbia* accident, the CAIB correctly wrote a recommendation (R4.2-1) requiring NASA to fix the problem. NASA has successfully redesigned, tested, and requalified the SRB bolt catcher, and the Task Group closed its assessment of this recommendation.

Although most of the management-related recommendations remain open, NASA has made substantial progress since the last plenary. Most notably, the response to Recommendation 7.5-1 (assessed as part of R9.1-1) to create an Independent Technical Authority (ITA) has been formulated, and implementation has begun. The first "warrants," the official delegation of authority to specific individuals, have been issued.

The role of the Mission Management Team, which received a great deal of attention immediately after the *Columbia* accident, has been clarified and expanded. The new Mission Management Team conducted 10 simulations of various aspects of the next mission and plans an end-to-end, full-mission simulation beginning in late February and lasting several days.

The systems engineering and integration function, which the CAIB noted had gradually atrophied, has been reinvigorated and has an expansive role in return to flight. However, the RTF TG remains concerned that without adequate documentation, the renewed vigor will dissipate soon after the launch of STS-114.

6.8 Summary of February 2005 Plenary

This plenary was held on February 17, 2005, by teleconference. This public meeting was primarily to deliberate closing the Task Group assessment on R3.3-1, Reinforced Carbon-Carbon Non-destructive Inspection. The Recommendation had been conditionally closed in April 2004, and NASA submitted the requested additional data on February 2, 2005. The Task Group had evaluated the revised closure package and conducted fact-finding to verify the status of the recommendation.

A public meeting was held after this plenary and members of the media were briefed during a press conference. After deliberating, the Task Group closed its assessment of R3.3-1, feeling that NASA had met the intent of the CAIB.

6.9 Summary of the March 2005 Plenary

This plenary was held March 28-30, 2005, in Houston, Texas, and was originally intended to be the final face-to-face meeting of the Task Group prior to writing the final report. However, in the weeks leading up to the meeting, it was apparent that NASA had not made sufficient

progress in documenting its compliance with the CAIB return-to-flight recommendations, and that it was unlikely all of the closure packages would be delivered to the Task Group in time to complete their assessments during the meeting. Therefore, even before the March 2005 meeting convened, it was expected that another plenary would be needed before the launch of STS-114 to evaluate the final closure packages yet to be received from NASA.

As the program's schedules for delivering final closure packages to the Task Group continued to slip, the RTF TG began to wonder if any assessments could be made at the meeting. When the plenary was convened on March 22, 2005, the Task Group's concerns were realized. During two days of fact-finding prior to a scheduled public deliberation scheduled for March 24, the Task Group decided that insufficient documentation existed for any assessments to be made. The public meeting was cancelled.

6.10 Summary of the Early June 2005 Plenary

This plenary was held June 6-8, 2005, in Houston, Texas. By this time, NASA had provided preliminary or final closure packages for all of the remaining CAIB recommendations. Fact-finding was held the afternoon of June 6 and all day June 7, with the Space Shuttle Program Manager and various other program officials providing detailed status briefings to the Task Group. The Associate Administrator for Space Operations briefed the Task Group on June 7, presenting the perspective from NASA Headquarters on the upcoming STS-114 mission and the changes being implemented by the new NASA Administrator.

The public meeting was held the morning of June 8, 2005. The Panel responsible for each recommendation provided a status or closure plan to the assembled Task Group, and in the end, the Task Group decided that five CAIB recommendations and the "raising the bar" Space Shuttle Program action had been completed. One of these, R3.4-1, Ground-Based Imagery, had been conditionally accepted during the December 2004 plenary; the Task Group now believed that NASA had provided the remaining data in a satisfactory manner and the recommendation was accepted to have fully met the intent of the CAIB. Four others: R3.4-3, High-Resolution Imagery of Orbiter; R6.2-1, Consistency with Resources; R6.3-1, Mission Management Team Improvements; and R9.1-1, Detailed Plan for Organizational Changes, were deliberated during the meeting. Task Group members agreed that the changes made by NASA for all four recommendations met the intent of the CAIB.



The Return to Flight Task Group conducts a deliberative public meeting on June 8, 2005, in Webster, Texas.

For the SSP-3, Contingency Shuttle Crew Support raising-the-bar action, the Task Group first discussed what criteria to measure against, since this was not a CAIB recommendation. Eventually, the Task Group decided that the original criteria defined by the Space Shuttle

Program would provide the measure, and it was agreed that the Space Shuttle and ISS Programs had both exceeded their initial goals. The Task Group concluded, “NASA set a raising the bar goal for itself and exceeded that goal by a significant margin.”

This left only three recommendations for the Task Group to consider before the return to flight: R3.2-1, External Tank Debris Shedding; R3.3-2, Orbiter Hardening; and R6.4-1, Thermal Protection System Inspection and Repair. The work on these recommendations is ongoing, with design reviews extended into late June. The Task Group decided to allow NASA additional time to complete work on these three recommendations and tentatively set a June 27 date for the last Task Group plenary. It is expected that NASA will have submitted closure packages on these last three CAIB recommendations by the time of the last plenary.

6.11 Summary of the Late June 2005 Plenary

As the scheduled launch date of STS-114 approached, the Task Group and NASA attempted to come to closure on the final three assessments of the CAIB return-to-flight recommendations. These included what many observers considered the most critical recommendations: R3.2-1, External Tank Debris Shedding; R3.3-2, Orbiter Hardening; and R6.4-1, Thermal Protection System Inspection and Repair. The major delay was that NASA’s final debris and design certification reviews were being conducted into late June, and the Task Group wanted to review the results of these reviews prior to completing their assessments. The final closure packages for R3.2-1 and R3.3-2 were not received by the Task Group until during the plenary meeting; R6.4-1 had been received earlier in June.

A meeting was set between the Task Group leadership and the NASA Administrator for the morning of June 28, so the final plenary meeting was scheduled to occur in Washington, D.C., on June 27. This would allow the Task Group to work through the evening to ready the Executive Summary that would be delivered to the Administrator the following morning.

Final fact-finding, including a required annual ethics briefing, was conducted during a closed meeting on the morning of June 27, with a public meeting held in the afternoon. The public meeting location had been changed late the day before because a broken fire sprinkler flooded the original location. The new location was approximately two blocks away.

At the public meeting the Technical Panel recommended closing R3.2-1 and R3.3-2 as having met the intent of the CAIB. However, after spirited discussion, the majority of the Task Group voted that NASA had not met the intent of the CAIB for R3.2-1, although in both cases the Task Group felt that NASA had accomplished some excellent work. The majority of the Task Group also voted that NASA had not met the intent of the CAIB for R3.3-2, although again, the group felt that excellent work had been accomplished and that extenuating circumstances (the mandate to retire the Space Shuttle by 2010) understandably caused NASA to cancel some future work. Relative to R6.4-1, despite extensive efforts on the part of the Tile Repair Project and RCC Repair Project to develop a practicable TPS repair capability, the majority of the Task Group voted that the intent of CAIB Recommendation 6.4-1 had not been met, although there was a minority opinion that may be found elsewhere in this report. A press conference was held after the public meeting.

An Executive Summary of this report was finalized in time to deliver it to the NASA Administrator on the morning of June 28, and copies were subsequently delivered to Congress and the White House. An electronic copy was posted to the Task Group’s website. The version contained at the beginning of this report has been slightly edited for readability without affecting its content.

APPENDIX A – RETURN TO FLIGHT TASK GROUP CHARTER

The original Task Group charter is shown below.

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, 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 recommendations of the Columbia Accident Investigation Board (CAIB), as they relate to the safety and operational readiness of STS-114. As necessary to its 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 the intent.
3. The Task Group may make other such 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 necessary to perform its advisory functions, including activities of both the Agency and its contractors.
5. The Task Group will function solely as an advisory body and will comply fully with the provisions of the FACA.

Organization

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

Membership

In order to reflect a balance of views, the Task Group will consist of non-NASA employees and one NASA non-voting, *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 with recognized knowledge and expertise in fields relevant to safety and space flight.

The Task Group members and the Co-Chairs of the Task Group 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).

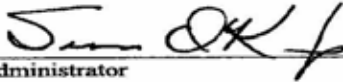
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Administrative Provisions

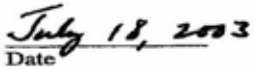
1. The Task Group will formally report its results to NASA on a continuing basis at appropriate intervals, including a final written report.
2. The Task Group will meet as often as required to complete its duties and will conduct at least two public meetings. Meetings will be open to the public, except 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 Official.
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 \$2 million, 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 2 years from the date of this charter, unless terminated earlier or renewed by the NASA Administrator.



Administrator



Date

Charter Extension

Because the Task Group did not complete their activities prior to the July 23, 2005, expiration of the original charter, an extension was required to complete the final report and prepare data for delivery to the National Archives. The revised charter is shown below.

Establishment and Authority

The NASA Administrator established the NASA Return to Flight Task Group (“Task Group”). Having determined that it is in the public interest in connection with performance of Agency duties under the law, and with the concurrence of the General Services Administration, the NASA Administrator hereby renews and amends the Task Group’s charter, 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 recommendations of the Columbia Accident Investigation Board (CAIB), as they relate to the safety and operational readiness of STS-114. As necessary to its 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 the intent.
3. The Task Group may make other such 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 necessary to perform its advisory functions, including activities of both the Agency and its contractors.
5. The Task Group will function solely as an advisory body and will comply fully with the provisions of the FACA.

Organization

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

Membership

To reflect a balance of views, the Task Group will consist of non-NASA employees and one NASA nonvoting, *ex officio* member, the Deputy Chief Safety and Mission Assurance Officer. 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 with recognized knowledge and expertise in fields relevant to safety and space flight.

The Task Group members and the Co-Chairs of the Task Group will be appointed by the Administrator. At the request of the Task Group, associate members and consultants will be appointed by the Deputy Chief Engineer/Independent Technical Authority.

Administrative Provisions

1. The Task Group will formally report its results to NASA on a continuing basis at appropriate intervals, including 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 FACA. Panel meetings will be held as required.
3. The Executive Secretary will be appointed by the Administrator and will serve as the Designated Federal Official.
4. The Space Operations Mission Directorate will provide technical and staff support through the Task Force on International Space Station Operational Readiness. The Space Operations Mission Directorate will provide operating funds for the Task Group and panels. The estimated operating costs total approximately \$3.5 million which includes 7 workyears 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 shall terminate upon the issuance of its final report unless terminated before that date or subsequently renewed by the NASA Administrator.



Michael D. Griffin
Administrator

JUL 22 2005

Date

APPENDIX B – RTF TG MEMBERS

Lieutenant General Thomas P. Stafford, U.S. Air Force (Retired)

Co-Chair, Return to Flight Task Group

President, Stafford, Burke & Hecker Inc., technical consulting firm

A member of NASA's second astronaut group, Stafford was pilot of Gemini 6 and commanded Gemini 9, and orbited the moon as Commander of Apollo 10. He was the American Commander in the Apollo-Soyuz Test Project, the first rendezvous between American and Soviet spacecraft. Stafford became head of the astronaut group and was later named Deputy Director of Flight Crew Operations at the NASA Manned Spaceflight Center. He left NASA in 1975 to head the Air Force Test Flight Center and in 1978 became Deputy Chief of Staff, Research, Development and Acquisition, U.S. Air Force Headquarters. A consultant since 1980, Stafford is Chairman of the NASA Advisory Council Task Force on International Space Station Operational Readiness. He served as Defense Adviser to President Ronald Reagan and headed The Synthesis Group, which planned for the U.S. return to the moon and eventual Mars missions. He was Chairman of the NASA Advisory Council Task Force on Shuttle-Mir Rendezvous and Docking Missions. Among his awards, Stafford received the Congressional Space Medal of Honor. 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. Stafford is an graduate of the U.S. Naval Academy.



Colonel Richard O. Covey, U.S. Air Force (Retired)

Co-Chair, Return to Flight Task Group

President, Boeing Service Company

Colonel Covey is a veteran of four Space Shuttle flights. He was the pilot of *Discovery* on the first return-to-flight mission following the *Challenger* accident, and he was commander of *Endeavour* on the first mission to service and repair the Hubble Space Telescope. He also held management positions in the Astronaut Office and Flight Crew Operations Directorate. As a fighter pilot, Covey flew 339 combat missions in Southeast Asia. He was an F-4 and A-7D weapons systems test pilot and Joint Test Force Director for electronic warfare testing of the F-15. Covey's organization at Boeing supports commercial and U.S. government space and communication programs. Earlier, he was Vice President of Boeing's Houston operations. Covey has received 27 Defense Department and Air Force medals, plus the National Intelligence Medal of Achievement. NASA awarded him the Distinguished Service Medal, the Outstanding Leadership Medal, and the Exceptional Service Medal. For his role on the Hubble servicing mission, Covey and his crew received both the Goddard Trophy and the Collier Trophy. He holds a B.S. in Engineering Sciences from the U.S. Air Force Academy and an M.S. in Aeronautics and Astronautics from Purdue University, and was named the Outstanding Graduate of his class at the Air Force Test Pilot School.



Colonel James C. Adamson, U.S. Army (Retired)

CEO, Monarch Precision, LLC



Colonel Adamson, a former astronaut, earned his B.S. in Engineering from the U.S. Military Academy at West Point and his M.S. in Aerospace Engineering from Princeton University. He returned to West Point as an Assistant Professor of Aerodynamics, after which he was selected to attend the Navy Test Pilot School. In 1981 he became Aerodynamics Officer for the Space Shuttle Operational Flight Test Program. Adamson became an astronaut in 1984 and flew two missions, one aboard *Columbia* and the other on *Atlantis*. After retiring from NASA, Adamson established his own consulting firm, Monarch Precision, and then became President/CEO of Lockheed Engineering and Sciences Company. In 1995 he helped create United Space Alliance and became the company's first Chief

Operating Officer. Adamson was then recruited to serve as President/CEO of Allied Signal Technical Services Corporation, which later became Honeywell Technology Solutions, Inc. Retiring from Honeywell in 2001; Adamson resumed part-time consulting with Monarch Precision. 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.

Major General William A. Anders, U.S. Air Force Reserve (Retired)



Major General Anders was selected for the astronaut corps in 1963. He was the Lunar Module Pilot of Apollo 8 and backup Command Module Pilot for Apollo 11. Anders subsequently received Presidential appointments to the National Aeronautics and Space Council, the Atomic Energy Commission and the Nuclear Regulatory Commission (where he was the first Chairman), and he served as U.S. Ambassador to Norway. Anders held executive positions at a number of corporations, including General Electric, Textron and General Dynamics, where he was Chairman and CEO. While in that position, he was awarded the National Security Industrial Association's "CEO of the Year" award. Anders established several world flight records

and has received numerous awards, including Distinguished Service Medals from the Air Force, NASA and the Atomic Energy Commission. He is a member of the National Academy of Engineering, the Society of Experimental Test Pilots and the Experimental Aircraft Association. He is also the founder and President of the Heritage Flight Museum. Anders received his B.S. in Electrical Engineering from the United States Naval Academy and earned his pilot's wings in 1956. He received his M.S. in Nuclear Engineering from the U.S. Air Force Institute of Technology, graduating with honors.

Dr. Walter D. Broadnax, Ph.D

President, Clark Atlanta University

Prior to his current position, Dr. Broadnax was Dean of the School of Public Affairs, American University, and Professor of Public Policy and Management at the University of Maryland, where he directed the Bureau of Governmental Research. Broadnax also served as: Deputy Secretary and Chief Operating Officer, U.S. Department of Health and Human Services; President, Center for Governmental Research; President, New York State Civil Service Commission; Lecturer and Director, Kennedy School of Government, Harvard University; Senior Staff Member, 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, Federal Executive Institute. Broadnax has held leadership positions in professional associations such as: the American Political Science Association, the Association of Public Policy and Management 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 has served as President, American Society for Public Administration, Fellow, National Academy of Public Administration and Trustee of the Academy's Board. He is a member of the Syracuse University Board of Trustees, Harvard University's Taubman Center Advisory Board and the United States Comptroller General Advisory Board.



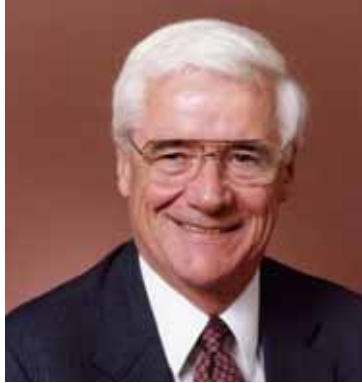
Dr. Kathryn I. Clark, Ph.D.

President, Docere (consulting firm specializing in science and education)

Dr. Clark served as NASA's Chief Scientist for the International Space Station Program and as Chief Scientist for the Human Exploration and Development of Space Enterprise. Her particular interest is in human factors, the elements necessary for the health, safety and efficiency of crews in long-duration space flight. Clark served as Deputy Director of the Center for Microgravity Automation Technology, one of the NASA Commercial Space Centers. Clark's NASA experience began with a neuromuscular development study that flew on *Atlantis* in 1994. These experiments were repeated and augmented on *Discovery* in 1995. She was also involved in the Neurolab project flown on *Columbia* in 1998 and a student-designed ladybug experiment that flew on *Columbia* in 1999. Clark is the recipient of the NASA Goddard Space Flight Center Customer Service Excellence Award. Clark received both her M.S. and Ph.D. from the University of Michigan and then joined the university faculty in the Department of Cell and Developmental Biology in 1993. Clark chairs the Academic Affairs Committee, Board of Control, Michigan Technological University. She also serves on the Board of Trustees of the Western Reserve Academy and the Board of Advisors of the Jean Michel Cousteau Society. She serves on the boards of the Space Day Foundation and Orion's Quest, both education-oriented not-for-profit organizations. Clark is also a member of the NASA Advisory Council Task Force on International Space Station Operational Readiness.



Mr. Benjamin A. Cosgrove
Consultant



In the course of a 44-year career with the Boeing Company, Mr. Cosgrove was an engineer and manager associated with most of the company's jet aircraft programs. He served as stress engineer or structural unit chief on the B-47, B-52, and KC-135, and on the Boeing 707, 727, 737, and 747 jetliners. He was Chief Engineer of the 767. Cosgrove was honored by *Aviation Week & Space Technology* for his role in converting the Boeing 767 transport design from a three-member to two-member cockpit configuration, and he received the Ed Wells Technical Management Award for his work addressing issues of aging aircraft. Cosgrove received the National Aeronautics Association's Wright Brothers Memorial Trophy 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 American Institute of Aeronautics and Astronautics and the Royal Aeronautical Society. After retiring in 1993 as Senior Vice President, Boeing Commercial Airplane Group, Cosgrove became a consultant. Cosgrove was elected to the National Academy of Engineering in 1992. He holds both a B.S. in Aeronautical Engineering and an honorary Doctorate of Engineering from the University of Notre Dame. Cosgrove has served on the NASA Advisory Committee's Task Force on International Space Station Operational Readiness and the Committee on Space Shuttle Upgrades.

Dr. Dan L. Crippen, Ph.D.
Former Director, Congressional Budget Office



Dr. Crippen served as the fifth Director of the Congressional Budget Office. His public service positions have also included: 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) – a position in which he advised the President on all issues relating to domestic policy, including the preparation and presentation of the federal budget. He has served on several national commissions, including the National Commission on Financial Institution Reform, Recovery, and Enforcement. He currently serves on the Aerospace Safety Advisory

Panel. Crippen has substantial experience in the private sector as well. Before joining the CBO, 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, an independent strategic planning and consulting firm. Crippen received a B.A. from the University of South Dakota in 1974, an M.A. from Ohio State University in 1976, and a Ph.D. in Public Finance from Ohio State in 1981.

Mr. Joseph W. Cuzzupoli

Vice President and K-1 Program Manager, Kistler Aerospace Corporation

Mr. Cuzzupoli has more than 40 years of experience in aerospace engineering and management. 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). As Rockwell's Assistant Program Manager for Apollo, Cuzzupoli managed the building and testing of Apollo 6, Apollo 8, Apollo 9, and Apollo 12. He later became Rockwell's Vice President of Operations and then Vice President and Program Manager for the Space Shuttle Orbiter Project. Cuzzupoli 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, he has primary responsibility for design and production of the K-1 reusable launch vehicle. Cuzzupoli holds a B.S. in Mechanical Engineering from the Maine Maritime Academy, a B.S. 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 Council's Task Force on International Space Station Operational Readiness.



Dr. Charles C. Daniel, Ph.D.

Engineering Consultant

From Saturn V to the International Space Station (ISS), Dr. Daniel has served as an engineer and manager in space flight vehicle design, analysis, integration and testing. His career began in 1968 at the Marshall Space Flight Center (MSFC) where he supported Saturn Instrument Unit operations for Apollo 11, 12 and 13. He performed avionics integration work for the Skylab program. For the Space Shuttle's Solid Rocket Boosters (SRB), he developed avionics and served as Flight Operations Lead. Daniel worked with the original Space Station Skunk Works for definition of the space station concept and developed the project's master engineering schedule. Following the *Challenger* accident, he led the evaluation of all Space Shuttle hazard analyses and coordinated acceptance analyses associated with modifications to the SRBs. During Space Station Freedom development, he was the Avionics Lead and served as MSFC Lead for Level II assembly and configuration development. Daniel helped plan Russian participation in the Space Station Restructure activity and later returned to MSFC as Chief Engineer for Space Station. Daniel holds a Ph.D. in Engineering and has completed postgraduate work at the University of California, Berkeley and MIT. He has served on one NASA Advisory Council task force on Shuttle-Mir Rendezvous and Docking Operations and another on ISS Operational Readiness.



Dr. Amy K. Donahue, Ph.D.

Assistant Professor of Public Policy, the University of Connecticut



Dr. Donahue teaches in the Master of Public Administration and Master of Survey Research programs. Her research focuses on productivity of emergency services organizations and on the nature of citizen demand for public safety services. Her published work deals with the design, management and finance of fire departments and other public agencies. Donahue has served as technical adviser to the Department of Homeland Security's Science and Technology Directorate, helping to develop programs for emergency responders. As Senior Adviser to the NASA Administrator from 2002 to 2004, Donahue sought opportunities within NASA to contribute to homeland security efforts government-wide. 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, Alaska and upstate New York. In addition, she has served as an officer in the U.S. Army's Medical Service Corps. In 2003, Donahue spent three months in the field in Texas managing the *Columbia* debris recovery operation. Donahue currently serves on the Aerospace Safety Advisory Panel (ASAP). Donahue received her B.A. in Geological and Geophysical Sciences from Princeton University and both her Ph.D. in Public Administration and her M.P.A. from the Maxwell School of Citizenship and Public Affairs, Syracuse University. Donahue currently serves on the Aerospace Safety Advisory Panel (ASAP).

General Ronald R. Fogleman, U.S. Air Force (Retired)

President and Chief Operating Officer, Durango Aerospace Inc.



General Fogleman has 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, after which he retired in 1997. Fogleman has served as a military adviser 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 chaired the National Research Council Committee on Aeronautics Research and Technology for Vision 2050. Fogleman received an M.A. in Political Science from Duke University, graduated from the Army War College, and earned an M.A. in Military History from the U.S. Air Force Academy. His military decorations include: 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

President, Center for Naval Analyses

A President of the CNA, a federally-funded research and development center, Ms. Fox is responsible for providing the Department of the Navy and Department of Defense with high-quality, independent analysis of key issues regarding manning, training, acquisition, and operations. Before becoming President, Fox was the Vice President and Director of the Center's Operations Evaluation Group. With approximately 45 field representatives and 45 Washington-based analysts, this group's analytical purpose is to help operational commanders execute their missions. Fox joined the CNA in 1981 and since then has served in a variety of analysis, leadership and management positions. These positions include: 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. Fox received her B.S. in mathematics and her M.S. in applied mathematics from George Mason University.



Colonel Gary S. Geyer, U.S. Air Force (Retired)

Consultant

Colonel Geyer has 39 years of experience in space engineering and program management. In senior positions in both government and industry, he has been responsible for all aspects of system 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, responsible for design, manufacture, test, launch and operation of several of the most important U.S. reconnaissance satellites. Geyer was one of 46 "Pioneers of National Reconnaissance" honored by the NRO in 2000 for their "significant and lasting contributions to the discipline of national reconnaissance," which contributed to the end of the Cold War. Following his NRO service, Geyer was Vice President for a major classified program at Lockheed Martin, where he was responsible for all aspects of program and mission success. Geyer teaches courses in space design and system engineering/ program management at New Mexico State University. He has a B.S. in Electrical Engineering from Ohio State University, an M.S. in Electrical Engineering, and M.S. in Aeronautical Engineering from the University of Southern California.



Brigadier General (Select) Susan J. Helms, U.S. Air Force

Deputy Director, Operations for Technical Training, Headquarters Air Education and Training Command



Before her current assignment, Colonel Helms was Vice Commander of the 45th Space Wing where she oversaw military space launches from Cape Canaveral Air Force Station (CCAFS) and Eastern Range support for commercial, NASA and military space launches from CCAFS and Kennedy Space Center, along with ballistic missile tests at sea. Selected for the astronaut program in 1990, she flew on five Space Shuttle flights and served aboard the International Space Station as member of the Expedition 2 crew. She logged 211 days in space, including a world-record extravehicular activity of 8 hours, 56 minutes. After receiving a B.S. in Aeronautical Engineering from the U.S. Air Force

Academy and her commission, Helms was assigned to the Air Force Armament Laboratory as F-16 Weapons Separation Engineer, and then became Lead Engineer, F-15 weapons separation. In 1985 she received her M.S. in Aeronautics/Astronautics from Stanford University and returned to the Air Force Academy as Assistant Professor of Aeronautics. After attending the Air Force Test Pilot School in 1988, Helms was assigned as Exchange Officer to Canada's Aerospace Engineering Test Establishment, where she worked as Flight Test Engineer and Project Officer on the CF-18. She was managing development of a CF-18 flight control system simulation when selected by NASA. Helms returned to the Air Force in 2002 to direct the Space Superiority Division, Space Command Requirements Directorate.

Mr. Richard H. Kohrs

Chief Engineer, Kistler Aerospace Corporation



Mr. Kohrs has over 40 years of experience in aerospace systems engineering, stress analysis and integration. He has held senior management positions in NASA programs from Apollo to Space Station. After Apollo, Kohrs's positions in the Space Shuttle Program included Manager of System Integration, Deputy Manager and then Deputy Director. 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, Kohrs became Director of Space Station Freedom, with overall responsibility for its development and operation. After years of public service, he left NASA to become

Director of the ANSER Center for International Aerospace Cooperation (1994-1997). Kohrs joined Kistler Aerospace in 1997. His primary responsibilities as Chief Engineer include vehicle integration, design specifications, design data books, interface control, vehicle weight, performance and engineering review board matters. In 1956, he received a B.S. from Washington University in St. Louis.

Ms. Susan Morrisey Livingstone

Policy and Management Consultant

From 2001 to 2003, Ms. Livingstone served as Under Secretary of the Navy. Her broad executive management portfolio comprised planning, budget and other functions, but she also focused on programs such as space, information technology, and criminal investigation. Currently, she serves on the Maxwell School's National Security Studies Board of Advisers and the Secretary of the Navy's Subcommittee on Naval History. Livingstone was CEO of the Association of the United States Army and Deputy Chairman of its Council of Trustees. She was a consultant to the Defense Science Board. At American Red Cross headquarters, her executive positions included Vice President, Health and Safety Services. Livingstone was Assistant Secretary of the Army for Installations, Logistics and Environment (1989-1993). Among several posts at the former Veterans Administration, Livingstone was Associate Deputy Administrator for Logistics. She worked on personal staffs of a Senator and two Congressmen. Livingstone received the Secretary of Defense Award for Outstanding Public Service and the highest civilian awards from the National Reconnaissance Office, the VA, and the Army and Navy Departments. Livingstone received her B.A. from the College of William and Mary (1968) and her M.A. in Political Science from the University of Montana (1972), and post graduate work at the Fletcher School of Law and Diplomacy.



Mr. James D. Lloyd, *ex-officio*

Deputy Chief Safety and Mission Assurance Officer, NASA

Mr. Lloyd has extensive experience in safety engineering and risk management and has supported a number of blue ribbon panels addressing safety problems. Beginning in 1969 as a safety engineering intern trainee and later as a journeyman system safety engineer with the U. S. Army Aviation Systems Command, he honed his skills with Army aircraft development programs. He was later appointed as Chief, Program Evaluation Division in the Army Material Command (AMC) Safety Office in Virginia. In 1979, he was again reassigned as Director, AMC Field Safety Activity in Indiana, where he managed safety engineering, evaluation and training support for the command's military-industrial operations located world-wide. After the Space Shuttle *Challenger* disaster in 1986, Lloyd joined NASA to help the Agency rebuild its SMA program. He was instrumental in fulfilling several of the recommendations from the Rogers Commission investigation report. Immediately after Space Shuttle flights resumed, Lloyd moved to the Space Station Freedom Program Office in Virginia, where he served in various roles culminating in Product Assurance Manager for the program. In 1993 he became Director, Safety and Risk Management Division, Office of Safety and Mission Assurance, serving as NASA's "Safety Director." He assumed his present position as Deputy Chief of the same office in 2003. Lloyd also serves as *ex-officio* member for the NASA Advisory Council's standing Task Force on International Space Station Operational Readiness. Lloyd holds a B.S. with honors in Mechanical Engineering from Union College, Schenectady, and an M.S. in Industrial Engineering, Texas A&M University.



Lieutenant General Forrest S. McCartney, U.S. Air Force (Retired)

Consultant



Lt. General McCartney was Commander of the Ballistic Missile Organization (responsible for development of the Minuteman and Peacekeeper ICBMs), Commander of the Air Force Space Division and Vice Commander, Air Force Space Command. He directed several major satellite programs. He received 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, as well as the General Thomas D. White Space Trophy and the Military Astronautical Trophy. Following the *Challenger* accident, McCartney was assigned to NASA and served as Director of the Kennedy Space Center until 1992. His numerous

awards include NASA's Distinguished Service Medal, the Presidential Rank Award, the National Space Club Goddard Memorial Trophy and the AIAA Von Braun Award for Excellence in Space Program Management. After 40 years of military and civil service, McCartney became an industry consultant, specializing in evaluation of hardware failure and flight readiness. At Lockheed Martin, from 1994 to 2001, he was Astronautics Vice President for Launch Operations. McCartney was Vice Chairman of the NASA Aerospace Safety Advisory Panel. He has a B.S. in Electrical Engineering from Auburn University, an M.S. in Nuclear Engineering from the Air Force Institute of Technology and an honorary doctorate from the Florida Institute of Technology.

Dr. Rosemary O'Leary, Ph.D

Distinguished Professor of Public Administration and Political Science, Syracuse University



As the Co-Director of the Program for the Analysis and Resolution of Conflict at the Maxwell School of Syracuse University, O'Leary also coordinates the Ph.D. program in public administration. A member of the NASA Aerospace Safety Advisory Panel and the National Academy of Public Administration, she was a Senior Fulbright Scholar in Malaysia and the Philippines. Previously, O'Leary was Professor of Public and Environmental Affairs at Indiana University and Co-Founder and Co-Director of the Indiana Conflict Resolution Institute. She served as Director of Policy and Planning for the Kansas Department of Health and Environment and has worked as an environmental attorney. O'Leary is the author or editor of seven books and more than 90 articles and has won

nine national research awards. She was awarded the Syracuse University Chancellor's Citation for Exceptional Academic Achievement, the highest research award at the university, and she has won eight teaching awards. She received the Distinguished Service Award of the American Society for Public Administration. O'Leary was Chair of the Public Administration Section, American Political Science Association, and the Section on Environment and Natural Resources Administration, American Society for Public Administration. O'Leary has a Ph.D. in Public Administration from The Maxwell School of Syracuse University, and a J.D., M.P.A., and B.S from the University of Kansas.

Dr. Decatur B. Rogers, Ph.D.

Dean, College of Engineering, Technology and Computer Science, Tennessee State University

Dr. Rogers has held the post of Dean since 1988, and he is also Professor of Mechanical Engineering. Before joining the faculty of Tennessee State University in Nashville, he was Professor and Dean at: Florida State University, Tallahassee; Prairie View A&M University, Prairie View, Texas; and Federal City College, Washington, D.C. At Tennessee State, Rogers has fostered a number of collaborations with fellow universities and other partners, such as NASA, Boeing, General Motors and the Office of Naval Research. One of these collaborations is the Strategic Manpower Development Project, which aims to increase the number of African Americans pursuing doctorates in the fields of engineering, technology and computer science. Rogers's areas of expertise include: mechanical and thermal engineering; heating, ventilation and air conditioning; two-phase flow; heat transport systems; and engineering management. Examples of his publication titles include: *Thermodynamics of Fiber-Power Insulation*; *The Engineering Pipeline: A Long-Term Talent Development Strategy for Minorities on the Recruitment and Retention of Minorities and Women in Engineering* and *Preparing Black Children to Become Engineers*. Rogers holds a Ph.D. in Mechanical Engineering from Vanderbilt University, an M.S. in Engineering Management and another in Mechanical Engineering from Vanderbilt University and a B.S. in Mechanical Engineering from Tennessee State University.



Mr. Seymour Z. Rubenstein

Aerospace Consultant and Former President of the Rockwell International Space Systems Division

Mr. Rubenstein has been a leader in commercial and government projects for more than 35 years. He served as President of the Rockwell International Space Systems Division and was a major contributor to the design, development and operation of the Space Shuttle. At Rockwell, the prime contractor for the Space Shuttle, he was the Director of Avionics System Engineering during the early development of the spacecraft. Subsequently he was promoted to Vice President of Engineering and Chief Engineer for Space Shuttle Development, followed in 1979 by Vice President and Program Manager. He then advanced to the position of President of the Rockwell Space Station Division before becoming the Space Division President. After his tenure at Rockwell, Rubenstein held several positions at McDonnell Douglas. For his contributions to manned space exploration and in recognition of his skills as an innovator and problem solver, Rubenstein has received the NASA Public Service Medal, the NASA Medal for Exceptional Engineering and the Space Systems Award of the American Institute of Aeronautics and Astronautics. He is a Fellow of both the AIAA and the American Astronautical Society. Mr. Rubenstein holds an MBA from California State University, an MEE from New York University, a B.S. in Electrical Engineering from MIT, and a certificate of completion from the Stanford Executive Program.



Mr. Robert B. Sieck
Aerospace Consultant



Mr. Sieck, former Director of Shuttle Processing at the Kennedy Space Center (KSC), has an extensive background in Space Shuttle systems, testing, launch, landing and processing. After serving in the Air Force involved with the activation of Titan II missiles, joined NASA in 1964 as Gemini Spacecraft Systems Engineer and served as Apollo Spacecraft Test Team Project Engineer. He became Shuttle Orbiter Test Team Project Engineer and was named Engineering Manager for the Shuttle Approach and Landing Tests at Dryden Flight Research Facility. Sieck was the Chief Shuttle Project Engineer for missions 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, serving as Shuttle Launch Director in 1984 and 1985. After the *Challenger* accident in 1986 he was again appointed Launch Director, and also Deputy Director, Shuttle Operations (1992-1995). He was Launch Director for the return-to-flight of STS-26R and all subsequent Shuttle missions through STS-63. He was appointed Director of Shuttle Processing in 1995. After his retirement from NASA, Sieck served with the NASA Aerospace Safety Advisory Panel. He earned his B.S. in Electrical Engineering, University of Virginia, in 1960 and had post graduate work at Texas A&M and the Florida Institute of Technology.

Mr. Thomas N. Tate
Consultant



Mr. Tate was Vice President of Legislative Affairs for the Aerospace Industries Association for 17 years. Before joining AIA in 1987, he served on the staff of the House Committee on Science and Technology in positions that included Counsel and Special Assistant to the Chairman. He also served with the House Subcommittee on Space Science and Applications and the House Subcommittee on Energy Research and Development. At the Space Division of Rockwell International, 1962-1973, Tate worked in engineering and marketing on programs such as the Gemini Paraglider, Apollo, Apollo/Soyuz, and the Space Shuttle. He eventually became Director of Space Operations. Earlier, he worked for RCA's Missile and Surface Radar Division (1958-1962), and he served in the U.S. Army as Artillery and Guided Missile Officer. Tate received a B.S. from the University of Scranton, 1956. With his 1970 J.D. from Western State University College of Law, he was named that year's most outstanding student. In 1991, he received the University of Scranton's Frank J. O'Hara Award for Distinguished Alumni in Science and Technology. Tate is adviser to the National Space Institute and member of aerospace and defense associations such as AIAA and the National Space Club. For 15 years, Tate served on the NASA Senior Executive Service Salary and Performance Review Board.

Dr. Kathryn C. Thornton, Ph.D.

Professor, School of Engineering & Applied Science, University of Virginia

Dr. Thornton teaches in the Department of Science, Technology and Society and in the Department of Mechanical and Aerospace Engineering. She also manages the Graduate Studies Office as Associate Dean for Graduate Programs. Selected as an astronaut in 1984, Thornton is a veteran of four Space Shuttle flights between 1989 and 1995, including the maiden flight of *Endeavour* in 1992 and the first Hubble Space Telescope Service Mission in 1993. She was Payload Commander in 1995 on the second U.S. Microgravity Laboratory mission. She has logged over 975 hours in space, including more than 21 hours of extravehicular activity. Her technical assignments at NASA included flight software verification in the Shuttle Avionics Integration Laboratory (SAIL). She was a member of the Vehicle Integration Test Team at the Kennedy Space Center, and she served as a Spacecraft Communicator, or CAPCOM. Thornton holds a B.S. in Physics from Auburn University and an M.S. and Ph.D. in Physics from the University of Virginia. She was awarded a NATO Postdoctoral Fellowship to continue her research at the Max Planck Institute for Nuclear Physics in Heidelberg, West Germany. She was then employed as a physicist at the U.S. Army Foreign Science and Technology Center in Charlottesville, Virginia.



Mr. William Wegner

Consultant

Mr. Wegner graduated from the U.S. Naval Academy in 1948. He then received M.S. degrees in Naval Architecture and Marine Engineering from Webb Institute in New York. In 1956, Admiral Hyman Rickover selected Wegner to join the Navy's nuclear program, and he was sent to MIT, where he received his M.S. in Nuclear Engineering. After a number of field positions, including Nuclear Power Superintendent at the Puget Sound Naval Shipyard, Wegner served for 16 years as Deputy Director to Admiral Rickover in the Naval Nuclear Program. He received Distinguished Service Awards from both the Defense Department and the Atomic Energy Commission. In 1979, Wegner retired from government service and formed Basic Energy Technology Associates with three fellow naval retirees. During its 10 years of successful operation, the firm provided technical services to over 25 nuclear utilities and other nuclear-related activities. Wegner has served on a number of panels, including one of 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 matters. He has supplied technical services to over 50 nuclear facilities. Wegner served on the Detroit Edison Board of Directors, 1990-1999.



Mr. Vincent D. Watkins

Executive Secretary, Return to Flight Task Group

Mr. Watkins has devoted his entire career, now 25 years, to the U.S. space program. Prior to his current position, he was Assistant Chief of the Flight Equipment Division in the Johnson Space Center's Safety and Mission Assurance Directorate. He managed assurance activities related to the definition, design, development and operation of government-furnished equipment (GFE) and extravehicular activity equipment. These engineering functions included flight readiness verification, risk assessments, hazard analysis, nonconformance tracking and product delivery. In 2003 Watkins served as Executive Officer to the Chief of Staff at NASA Headquarters. During this assignment in the Office of the Administrator, he was instrumental in developing and implementing several key initiatives, including the Columbia Families First Team and the Columbia Accident Rapid Reaction Team. Watkins joined NASA in 1980 as Control System Engineer on the Shuttle Training Aircraft. From 1997 to 2003, he served as Chief of the Flight Equipment Division's GFE Assurance Branch. At UCLA in 2003, he completed a NASA Fellowship on Creativity and Innovation in the Organization. He was an inaugural member of the JSC Leadership Development Program in 2002. He received the Mark D. Heath Aircraft Engineering Award, the NASA Exceptional Service Medal and numerous NASA Group Achievement Awards. Watkins has a B.S. in Mathematics from Albany State University.

Colonel Michael J. Bloomfield, U.S. Air Force

Astronaut Office Operations Officer, NASA

Colonel Bloomfield is a NASA astronaut who has logged more than 753 hours in space. The Space Shuttle veteran was a crewmember aboard *Atlantis* in 1997, *Endeavour* in 2000 and *Atlantis* in 2002. A Shuttle Commander and Pilot, he has served as Director of Shuttle Operations, Chief Instructor Astronaut, and Chief of Safety in the Astronaut Office. He was Astronaut Representative to the Columbia Accident Investigation Board. Before entering training at the Johnson Space Center in 1995, Bloomfield served as test pilot for all models of the F-16 at Edwards Air Force Base, as well as Safety Officer and Flight Commander for the 416th Flight Test Squadron. From 1983 until 1991, he served as a combat-ready pilot and instructor pilot in the F-15. He completed the F-15 Fighter Weapons Instructor Course and was honored as a Distinguished Graduate of the U.S. Air Force Test Pilot School. In 1983 he won the Commanders Trophy as Top Graduate from Air Force Undergraduate Pilot Training. Bloomfield holds a B.S. in Engineering Mechanics from the U.S. Air Force Academy and an M.S. in Engineering Management from Old Dominion University. He was also 1980 Captain of the U.S. Air Force Academy Falcon Football Team.

APPENDIX C – RTF TG STAFF

Name	Role	Affiliation
Shannon K. Bach	Administrative Support	Valador, Inc. Consultant
Thomas E. Diegelman	IVASP Support	NASA Johnson Space Center
David B. Drachlis	Public Affairs Officer	NASA Marshall Space Flight Center
Maj. Gen. Joe H. Engle, U.S. Air National Guard (Ret.)	Task Group Support	Engle Technologies
Malise M. Fletcher	Technical Panel Support	NASA Johnson Space Center
Paula B. Frankel	Recorder	Westover and Associates, Inc.
Lillian M. Hudson	Travel Coordinator	Valador, Inc. Consultant
Dennis R. Jenkins	Task Group Support	Valador, Inc. Consultant
Jennifer L. LeStourgeon	Information Technology	NASA Johnson Space Center
Mario Loundermon	Report Cover Artist	Valador, Inc.
Sharon J. Martin	Budget Manager	Al-Razaq Computing Services
Susan E. Mauzy	Task Group Support	NASA Johnson Space Center
Lt. Col. George E. “Ned” Mueller, U.S. Marine Corps (Ret.)	Management Panel Support	Valador, Inc. Consultant
Lester A. Reingold	Report Editor	Valador, Inc. Consultant
Anna K. “Kitty” Rogers	Project Manager	Valador, Inc.
Susan K. Stone	Travel Coordinator	Valador, Inc. Consultant
Barbara J. Teague	Operations Panel Support	NASA Johnson Space Center
Tamara R. West	Administrative Support	NASA Johnson Space Center



Discovery mated to ET-120 in the Vehicle Assembly Building at the Kennedy Space Center; anomalies with this ET eventually forced the program to switch to ET-121 for STS-114.

APPENDIX D – RTF TG FACT-FINDING ACTIVITIES

June 2003

- June 10, 2003 NASA Headquarters, RTF TG Charter.
- June 24, 2003 Johnson Space Center, RTF TG Meeting with Managers for Space Shuttle and International Space Station.

August 2003

- August 5-7, 2003 Kennedy Space Center, Plenary Meeting.
- August 18, 2003 Johnson Space Center, NASA-National Geospatial-Intelligence Agency (NGA) Memorandum of Agreement (MoA).
- August 19-20, 2003 Johnson Space Center, discussions with Space Shuttle Program, USA, and Boeing Management.
- August 21, 2003 Videoconference, Space Flight Leadership Council Meeting.
- August 25, 2003 Kennedy Space Center, Ground-based Imagery Discussions.
- August 27, 2003 Lockheed Martin Missiles and Fire Control, Dallas, Texas, Reinforced Carbon-Carbon Non-Destructive Inspection.
- August 28, 2003 Michoud Assembly Facility (MAF), External Tank Return to Flight Status.

September 2003

- September 9-11, 2003 Johnson Space Center, Plenary Meeting.
- September 17, 2003 House Science Committee Members and Senior Staff visit.



Charles G. Stevenson of the Kennedy Space Center (foreground) briefs staff and members of the Return to Flight Task Group during an August 5, 2003 visit to the Columbia Debris Hangar at the Kennedy Space Center.

Final Report of the Return to Flight Task Group

September 17, 2003	Senate Committee on Commerce, Science and Transportation Members and Senior Staff visit.
September 18, 2003	Johnson Space Center, Extravehicular Activity Tile and Reinforced Carbon-Carbon Repair.
September 23, 2003	NASA Headquarters, CAIB Recommendation 9.1-1 Fact-Finding.
September 24, 2003	Kennedy Space Center, Foreign Object Debris (FOD) and Non-Destructive Inspection.
September 30, 2003	Michoud Assembly Facility, External Tank Return to Flight Status.
October 2003	
October 3, 2003	Videoconference, Space Flight Leadership Council Meeting.
October 8, 2003	Kennedy Space Center, Waivers and Deviations for Kennedy Space Center Ground Support Equipment.
October 14, 2003	Washington, D.C., NASA-National Geospatial-Intelligence Agency (NGA) Memorandum of Agreement (MoA).
October 20, 2003	Kennedy Space Center, Ground-based Imaging.
October 20, 2003	House Science Committee Senior Staff visit.
October 22-23, 2003	Ogden, Utah, Program Managers Review.
October 27-28, 2003	NASA Headquarters, Submarine Safety Colloquium.

Frank Benz of the Johnson Space Center in Houston, briefs members of the Return to Flight Task Group's Technical Panel on the reinforced carbon-carbon (RCC) impact test rig during a fact-finding visit to the Southwest Research Institute in San Antonio, Texas on October 29, 2003. Task Group members and supporting staff are, from left, Sy Rubenstein, Astronaut Carlos Noriega, Rob Hammond, and Ben Cosgrove.





Return to Flight Task Group Technical Panel members and support staff inspect the External Tank planned for the STS-114 mission during a December 2, 2003 fact-finding visit to the Michoud Assembly Facility near New Orleans. Lockheed Martin Space Systems Company's Michoud Operations builds the External Tank for NASA at the facility.

- October 28-30, 2003 Johnson Space Center and Southwest Research Institute, San Antonio, Texas, Thermal Protection System Meetings.
- October 29-30, 2003 Cape Canaveral, Florida, Service Life Extension Program Summit.
- October 31, 2003 Teleconference, *Atlantis* Nosecap Non-Destructive Inspection.
- November 2003**
- November 5-30, 2003 Marshall Space Flight Center, SRB Bolt-Catcher Critical Design Review.
- November 12, 2003 Johnson Space Center, JAXA Fact-Finding.
- November 20, 2003 Johnson Space Center, Management Meetings.
- November 20, 2003 Johnson Space Center, Mission Management Team Normal Accident Theory.
- November 21, 2003 Johnson Space Center, Space Flight Leadership Council Meeting.
- December 2003**
- December 3-4, 2003 Johnson Space Center, Mission Management Team Simulation (Flight 12A.1).
- December 2, 2003 Michoud Assembly Facility, External Tank Status.
- December 3, 2003 Kennedy Space Center, Digital Closeout Imagery.
- December 9-10, 2003 Johnson Space Center, Plenary Meeting.

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December 11-12, 2003 Marshall Space Flight Center, Space Shuttle Certification Status Review.

December 16, 2003 NASA Headquarters, Space Flight Leadership Council Meeting.

January 2004

January 15, 2004 Johnson Space Center, STS-114 Flight Techniques Panel.

January 22, 2004 Teleconference, Regarding R3.4-1, R3.4-2, R3.4-3, Imagery and R6.4-1, TPS Inspection and Repair with Mr. Steve Wallace (CAIB member).

January 26, 2004 Teleconference, with Bryan O'Connor, Chief Safety and Mission Assurance Officer Regarding CAIB Recommendation 9.1-1.

January 27, 2004 Teleconference, Jim Halsell Regarding Planning Framework for STS-114 and STS-121.

January 28-30, 2004 Kennedy Space Center, SEIO Summit II.

January 29, 2004 Johnson Space Center, Sub-nominal Bond Technical Interchange Meeting.

February 2004

February 2, 2004 Teleconference, ADM Harold W. Gehman (CAIB Chairman)

February 3, 2004 Michoud Assembly Facility, External Tank Mini-Technical Interchange Meeting.

February 3, 2004 Integrated Vehicle Assessment Sub-Panel, Organizational Telecon.

February 4, 2004 Johnson Space Center, DTO 848 Preliminary Design Review.

February 2-5, 2004 Kennedy Space Center, Launch and Landing Imagery Program Requirements Document Requirements Review.

February 4, 2004 NASA Headquarters, ITEA Meeting.

February 5, 2004 Johnson Space Center, STS-114 Joint Operations Panel #9 Telecon.

February 6, 2004 Kennedy Space Center, Solid Rocket Booster Thermal Protection System Mini-Technical Interchange Meeting.

February 10, 2004 Johnson Space Center, Imagery Technical Interchange Meeting.

February 11, 2004 Johnson Space Center, Mission Management Team Simulation.

February 12, 2004 Teleconference, with Johnson Space Center MER Personnel Regarding SIMS Database.

February 12-13, 2004 Johnson Space Center, Debris Summit II Summit.

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February 17-18, 2004 Galveston, Texas, SLEP II Summit.

February 18, 2004 NASA Headquarters, JAXA Fact-Finding.

February 19, 2004 Johnson Space Center, Space Flight Leadership Council Meeting.

February 19, 2004 Johnson Space Center, STS-114 Joint Operations Panel #10 Telecon.

February 18-19, 2004 Johnson Space Center, NASA-NGA MoA Meeting.

February 20, 2004 Johnson Space Center, Integrated Vehicle Assessment Sub-Panel Meeting.

February 24-25, 2004 NASA Headquarters, Management Panel Meetings.

March 2004

March 4, 2004 Johnson Space Center, STS-114 Joint Operations Panel #11 Telecon.

March 11, 2004 Kennedy Space Center, FOD and Digital Closeout Imagery.

March 23-24, 2004 Johnson Space Center, OBSS Status Meeting.

March 30, 2004 Johnson Space Center, STS-114 Joint Operations Panel #12 Telecon.

March 31, 2004 Sandia Labs, Albuquerque, New Mexico, OBSS Status Meeting.

April 2004

April 1, 2004 Kennedy Space Center, External Tank Monthly Review.

April 2, 2004 Kennedy Space Center, Two-Person Closeout, Orbiter Hardening, and RCC Non-Destructive Inspection Briefings.

April 2, 2004 Kennedy Space Center, Pre-Launch Mission Management Team Simulation.

April 9, 2004 Kennedy Space Center, Two-Person Closeout, Orbiter Hardening, and RCC Non-Destructive Inspection Dry Run Briefings.

April 12-15, 2004 Johnson Space Center, Plenary Meeting.

April 28-30, 2004 Marshall Space Flight Center, SRB Bolt Catcher Delta Critical Design Review.

May 2004

May 14, 2004 Kennedy Space Center, Foreign Object Debris and Digital Closeout Imagery Status Review.

May 19, 2004 Marshall Space Flight Center, SRB Bolt Catcher Critical Design Review Pre-board.

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May 26, 2004	Johnson Space Center, Mission Management Team Simulation #5.
May 27, 2004	Johnson Space Center, Reinforced Carbon-Carbon Plug Repair Preliminary Design Review.
May 27, 2004	Marshall Space Flight Center, SRB Bolt Catcher/NSI Pressure Cartridge Critical Design Review.
June 2004	
June 8-9, 2004	Johnson Space Center, LDRI Orbiter Inspection System Critical Design Review.
June 9, 2004	Ogden, Utah, Space Flight Leadership Council Meeting.
June 10, 2004	Ogden, Utah, Engineering Test Motor Firing at ATK-Thiokol.
June 14-15, 2004	Kennedy Space Center, Systems Engineering & Integration Office Summit .
June 17, 2004	Johnson Space Center, Operations Panel Fact-Finding Telecon with Space Shuttle Program regarding CAIB Recommendation 6.4-1.
June 22, 2004	Langley Research Center, Virginia, Management Panel visit to the NASA Engineering and Safety Center regarding CAIB Recommendations 6.2-1, 7.5-1, and 7.5-2.
June 23, 2004	NASA Headquarters, Management Panel visit regarding CAIB Recommendations 6.2-1, 7.5-1, and 7.5-2.
June 25, 2004	Michoud Assembly Facility and Stennis Space Center, External Tank Monthly Review.

A full-scale Reusable Solid Rocket Motor is fired at ATK Thiokol Propulsion Division's Promontory, Utah, test facility on June 10, 2004. This motor tested modifications designed to enhance the safety and integrity of the Space Shuttle. Members of the Return to Flight Task Group observed the test during a fact-finding visit to the facility.





Return to Flight Task Group Management Panel members and staff meet with NASA officials during a fact-finding meeting in Washington, D.C. June 23, 2004.

- June 28, 2004 Johnson Space Center, Tile Test Article Review.
- June 29, 2004 Kennedy Space Center, SIMS Production Tool Demonstration.
- June 30, 2004 Kennedy Space Center, Mission Management Team Simulation #6.
- July 2004**
- July 1, 2004 NASA Headquarters, NASA Administrator's Retreat on Agency's Space Shuttle Return to Flight.
- July 8, 2004 Kennedy Space Center, Operations Panel Fact-Finding on Space Shuttle Program-3, Contingency Shuttle Crew Support.
- July 8, 2004 Kennedy Space Center, Fact-Finding on CAIB Recommendations 4.2-5 and 10.3-1.
- July 16, 2004 Teleconference, Fact-Finding on CAIB Recommendation 3.2-1.
- July 21, 2004 Teleconference, Plenary for Conditional Closures to CAIB Recommendations 4.2-5 and 10.3-1.
- July 26-27, 2004 Johnson Space Center, Reinforced Carbon-Carbon Test Article Review.
- July 27-28, 2004 Johnson Space Center, Mission Management Team Simulation #7.
- July 27-28, 2004 Johnson Space Center, Integrated Vehicle Assessment Sub-Panel Fact-finding Meeting with Simulation Planning Team, Mission Management Team training community, and System Engineering and Integration Office on Thermal Protection System Integrated Operations Plan.
- July 28, 2004 Johnson Space Center, Technical Panel Fact-finding with Space Shuttle Program on Integrated Risk Assessment for CAIB Recommendation 3.2-1.

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August 2004

August 10, 2004 Kennedy Space Center, Operations Panel Fact-finding on Space Shuttle Program-3, Contingency Shuttle Crew Support.

August 10-12, 2004 Johnson Space Center, Space Shuttle Program Impact Testing and Debris Summit.

August 13, 2004 Johnson Space Center, R6.4-1 Strategy Session.

August 16, 2004 Teleconference, Internal Review of CAIB Recommendation 4.2-1 Closure.

August 18, 2004 Johnson Space Center, Fact-Finding with Space Shuttle Program on CAIB Recommendations 6.3-1 and 7.5-3.

August 18-19, 2004 Kennedy Space Center, External Tank TPS Certification Technical Interchange Meeting.

August 25, 2004 Kennedy Space Center, External Tank Monthly Review.

August 30, 2004 Kennedy Space Center, Management Panel and Operations Panel Fact-finding with Space Shuttle Program Workforce.

August 30-3, 2004 Michoud Assembly Facility, ET Flange Critical Design Review.

August 31-1, 2004 Johnson Space Center, Orbiter Boom Sensor System Design Review.

September 2004

September 1, 2004 Marshall Space Flight Center, Space Flight Leadership Council Meeting.

September 3, 2004 Teleconference, Debris Summit Debrief.

September 13, 2004 Johnson Space Center, Tile Repair System Design Review.

September 13, 2004 Johnson Space Center, Integrated Vehicle Assessment Sub-Panel Fact Finding on TPS Integrated Operations Plan.

September 14-16, 2004 Johnson Space Center, Plenary Meeting.

September 22-23, 2004 Johnson Space Center, On-Orbit Mission Management Team Simulation.

October 2004

October 5-6, 2004 Ogden, Utah, RCC Plug Repair Technical Interchange Meeting.

October 08, 2004, Washington, D.C., Meeting with OMB, OSTP, and White House staff.

October 19-20, 2004 Marshall Space Flight Center, RCC Crack Repair Preliminary Design Review.

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October 20-21, 2004	Michoud Assembly Facility, ET TPS Certification Technical Interchange Meeting.
October 25-26, 2004	Kennedy Space Center, Ground Camera Ascent Imagery Project Critical Design Review.
October 27, 2004	Teleconference, on Verification, Validation and Certification Definitions.
October 28, 2004	NASA Headquarters, RTF TG Leadership Meeting.
October 28-29, 2004	Johnson Space Center, RTF Flight Operations Progress Review.
October 29, 2004	Videoconference, Space Flight Leadership Council Meeting.
November 2004	
November 8-10, 2004	Johnson Space Center, Space Shuttle Program Impact Testing Debris Summit.
November 9-10, 2004	Michoud Assembly Facility, External Tank TPS Certification Status Briefing.
November 15, 2004	Johnson Space Center, Management Panel Briefing to the Aerospace Safety Advisory Panel.
November 16, 2004	Johnson Space Center, Management Panel Fact Finding on CAIB Recommendation 6.3-1.
November 16-18, 2004	Marshall Space Flight Center, SRB Bolt Catcher Design Certification Review Onsite Documentation Review.



Return to Flight Task Group members and staff inspect the Space Shuttle External Tank being prepared for the STS-114 mission during a visit to the Michoud Assembly Facility in New Orleans November 10, 2004.

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November 16-19, 2004	Johnson Space Center, STS 114 On-Orbit Mission Management Team Simulation.
November 18, 2004	Telecon with Space Shuttle Program on CAIB recommendation R3.3-2.
November 22, 2004	Johnson Space Center, Space Shuttle Program Presents R3.3-2 and 4.2-1 Closures to Technical Panel/Integrated Vehicle Assessment Sub-Panel.
November 23, 2004	NASA Headquarters, Deputy Chief Engineer Presents R7.5-1 and R9.1-1 Closures.
November 30, 2004	Johnson Space Center, Space Shuttle Program Presents R3.4-1, R3.4-2, R3.4-3 Closures to Operations Panel and Integrated Vehicle Assessment Sub-Panel.
November 30-1, 2004	Johnson Space Center, RCC Plug Repair Technical Interchange Meeting #3.
November 30, 2004	Marshall Space Flight Center, SRB Bolt Catcher Design Certification Review Pre-Board.

December 2004

December 2, 2004	Johnson Space Center, Cure-In-Place Ablator (CIPA) Critical Design Review.
December 3, 2004	Marshall Space Flight Center, SRB Bolt Catcher Design Certification Review Board.



Return to Flight Task Group Management Panel Lead Dr. Dan L. Crippen, left, confers with Technical Panel Lead Joseph W. Cuzzupoli during a December 2004 fact-finding plenary at the Marshall Space Flight Center in Huntsville, Alabama.

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December 9, 2004 Videoconference, Space Flight Leadership Council Meeting.

December 10, 2004 Marshall Space Flight Center, SRB Bolt Catcher Design Certification Review Delta Board.

December 13, 2004 Johnson Space Center, Integrated Vehicle Assessment Sub-Panel Fact Finding on TPS Integrated Operations Plan.

December 14-15, 2004 Marshall Space Flight Center, Plenary Meeting.

December 15, 2004 Johnson Space Center, Space Shuttle Program Fact Finding on CAIB Recommendation 6.4-1.

January 2005

January 7, 2005 Johnson Space Center, Orbiter Return to Flight Working Group – Down Select for Repair Option Meeting.

January 10-14, 2005 Johnson Space Center, Debris Summit.

January 13, 2005 Johnson Space Center, Program Requirements Control Board – Down Select for Repair Option.

January 21, 2005 Kennedy Space Center, Imagery Technical Interchange Meeting .

January 24, 2005 Michoud Assembly Facility, External Tank Design Certification Review II.

January 26-27, 2005 Johnson Space Center, R6.4-1 Fact Finding.

January 27, 2005 Johnson Space Center, Component Simulation.

February 2005

February 2-3, 2005 Johnson Space Center, Japanese Space Agency (JAXA) Fact-Finding.

February 7-10, 2005 Johnson Space Center, Orbiter Delta Design Certification Review.

February 8, 2005 Washington, D.C., Imagery Technical Interchange Meeting.

February 15, 2005 Teleconference Plenary for Conditional Closure of CAIB Recommendation 3.3-1.

February 18, 2005 Videoconference, Space Flight Leadership Council Meeting.

February 22-23, 2005 Kennedy Space Center, Systems Design Certification Review II.

February 24-25, 2005 Michoud Assembly Facility, ET Design Certification Review II Pre-Board.

February 25, 2005 Johnson Space Center, Component Simulation.

February 25, 2005 Johnson Space Center, RCC On-Orbit Crack Repair Gun Critical Design Review.

Return to Flight Task Group Technical Panel members and staff observe Space Shuttle Solid Rocket Booster stacking operations in the Vehicle Assembly Building during a February 22, 2005, fact-finding visit to the Kennedy Space Center, Florida.



February 28-March 7, 2005	Kennedy Space Center and Johnson Space Center, STS-114 On-Orbit Mission Management Team Simulation.
March 2005	
March 8-9, 2005	Michoud Assembly Facility, ET Design Certification Review I and II Board.
March 10, 2005	Johnson Space Center, Space Shuttle Program Closure Presentation to Operations Panel and the Integrated Vehicle Assessment Sub-Panel on Space Shuttle Program-3, Contingency Shuttle Crew Support.
March 15, 2005	Johnson Space Center, Space Shuttle Program Closure Presentation to Technical Panel and Integrated Vehicle Assessment Sub-Panel on CAIB Recommendation 3.2-1, ET Debris Shedding.
March 15, 2005	Washington, D.C., Meeting with Congressman Calvert and Staff.
March 21, 2005	NASA Headquarters, Management Panel Closure Discussion on CAIB Recommendations 9.1-1, 6.2-1, and 6.3-1.
March 22, 2005	Johnson Space Center, Operations Panel Fact Finding with Mr. Wayne Hale, Deputy Space Shuttle Program Manager on Space Shuttle Program-3, Contingency Shuttle Crew Support.
March 24, 2005	Johnson Space Center, Space Shuttle Program Closure Presentation Telecon with Technical Panel and Integrated Vehicle Assessment Sub-Panel on CAIB Recommendation 3.3-2.
March 28, 2005	Johnson Space Center, Management Panel Splinter Session on Space Shuttle Program Closure Packages for CAIB Recommendations 9.1-1, 6.2-1, and 6.3-1.
March 29, 2005	Johnson Space Center, Integrated Vehicle Assessment Sub-Panel Splinter Session on Final Report Comments.
March 29-31, 2005	Johnson Space Center, Plenary Meeting.

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April 2005

- April 4, 2005 Johnson Space Center, Stafford Task Force/Anfimov AEC Fact Finding.
- April 4, 2005 NASA Headquarters, RTF TG Meeting.
- April 5, 2005 Jet Propulsion Laboratory, California, RTF TG to ASAP Transition Meeting.
- April 6, 2005 Johnson Space Center, System Design Certification Review II Board.
- April 7-8, 2005 Teleconference, Operations Panel Mission Management Team Training Fact-Finding.
- April 7-9, 2005 Johnson Space Center, System Design Verification Review III (Debris) Board.
- April 12, 2005 Teleconference, Space Shuttle Program Fact Finding on Certificate of Flight Readiness Process.
- April 13, 2005 Johnson Space Center, RCC Repair Interim Design Review.
- April 19, 2005 Kennedy Space Center, Program Design Certification Review.
- April 20, 2005 Washington, D.C., RTF TG Co-Chair and Management Panel Lead Meeting with Congressmen Gordon and Udall and Staff.
- April 20, 2005 Washington, D.C., RTF TG Co-Chair and Management Panel Lead Meeting with House Science Committee Staff.
- April 25, 2005 Johnson Space Center, CAIB Recommendation 6.4-1 Fact Finding.
- April 26-27, 2005 Johnson Space Center, Delta System Design Verification Review III (Debris).
- April 26-28, 2005 Johnson Space Center, Operations Integration Plan Simulation #3 Flight Day 04-06.

May 2005

- May 3-4, 2005 Michoud Assembly Facility, Monte Carlo Inputs Review of External Tank Debris Data.
- May 4, 2005 Johnson Space Center, Mission Management Team Simulation #13, Contingency Shuttle Crew Support.
- May 9, 2005 NASA Headquarters, RTF TG Co-Chair Meeting with NASA Administrator.
- May 10, 2005 Johnson Space Center, Review of Debris Transport Validation.
- May 11, 2005 Johnson Space Center, Orbiter Impact and Damage Tolerance Models for RCC and Tile.

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May 12, 2005	Johnson Space Center, R6.4-1 Closure Discussion with Space Shuttle Program.
May 18, 2005	Michoud Assembly Facility, Foam Divot-Transport-Impact Damage Technical Interchange Meeting.
May 24, 2005	Johnson Space Center, Ice Technical Interchange Meeting.
May 25, 2005	Johnson Space Center, Unexpected Debris Review Foam Divot-Transport-Impact Damage Technical Interchange Meeting.
May 26, 2005	Johnson Space Center, Aerospace Corp. Go/No-Go Decision for Monte Carlo Analysis.
June 2005	
June 2-3, 2005	Johnson Space Center, Debris Design Verification Technical Review Dry-Run.
June 6-7, 2005	Johnson Space Center, Plenary Meeting.
June 15, 2005	Johnson Space Center, R6.4-1 Closure Data Review.
June 16-17, 2005	Johnson Space Center, Debris Verification Technical Review Dry Run.
June 20, 2005	Michoud Assembly Facility, Bellows Heater Design Certification Review.
June 22, 2005	Johnson Space Center, STS-114 Delta Safety and Mission Assurance Readiness Review.
June 23, 2005	Kennedy Space Center, Delta Systems Design Certification Review.
June 24, 2005	Kennedy Space Center, Final Debris Design Verification Review.
June 25, 2005	NASA Headquarters, R3.2-1 and R3.3-2 Closure Data Review.
June 27, 2005	NASA Headquarters, Plenary Meeting.
June 28, 2005	NASA Headquarters, RTF TG Co-Chairmen and Panel Leads Meeting with NASA Administrator.
July 2005	
July 1, 2005	Johnson Space Center, Japanese Space Agency (JAXA) Fact-Finding.

APPENDIX E – ACRONYMS

AFB	Air Force Base
AFRSI	Advanced Felt Reusable Surface Insulation (TPS blankets)
ASAP	Aerospace Safety Advisory Panel
ATOTS	Advanced Transportable Optical Tracking System
BFS	Backup Flight System (Orbiter avionics)
BST	Behavioral Science Technology, Inc.
C-SiC	Carbon-Silicon Carbide
CAD	Computer-Aided Design
CAIB	Columbia Accident Investigation Board
CDR	Critical Design Review
CIA	Central Intelligence Agency
CIPA	Cure In-Place Ablator
CIPAA	CIPA Applicator
CO2	Carbon Dioxide
CSCS	Contingency Shuttle Crew Support
DCR	Design Certification Review
DFO	Designated Federal Official (FACA)
DOAMS	Distant Object Attitude Measurement System
DoD	Department of Defense
DTO	Development Test Objective
DVR	Design Verification Review
ECLSS	Environmental Control and Life Support System
EFM	Equivalent Flow Model (Scheduling tool)
EPOCC	Expanded Photographic Optic Control Center
ET	External Tank
EVA	Extra-Vehicular Activity
FACA	Federal Advisory Committee Act
FOD	Foreign Object Debris
FRCS	Forward Reaction Control System
HDTV	High Definition Television
HQ	Headquarters
HSC	House Science Committee
HSDT	High Speed Digital Television
HST	Hubble Space Telescope
JSC	Johnson Space Center (Texas)
ICB	Integration Control Board
ISS	International Space Station
ITA	Independent Technical Authority
ITAR	International Traffic in Arms (Federal law)
IVA	Intra-Vehicular Activity
IVASP	Integration Vehicle Assessment Sub-Panel
KSC	Kennedy Space Center (Florida)
KTM	Kineto Tracking Mount
LCC	Launch Commit Criteria
LO2/LOX	Liquid Oxygen
LH2	Liquid Hydrogen
LON	Launch-on-Need
MAF	Michoud Assembly Facility (Louisiana)
MAS	Manifest Assessment System (scheduling tool)
MER	Mission Evaluation Room
MMT	Mission Management Team
MoA	Memorandum of Agreement
MPP	Material Processing Plan
MR	Material Review

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MRB	Material Review Board
MSFC	Marshall Space Flight Center (Alabama)
NASA	National Aeronautics and Space Administration
NESC	NASA Engineering and Safety Center
NDE	Non-Destructive Evaluation
NDI	Non-Destructive Inspection
NGA	National Geospatial-Intelligence Agency (formerly NIMA)
NIMA	National Imagery and Mapping Agency (now NGA)
NOAX	Non-Oxide Adhesive eXperimental
NSI	NASA Standard Initiator
NSTS	National Space Transportation System (Space Shuttle)
O2	Oxygen
OBSS	Orbiter Boom Sensor System
OIP	Operations Integration Plan
OMM	Orbiter Major Modifications
OMDP	Orbiter Modification and Down Period
OMRS	Operation and Maintenance Requirements System
ORM	Orbiter Repair Maneuver
OV-102	<i>Columbia</i>
OV-103	<i>Discovery</i>
OV-104	<i>Atlantis</i>
OV-105	<i>Endeavour</i>
PAL	Protuberance Air Load (ramps on ET)
PASS	Primary Avionics Software System (Orbiter avionics)
PDL	Polymer Development Laboratories (TPS foam)
PDR	Preliminary Design Review
POCS	Photographic Optic Control System
PR	Problem Report
PRCB	Program Requirements Control Board
PRR	Production Readiness Review
PTS	Pad Tracker System
RCC	Reinforced Carbon-Carbon
RFI	Request for Information
RPM	R-bar Pitch Maneuver
RSRM	Reusable Solid Rocket Motor (propulsion part of SRB)
RTF TG	Return to Flight Task Group
SDTV	Standard Definition Television
SEIO	Systems Engineering and Integration Office (also SE&IO)
SFLC	Space Flight Leadership Council
SiC	Silicon Carbide
SIMS	Shuttle Image Management System
SMA	Safety and Mission Assurance
SRB	Solid Rocket Booster
SRMS	Shuttle Remote Manipulator System
SSME	Space Shuttle Main Engine
SSP	Space Shuttle Program
SSPO	Space Shuttle Program Office
SSRMS	Space Station Remote Manipulator System
STS	Space Transportation System (Space Shuttle)
TPS	Thermal Protection System
TZM	Titanium, Zirconium, Molybdenum (metal alloy)
USA	United Space Alliance
WAVE	WB-57 Ascent Video Experiment
WLE	Wing Leading Edge (on Orbiter)



Discovery being lifted to a vertical position in the transfer aisle of the Vehicle Assembly Building at the Kennedy Space Center. After the Orbiter is vertical, it will be lifted into one of the high bays to be mated with a waiting stack of Solid Rocket Boosters and an External Tank.



Discovery hangs in the transfer aisle of the Vehicle Assembly Building at the Kennedy Space Center. The two green squares are the undersides of the umbilical well doors; after the External Tank separates, these doors close over the areas just outboard of them.

ANNEX A – INDIVIDUAL MEMBER OBSERVATIONS

During two years of fact-finding, some members of the Task Group made observations that they believe should be brought to the attention of the NASA Administrator as he leads the Agency past the return to flight. Those observations, which are not related to the safety or operational readiness of STS-114, are presented in this annex. These are not Task Group observations but rather represent the views of the individual authors; where additional Task Group members have chosen to support these views, they are so identified.

A.1 Observations by Maj. Gen. William A. Anders

1. NASA’s response to the CAIB findings and the Agency’s support of the RTF TG:

I believe that NASA as a whole has made a commendable effort in these regards. It has not been perfect or totally efficient, but that should be understandable for such a massive Agency-wide challenge coming out of the shock of the *Columbia* accident.

2. Safety of Human Spaceflight and Space Shuttle operations: The Space Shuttle is a high-performance vehicle with thin margins as is necessary to support the very challenging field of human space flight. NASA has done a commendable job in addressing the issues raised by the CAIB report to the extent such issues can be addressed practicably. Nonetheless, the Space Shuttle will never be particularly safe. If the United States chooses to operate in this demanding environment, we need to be continually alert to minimize risk and be sure it is worth the gain. And, we should not be too surprised if or when another accident happens.

3. America’s “vision” and NASA’s strategy for space exploration and exploitation: It is desirable and unavoidable that humans will explore and exploit space. The major questions are: how, and at what pace? A key necessity for implementing any successful strategy/vision is that the scope and pace be in balance with the available resources. This seems to have been forgotten or ignored by both the Executive and Legislative branches. Over the past four decades NASA has experienced an almost continuous series of cost overruns and performance short-falls; the Space Shuttle has been the “poster child” for this phenomenon. Apollo was established to demonstrate to Americans and the rest of the world that the United States was *not* a second-rate power as had been strongly suggested by *Sputnik*, Gagarin, and the “missile gap.” It was a jingoistic program during the height of the Cold War that was strongly supported by the American (tax-paying) public. That program was successfully demonstrated on July 19, 1969, when Neil Armstrong and Buzz Aldrin planted an American flag at Tranquility Base. Unfortunately, NASA and a host of space enthusiasts incorrectly assumed (hoped?) that America’s political will and financial support extended beyond that necessary to “beat the Soviets” (Apollo 11 and prior). These enthusiasts continued intense and expensive exploitation and exploration programs (e.g. up to Apollo 17, Space Shuttle, the International Space Station ...) while political and financial support waned. These ambitious new programs, coupled with the political necessity to maintain the Apollo-derived NASA infrastructure (Centers), put the Agency’s scope in serious imbalance with its resources. Such is still the case. Until hard choices are made to bring the Agency’s scope (the Vision for Space Exploration) into balance with its resources, we should not be surprised by future mishaps and short-falls in our currently over-stressed human space flight programs. Since it is not likely that the American public will provide Apollo-like support for the current vision, it seems that its scope and pace should be reduced to more realistic levels (balance).

4. Make-up of the RTF TG: In my view, the Task Group was too large to carry out its charter effectively and efficiently. In addition, it would have been advisable to slant the talents of the Task Group members more toward those with experience in accident investigation, large-program management, and human space flight.

**A.2 Observations by Dr. Dan L. Crippen, Dr. Charles C. Daniel,
Dr. Amy K. Donahue, Col. Susan J. Helms, Ms. Susan Morrissey
Livingstone, Dr. Rosemary O’Leary, and Mr. William Wegner**

Taken one-at-a-time, the RTF TG assessments of the NASA implementation of the CAIB return-to-flight recommendations may leave an impression of accomplishment that we believe does not present a comprehensive picture of NASA’s return-to-flight effort. Without a doubt, we share with NASA the same fervent desire to see the Space Shuttle Program successfully continue as a healthy, vibrant tribute to the achievements of human spaceflight. To this end, although it was not within the explicit charter of the Return To Flight Task Group, we have documented additional observations relevant the post-*Columbia* environment that we believe are important to share with NASA leadership to help them address what we perceive to be continuing challenges. This is not a set of conclusions, but is a detailed summary of persistent cultural symptoms we observed throughout the assessment process.

We agree that the improvements to the Space Shuttle and its organization are real, and often significant. This is a tribute to the dedicated efforts of many people working hard at all levels and in all parts of the Agency. At the same time, we believe that the leadership and management climate that governed NASA’s return-to-flight effort was weak in some important ways that bear discussion. While we explicitly address the Space Shuttle return-to-flight effort, we believe these organizational and behavioral concerns are still pervasive throughout the human spaceflight programs.

These observations are not intended as criticism of the entire NASA workforce. We have stated several times – in this report and elsewhere – that within the “working levels,” much of the NASA and contractor workforce “got it” and we believe at least some have always gotten it. And, indeed, there are some capable leaders at NASA who also “get it.”

Our observations also are not meant to diminish the achievements made in addressing the individual CAIB recommendations. The workforce performed to the best of its ability, often with little direction. We commend their efforts and recognize their accomplishments. We also believe, however, that leadership and managerial shortfalls generally made the return-to-flight effort more complicated, more costly, and lengthier than it needed to be.

The Rogers Commission and the Columbia Accident Investigation Board (CAIB) reports are both rich in explanation of factors that have weakened NASA’s ability to effectively manage a high-risk program. Yet while NASA leadership was focused on the 15 CAIB return-to-flight recommendations, they missed opportunities to address the enduring themes of dysfunctional organizational behavior that the CAIB and other external evaluators have repeatedly found. As a result, in our view, many fundamental concerns persist. Our intent here is to present some of the most prominent of these that we observed.

The advantage of hindsight, and the opportunity to second-guess decisions made since February 2003, permeates these observations. All of them were, however, written prior to the launch of STS-114. It is also important to recognize that the behaviors and attitudes described here were not chance occurrences that were observed only once or twice, but that emerged numerous times throughout the Task Group’s interactions with NASA. The intent of these observations is to help NASA leadership identify and rectify these concerns. We will address four main areas: rigor, risk, requirements, and leadership. At the conclusion of our discussion, we cite specific examples to support and clarify our observations.

Rigor

“Rigor” refers to the scrupulous adherence to established standards for the conduct of work. In NASA’s context, the safe and reliable execution of high-risk, complex technical endeavors

requires the rigorous and consistent understanding of, and adherence to, standard process. These processes should be enforced across all projects and elements, and preferably even across programs. Implementing standard processes across programs allows more consistent evaluations of the programs, and eases the transition of personnel moving from one program to another. As we observed them, the return-to-flight activities often demonstrated a lack of standard processes, and, in some cases, simply a lack of any process at all.

One dilemma the Agency faced in this regard was how to communicate about its goals and standards of achievement. Once the Agency is on record as committed to a specific achievement, it becomes unpalatable to back off of that target for fear of appearing to fail. Instead, the adjustment of performance standards to allow a “best-effort” provides the appearance that the goal has been met, but without the rigor and discipline necessary do so safely or completely. Before making commitments to specific achievements, NASA should fully consider how much progress is feasible, and motivate public and private expectations accordingly. When achievements are mandatory at first but become “goals” when the going gets tough, it sends a strong message to everyone that *nothing* is mandatory.

With the benefit of hindsight, the Agency’s unquestioned endorsement of, and commitment to comply with, the CAIB return-to-flight recommendations may have been laudable and reasonable – and perhaps even necessary under the circumstances the Agency faced at the time – but it may also have been a mistake. The endorsement of the CAIB recommendations, before conducting a thorough engineering and programmatic assessment of their implications, short-circuited a more traditional and rigorous process. NASA has long maintained a list of the hardware risks to the vehicle, and had an upgrades program in place before the *Columbia* accident. Ideally, NASA should have determined the importance of the CAIB recommendations in relation to the risks and upgrades it was already tracking. Then leaders should have prioritized the implementation of the CAIB recommendations against other desired risk mitigation efforts to determine the best expenditure of limited program resources to provide the largest reduction in overall risk.

The change in National Policy dictating the Space Shuttle be retired in 2010 presented the Agency with an opportunity to re-evaluate the decision to fully implement all of the CAIB recommendations and to curtail actions that were proving to be unproductive or inefficient; NASA did not.

In our view, NASA leadership should not have foregone their traditional process of conducting detailed assessments of proposed changes. The CAIB recommendations were important, but the accident board fully acknowledged that they had not considered their recommendations within the larger context of the Space Shuttle Program. In addition, before committing to a short-term launch date – that ultimately drove any number of important implementation decisions – NASA should have conducted detailed engineering assessments of the CAIB recommendations, traded them against other risk mitigation efforts, developed a clear understanding of the physics of foam loss, and devoted serious consideration of alternatives to “fix the foam;” e.g., Orbiter hardening or a redesigned External Tank. This would have allowed the program to determine how long a stand-down was necessary to implement a reasonable set of requirements to reduce the risk of flying the vehicle.

As we reviewed the return-to-flight effort, it was apparent that there were numerous instances when an opportunity was missed to implement the best solution because of this false schedule pressure. As early as September 2003 the RTF TG was told that specific technical activities were not being performed because they could not meet the schedule. Too often we heard the lament: “If only we’d known we were down for two years we would have approached this very differently...”

This overall lack of integrated planning resulted in *ad hoc* and redundant efforts. Even the *NASA Implementation Plan* disappoints: it has no document number, no change history, and

no clear place in the program's effort. Its subtitle – “A periodically updated document demonstrating our progress ...” – makes clear that it is not an executable “plan” but, instead, a status report. Many of the lower-level “plans” that were presented in formal meetings were developed after implementation was initiated, instead of setting clear objectives and acceptance criteria before the work was begun. Activities were undertaken without an understanding of how they contributed to the overall return-to-flight effort and without any sense of budgetary or other limits. As a result, at the end of 2-½ years and \$1.5 billion or more, it is not clear what has been accomplished.

While solving the technical problems associated with return to flight was always seen as the highest priority, the cost associated with accomplishing this was for the most part neither effectively monitored nor managed. In fact, many of the return-to-flight efforts were initiated at mid- to lower-levels with little visibility or traceability to the Space Shuttle Program level (Level II). These factors have combined to allow for uncontrolled cost growth and an overall lack of cost management. If the return-to-flight effort had been better managed to control costs, it is possible that funding would exist to upgrade the Orbiter with newer systems and eliminate risks posed by hardware not involved in the *Columbia* accident.

We also observed that instead of concise engineering reports, decisions and their associated rationale are often contained solely within Microsoft PowerPoint® charts or emails. The CAIB report (Vol. I, pp. 182 and 191) criticized the use of PowerPoint as an engineering tool, and other professional organizations have also noted the increased use of this presentation software as a substitute for technical reports and other meaningful documentation. PowerPoint (and similar products by other vendors), as a method to provide talking points and present limited data to assembled groups, has its place in the engineering community; however, these presentations should never be allowed to replace, or even supplement, formal documentation.

Several members of the Task Group noted, as had CAIB before them, that many of the engineering packages brought before formal control boards were documented *only* in PowerPoint presentations. In some instances, requirements are defined in presentations, approved with a cover letter, and never transferred to formal documentation. Similarly, in many instances when data was requested by the Task Group, a PowerPoint presentation would be delivered without supporting engineering documentation. It appears that many young engineers do not understand the need for, or know how to prepare, formal engineering documents such as reports, white papers, or analyses.

Another disturbing trait that we observed was that personalities were allowed to dominate over strict process – examples exist of strong personalities attempting to avoid process and others allowing avoidance to occur. Many in senior leadership observed these lapses in process, but did little to correct the situation. For example, during the System Design Certification Review (DCR) II on February 23, 2005, a senior program manager commented that, “It is no longer an important question as to whether or not any given item is certified. Some things won't be certified ... Items don't have to be certified to fly, and we can even get waivers for the safety cert if need be.” It was astounding that there was no rebuttal to this statement, even though the individual was not the most senior person at the table. This mocking of rigor sends a message to junior staff that it is acceptable to modify or avoid established processes. As a result, both organizational and individual accountability fell by the wayside. Senior leadership should not trivialize established processes since their attitudes can be infectious, either to the benefit or detriment of the Space Shuttle Program and the Agency.

Risk

The CAIB report (Vol. I, p. 193, F7.4-3) states: “Over the last two decades, little to no progress has been made toward attaining integrated, independent, and detailed analyses of risk to the Space Shuttle System.” In terms of the propensity to accept cumulative risk, the CAIB noted (Vol. I, p. 139): “These little pieces of risk add up until managers are no longer aware

of the total program risk, and are, in fact, gambling.” Throughout the return-to-flight effort, we observed these propensities still exist.

Very few human endeavors, particularly related to high energy activities involving advanced technologies, are completely free of risk. Spaceflight in general and human spaceflight in particular, is such that it is impossible to drive the risk to zero. Most who have led high risk, technical organizations will readily admit one of the greatest threats resides is unknown, unrecognized, or unacknowledged risks. Ultimately, all three of NASA’s human spaceflight mishaps resulting in crew loss fell prey to one or more of these. To eliminate these threats, successful risk management approaches mandate thorough, ongoing, and critical assessments of potential individual and systemic vulnerabilities. While the return to flight efforts may have reduced some known risks, Space Shuttle missions will always be “accepted risk” operations. NASA must be vigilant to prevent the development of a false sense of security by accepting faulty assumptions, or otherwise inappropriate analyses, to justify continued Space Shuttle missions. The vehicle is not inherently unsafe, but it demands a high degree of vigilance to fly safely.

Unfortunately, we do not believe the risk management processes in place within the Space Shuttle Program are sufficiently robust. One telling sign is the program’s development of a document entitled, *The Integrated Risk Acceptance Approach For Return To Flight*, which was revised several times during early 2005. This narrative has little substance regarding classical risk management. It is more a brief status report on a list of known and significant risks, noting where risk has been “accepted,” with no rationale or explanation. The document exhibits the very lack of accountability we referenced previously: it does not have an official document number, has no change history, appears not to be under configuration management, lists no authors, and has no approval signatures. The Task Group was informed that this document did not reflect the complete integrated risk acceptance for the return to flight, but to our knowledge, a total integrated risk acceptance rationale was never provided to the Task Group.

We note that NASA managers also tend to confuse the exhaustive and laudable Integrated Hazard Report system with integrated risk management. The Space Shuttle Program has executed a thorough review of all Integrated Hazard Reports on its own initiative and at a considerable cost in hours and funds. As commendable as this effort has been, the review of thousands of Integrated Hazards does not constitute, nor should it be a substitute for, a comprehensive integrated risk management approach.

Throughout the return-to-flight effort, there has been a reluctance to appropriately characterize the risks inherent in the Space Shuttle Program. As an example, it has proven irresistible for some officials to characterize the modified External Tank as “safer,” the “safest ever,” or even “fixed,” when neither the baseline of the “old” tanks nor the quantitative improvement of the “new” design has been established. The tank may well be safer, but without adequate risk assessment based on objective evidence it is impossible to know.

The CAIB noted (Vol. I, pp. 118, 189-190, 200) that as the Space Shuttle became “operational,” NASA did not sustain the rigorous risk identification, assessment, management capabilities, or mindset required for what in reality was a developmental vehicle operating in a high-risk environment. Prior flight history became, incorrectly, an accepted risk rationale. In the end, few human spaceflight activities are more important than identifying and assessing the residual risk to flight and determining if it is acceptable from both a cumulative and integrated perspective. It is axiomatic that a fundamental capability of a “high-risk” agency is the ability to analyze risk, and failure to do so rigorously is a failure of leadership.

It is ironic that the Space Shuttle will need to be treated as a developmental vehicle even as the program is winding down toward retirement; the risks of the last flight will be every bit as great as the risks for each of the flights before it. History has shown that leadership has

occasionally, but boldly, made the wrong choices and has been too easily convinced that the risk is acceptable. For the future of manned spaceflight, NASA leadership must protect against such tendencies.

Requirements

The Space Shuttle Program does not seem to have a basic understanding of what requirements are, what they can do for the program, and what they can do to the program. In many cases during the return-to-flight effort, hardware was built or modified, and models or analysis tools were coded and used, before any requirements were generated. This was explained by one program official as, "... if this were 'business as normal' ... we would follow the classic approach of defining requirements first. Return to flight is not in that mode, if we want to fly anytime soon." The fact was, they didn't fly anytime soon, partly because they did not have adequate requirements. The same program official continued, "We are pushing for answers on RCC vulnerability, test results on debris allowables, best available resolution for imagery – best effort across the board – without really knowing what the requirements are." We are not convinced that implementing changes to man-rated systems without first defining requirements is a desirable approach. The lack of requirements also partially explains the difficulties the program has in determining how to verify, validate, and certify the new capabilities, and how to adequately determine how much remaining risk needs to be accepted.

The discipline of defining integrated requirements before embarking on implementation allows an overall picture of work to be done, including associated interdependencies. This in turn facilitates prioritization of those requirements and therefore also prioritization of tasks to be done. Had this been accomplished, NASA would have been in better position to determine which tasks should have been constraints to the return to flight and which should not. This would also have allowed the development of proper schedules and plans, the generation of reasonable budget and resource estimates, and their allocation as established by priorities. As it was, it seemed that when it became apparent that a particular function would not be completed before return to flight (e.g., TPS repair), the program simply decreed that it was no longer mandatory for STS-114.

Because of this lack of discipline, the Space Shuttle Program experienced instances where flight hardware was manufactured, accepted, and manifested prior to the completion of design reviews and the release of approved engineering documentation. Major testing and design activities were undertaken without specific requirements or success criteria. In some cases, the program simply refused to write down requirements, citing the "work" as more important than documentation. Lacking specific direction from the program, working-level personnel proceeded to perform test, design, and analysis activities based on their best guess of what was required. This resulted in designs that failed to meet the requirements that were ultimately written, tests that did not apply to the actual environments, models based on flawed assumptions, and a general expenditure of resources in an uncoordinated manner.

It is recognized that even with correctly-written requirements, non-conformances will exist on either a temporary or permanent basis. These non-conformances need to be documented, completely assessed, and formally presented to management for a determination if the requirement should be changed, waived, or if it should be met as-stated and the non-conformance eliminated. Although a process exists to manage this, it is not rigorously followed in all instances.

The Space Shuttle Program has been repeatedly cited for having too many waivers, and has become reluctant to add additional waivers, choosing instead to "beat" the system by using other means. Evidence of this involved open work on the External Tank despite its generally rigorous process. Numerous open items came out of the External Tank DCR. Instead of capturing each one of these as a separate piece of open work, the ET Project announced at the February 24-25, 2005, DCR pre-board that it would document them in a "Verification

Limitations Document.” While it is laudable that the project at least captured the deficiencies in the certification (unlike some others), the stated rationale for this approach was that the Verification Limitations Document would negate the need for any waivers. This, in effect, clouds the number of requirements that are not being met and diminishes the certification of the External Tank.

The Use of Models

As part of the return-to-flight effort, NASA initiated the development of a suite of more than 20 new models to assist in assessing both pre- and post-launch risk. Standard engineering practice calls for objectives (requirements and interface definitions) to be established prior to development for any model or system of models, and processes and criteria defined for validating and verifying the model’s results. Also, it is not unusual for a peer review by outside experts to be employed, especially to evaluate systems of complex models that are by necessity inter-related but do not naturally resolve themselves to systemic specification. Initially, we did not observe these normal processes being followed during the development of these models, and a formal request by Ralph Roe of the NESC for a stand-down to evaluate the completed works was ignored. Later the NESC and other organizations did undertake limited peer reviews.

In the case of debris analysis, models for: 1) debris liberation; 2) aerodynamic characteristics of the debris; 3) transport analysis of debris; 4) impact tolerance of the thermal protection system; and, 5) the resultant thermal and structural models of the effects of damage, are all necessary to assess risk. The uncertainties in one model (or system) inherently feeds into and compounds the uncertainty in the second model (or system), and so on. It appears, however, that NASA largely designed these five classes of models without the attention to the interdependencies between the models necessary for a complete understanding of the end-to-end result. Understanding the characteristics of, and validating and verifying, one type of model without examining the implications for the end-to-end result is not sufficient.

Further compounding the modeling challenge is the fact that the models most often used for debris assessment are deterministic, yielding point estimates, without incorporating any measure of uncertainty in the result. Methods exist to add probabilistic qualities to the deterministic results, but they require knowledge of the statistical distribution of the many variables affecting the outcome. Typically, the distributions of the “independent” variables would be derived from empirical observation. In the case of spaceflight, however, empirical evidence is often limited or non-existent, so theoretical or engineering distributions must be substituted. The probabilistic analysis therefore is very dependent on the quality of the assumptions made by the developers. Although they evaluated some of the assumptions used by the model developers, the NESC end-to-end “peer review” primarily analyzed whether the output of one model could be incorporated into the next, not the joint probability associated with any given output ... without which it is difficult to know the reliability of the result.

Probability distributions are analytic methods necessary when assessing risk. Without an understanding of the *likelihood* of an outcome, risk acceptance is a judgment based on instinct and experience. But, as the *Columbia* accident showed, in a high risk environment that involves many unknowns like human space flight, experience and instinct are poor substitutes for careful analysis of uncertainty. This requires that analytical models be used appropriately to inform decisions within a rigorous engineering process.

Leadership

Leadership is critical to the success of any organization of the size and complexity of NASA. Without leadership the organization lacks cohesiveness and its goals lack coherence, resulting in wasted resources and, potentially, compromised products. A true leader is one who creates/coerces/compels/attracts/demands a responsive organization. It is never enough for a

leader to say: “I made that decision, what more do you want me to do?” Instead, at NASA, leaders must follow through to ensure decisions are executed with the rigor and discipline necessary for safe human spaceflight.

Nonetheless, what our concerns about rigor, risk, and requirements point to are a lack of focused, consistent, leadership and management. What we observed, during the return-to-flight effort, was that NASA leadership often did not set the proper tone, establish achievable expectations, or hold people accountable for meeting them. On many occasions, we observed weak understanding of basic program management and systems engineering principles, an abandonment of traditional processes, and a lack of rigor in execution. Many of the leaders and managers that we observed did not have a solid foundation in either the theory or practice of these basic principles. As the CAIB noted (Vol. I, p. 223, O10.12-1), “Unlike other sectors of the Federal Government and the military, NASA does not have a standard agency-wide career planning process to prepare its junior and mid-level managers for advanced roles.” In fact, NASA’s early successes are rooted in program management techniques and disciplines that few current managers in the human spaceflight arena have been willing to study. As a result, they lack the crucial ability to accurately evaluate how much or how little risk is associated with their decisions, particularly decisions to sidestep or abbreviate any given procedure or process.

It is essential that senior managers have previously-demonstrated program management and systems engineering skills and a dedication to well-established, rigorous principles as they apply to complex, geographically and organizationally dispersed programs. More to the point, we remain concerned that NASA senior leadership did not recognize or correct this, and indeed sent contrary signals that the rigor and discipline of a sound program management process was not required.

The Role of Accountability

A crucial factor in creating a responsive and responsible organization is accountability. Within the human spaceflight programs, the lack of accountability appears to be pervasive, from the failure to establish responsibility for the loss of *Columbia*, up to and including a failure to require an adequate risk assessment of the next flight. While accountability takes many forms, to inculcate an organization and its culture with accountability requires, at a minimum, the consistent setting of expectations, as well as appropriate consequences for not meeting them. This is an important role of a leader. If no one, or no part of the organization, is held accountable for failing to meet those expectations, performance becomes simply a case of “best effort” – a term that became common during many return-to-flight discussions.

A general attitude within the Space Shuttle Program seems to be that best-effort is a satisfactory substitute for meeting specific technical requirements; often requirements were not even documented to avoid the chance they could not be met. However, best-effort is a very poor substitute for a thorough understanding of the technical situation. Parts of the Agency seem to have forgone their traditional engineering rigor in favor of “when you have done your best effort, you are good to go.” This is not an appropriate philosophy for a high-performance organization that routinely puts the lives of its employees into high-risk situations. As Richard Feynman pointed out in his appendix to the Rogers Commission report, “... reality must take precedence over public relations, for nature cannot be fooled.”

Although not described as such, the CAIB noted many of the symptoms of an organization operating with a best-effort attitude. The accident board wrote, “... traits and organizational practices detrimental to safety were allowed to develop, including: reliance on past success as a substitute for sound engineering practices (such as testing to understand why systems were not performing in accordance with requirements); organizational barriers that prevented effective communication of critical safety information and stifled professional differences of opinion; lack of integrated management across program elements; and the evolution of an

informal chain of command and decision-making processes that operated outside the organization's rules" (CAIB, Vol. I, p. 9). Yet we witnessed the best-effort approach during the return-to-flight effort; we saw it in the NASA responses to Task Group requests for information (RFI), observed it during briefings, and experienced it while processing the closure packages sent to us by the Space Shuttle Program.

Since NASA leadership had few rigorous requirements or expectations for CAIB compliance, the closure packages, which should have represented the auditable, documented status of the NASA implementation of the CAIB recommendations, tended to rely on mass, rather than accuracy, as proof of closure. The closure packages showed an organization that apparently still believes PowerPoint® presentations adequately explain work and document accomplishments. Our frustration with these packages drew the response that the engineering teams able to provide the detail were too busy preparing for launch and "doing real work" to properly document their actions. The inadequate and disorganized closure packages frequently required significant effort to obtain even minimally essential documentation. The packages themselves were often provided prematurely presumably (and sometimes with direct request) to seek guidance on "what it would take" to get the Task Group to "pass the recommendation."

Individual accountability – what the Agency is now calling "technical conscience" – can overcome the best-effort malaise if accompanied with sufficient positive and negative consequences. Part of being accountable, providing more than best-effort, includes having a well thought-out, focused plan prior to beginning implementation. Technical conscience provides the impetus to carry out those plans with rigorous adherence to engineering discipline. We feel significant progress can be made if this new technical conscience can be spread throughout the Space Shuttle Program and the rest of NASA.

Attitude and Learning

The CAIB noted an air of "arrogance" within NASA that led leaders and managers to be dismissive of the views of others, both within the organization and, especially, from outside the Agency. A less critical way to describe the phenomenon is one of "comfort" – comfort with existing beliefs, comfort with past experience, and comfort with information developed inside NASA. As an excuse for not listening, especially to criticism from outside the agency, NASA often proclaims itself to be unique. We readily admit that few organizations of any type – governmental, academic, or commercial – do the kind of work NASA does. Although the end product may be different, however, many of the processes are not different from those found in many large organizations. Whatever the source of this apparent insularity, it is inappropriate for an agency that routinely operates in a high-risk environment. The recurrence of apparently preventable accidents and the seeming unwillingness to learn should be sufficient to instill some humility to temper what often looks like arrogance. During the past two years, we have not witnessed very much of such humility.

During the return to flight effort, even while NASA was systematically encouraging everyone to speak up and many processes were opened to more participation, the result was still very much the same as before the accident – roles, positions, and strength of personality often determined critical outcomes more than facts and analysis. More people were talking, but not many more were listening.

Not listening manifests itself in other ways. It appears to us that NASA, unlike most high-performance organizations, rarely studies its own, or anybody else's, mistakes; the CAIB also commented on this trait (CAIB Vol. I, p.11). It is widely believed that organizations that study and learn from small mistakes can often avoid larger ones. Conversely, those who do not learn as they go have no experience base to help avoid the big mistakes – such as the *Challenger* and *Columbia* accidents. An organization that places little value on sustained improvement from prior mistakes will tend to repeat them and certainly will not effectively carry the

necessary lessons forward to other programs. We have seen little evidence of renewed commitment to learning lessons from past mistakes at NASA.

For instance, while many academic and government entities use the *Challenger* accident as a case study, ironically the human spaceflight programs do not. Similarly, NASA scarcely considers lessons from other organizations involved in high-risk endeavors, such as the Navy's courses on the *Scorpion* and *Thresher* submarine accidents and its SUBSAFE program. As stated in the CAIB Report, Chapter 7, "The submarine Navy has a strong safety culture that emphasizes understanding and learning from past failures. NASA emphasizes safety as well, but training programs are not robust and methods of learning from past failures are informal." Although NASA has maintained a "lessons learned" system since 1992, the human spaceflight activities appear not to have embraced it.

In addition to not being willing to learn from mistakes, many NASA managers are not willing to learn from success, either. NASA's early successes, as well as many in DoD are rooted in program management techniques and disciplines that few managers in the human spaceflight arena have been willing to study. Having apparently not done so, they lack the ability to accurately evaluate how much or how little risk is associated with sidestepping or abbreviating any given procedure or process.

Summary

It is difficult to be objective based on hindsight, but it appears to us that lessons that should have been learned have not been. Perhaps we expected or hoped for too much. The CAIB report should have served NASA as a "wake-up" call. As the CAIB noted (Vol. I, p. 208), "The recognition of human spaceflight as a developmental activity requires a shift in focus from operations and meeting schedules to a concern for the risks involved. Necessary measures include ... Barring unwarranted departures from design standards, and adjusting standards only under the most rigorous, safety-driven process."

We expected that NASA leadership would set high standards for post-*Columbia* work. We expected upfront standards of validation, verification and certification. We expected rigorous and integrated risk management processes. We expected involved and insightful leadership from NASA Headquarters. We were, overall, disappointed.

There certainly are capable leaders to be found in the Space Shuttle Program and throughout NASA. In our view, though, the return-to-flight effort, when taken as a whole, was not effectively led or managed. The absence of accountability, of having managers dedicated to program management processes, and of managers being assigned to programs only after demonstrating these skills are what we believe to be the causes of the surface-level symptoms we saw so often. In particular, leadership and managerial failures to set expectations and requirements and a failure to hold people accountable; these promoted a lack of engineering rigor, discipline, and integrated risk assessment. Ultimately, this cost the program significant time and money while producing, in some areas, suspect, disappointing and/or inadequate results. Learning the lessons of these failures is important to NASA's future.

Conclusion

Among the most damning observations CAIB made of NASA was the sense of complacency toward the problem of the External Tank shedding of foam. Despite program requirements that no debris should be shed, there were over 15,000 instances of damage to the Orbiter, most of which came from debris from the Space Shuttle elements. As has been widely reported, two flights before *Columbia*, a large piece of foam was shed and caused minor damage to one of the Solid Rocket Boosters. Photographic documentation was available of major foam shedding from the External Tanks on at least seven previous flights (CAIB Vol. I, p. 85). Despite all this evidence, foam had never destroyed an Orbiter and the program relied on this

“flight history” to justify inactivity before and during the flight of *Columbia*.

This “We’ve seen this before” mentality is still present, and it appeared on more than one occasion during MMT simulations. In addition, leading up to the return-to-flight, the program justified not pursuing potential ice damage to the Orbiter umbilical doors because there had not been substantial damage on previous flights. Despite the evidence of impacts all around the area, the official rationale for accepting the risk was listed as “flight history;” i.e., we’ve never had critical damage there before.

NASA’s leaders and managers must break this cycle of smugness substituting for knowledge. NASA must be able to quantify risk, even if imperfectly, set requirements and expectations, and hold organizations and individuals accountable. Analytical models – while valuable tools – cannot substitute for engineering judgment and conscience. Rigor must be reestablished throughout the Agency. Opinion, no matter how well informed, cannot replace objective evidence. Flight history, while critical for informed judgment, cannot substitute for it. “We’ve been lucky” is a statement that should never be associated with the human spaceflight programs.

Perhaps most disturbing is the engineering legacy that seems to be developing within NASA. As with many professions, the basics of engineering are learned in school. However, good engineering practices – such as rigor in process and documentation – are learned outside the classroom in an apprentice-like environment. These practices are passed onto future generations as part of the “culture” of an organization. However, when an organization loses focus on its core values, the effects stretch far beyond the present because those principles are no longer passed onto future generations. Senior leaders do not appear to be concerned with following defined processes and are passing this legacy on to future leaders.

In order to properly prepare the Agency for the future, including the return to the Moon and journey to Mars, we offer the following suggested actions, all of which must start at the top and flow down to the programs, projects, and workforce:

- 1) Clearly set achievable expectations and hold people accountable; in addition to positive consequences, this includes negative consequences for not performing to expectations;
- 2) Return to classic program management and systems engineering principles and practices (including integrated risk management), and execute these with rigor;
- 3) Ensure managers at all levels have a solid foundation in these attributes before appointing them to such responsibilities; this requires not only training, but successful demonstration of these skills at a lower level;
- 4) Eliminate the prejudices and barriers that prevent the Agency, and especially the human spaceflight programs, from learning from their own and others’ mistakes.

NASA needs to learn the lessons of its past ... lessons provided at the cost of the lives of seventeen astronauts.

Specific Examples

The examples that follow this narrative are just that – examples. However, the behaviors and attitudes were not random events that were seen merely once or twice, but numerous times throughout the Task Group’s interactions with NASA. Many of the examples presented are not intended as detailed case studies, but are meant to provide evidence demonstrating behaviors of concern. We offer these observations for consideration and future improvement.

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Rigor Example 1

From our vantage point, the process for selecting a launch date was flawed, if indeed there was a process. We understand these were not normal circumstances, and the usual processes used to establish launch dates – hardware processing templates and payload readiness, to name two – were not applicable. However, we feel that the establishment of launch dates that seemingly did not take into account the full ramifications of the analysis and development efforts being conducted ultimately proved detrimental to the program.

As discussed in the narrative of this observation, we feel the program should have begun the return-to-flight effort with a process that determined what work needed to be accomplished to return to flight, what the interdependencies were among that work, then develop schedules that supported the execution of the work. This process would have helped determine which efforts needed to be accomplished first since their results were required by other efforts. For example, determining the damage tolerance of the Orbiter before giving the ET Project their debris allowables requirements would have helped ensure the tank modifications would eliminate the appropriate debris. Establishing the RCC damage thresholds early would have provided the OBSS effort with their inspection criteria.

Instead, it appears to us that senior management selected launch dates based on non-technical concerns, ultimately placing unnecessary and unrecoverable restrictions on teams working return-to-flight hardware development. In addition, several important requirements – such as the critical damage and debris size – were scheduled to be finalized at FRR, far too late to influence the products being provided by the External Tank Project, OBSS, and other systems. In addition, the constant setting of a launch date only a few months away never allowed the development efforts to take full advantage of the ultimate two-year stand-down; we heard several times that different solutions to various problems would have been selected if launch had not been 90 days away.

Scheduled Return-to-Flight Launch Dates			
Meeting Date	STS-114 Launch Date	Days Until Launch	Months Until Launch
Jan 29, 2003	Mar 01, 2003	31	1.0
Feb 10, 2003	Mar 01, 2003	19	0.6
Feb 11, 2003	Apr 03, 2003	51	1.7
Feb 24, 2003	Apr 03, 2003	38	1.3
Feb 25, 2003	Jul 21, 2003	146	4.9
Apr 16, 2003	Jul 21, 2003	96	3.2
Apr 17, 2003	Oct 01, 2003	167	5.6
May 21, 2003	Oct 01, 2003	133	4.4
May 22, 2003	Dec 18, 2003	210	7.0
Jul 28, 2003	Dec 18, 2003	143	4.8
Jul 29, 2003	Mar 11, 2004	226	7.5
Oct 05, 2003	Mar 11, 2004	158	5.3
Oct 06, 2003	Sep 12, 2004	342	11.4
Mar 08, 2004	Sep 12, 2004	188	6.3
Mar 09, 2004	Mar 06, 2005	362	12.1
Oct 28, 2004	Mar 06, 2005	129	4.3
Oct 29, 2004	May 12, 2005	195	6.5
Feb 15, 2005	May 12, 2005	86	2.9
Feb 16, 2005	May 14, 2005	89	2.9

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Apr 06, 2005 (SFLC)	May 15, 2005	39	1.3
Apr 19, 2005 (SFLC)	May 22, 2005	33	1.1
Apr 29, 2005 (HQ)	July 13, 2005	75	2.5
Jul 13, 2005 (scrub)	July 16, 2005	3	0.1
Jul 16, 2005 (HQ)	July 26, 2005	10	0.3

When a revised launch date was proposed to the Spaceflight Leadership Council in February, 2005 for consideration, the briefing leading up to the decision only identified KSC processing timelines; no questions were asked regarding the ability of the elements to complete their work with adequate rigor in time to support this date; activities that were ongoing to support meeting the CAIB recommendations. Additionally, the debris/flight rationale requirements were discussed after the launch date was set, thereby never entering into the launch rationale.

As we reviewed the path that NASA has taken to prepare for STS-114, it became apparent that there were numerous instances when an opportunity was missed to implement the best solution because of this false schedule pressure. Many times technical-level personnel indicated that if they had known that they were going to be grounded for 2 years, the solutions chosen would have been much different. The following examples illustrate how an unrealistic schedule for return-to-flight compromised standard processes:

1. A decision was made not to install LO2 feedline bellows heaters on ET-120 (the first STS-114 tank) and ET-121 (the initial STS-121 tank, ultimately used on STS-114) despite evidence one might be required. Instead, only a relatively easy, but ultimately questionably effective, “drip lip” was installed on the first two tanks. Continued questions about its effectiveness eventually drove the program to roll-back STS-114 from the launch pad to install the heater.
2. The implementation of the OBSS sensor package was selected before knowing the size of the damage that needed to be detected. In fact, as of July 11, 2005, the NSTS 60517, *PRD for the Shuttle On-Orbit TPS Inspection System* still had numerous TBDs for critical requirements regarding the required resolution capability. On several occasions, members of the NASA workforce have expressed that methods other than the OBSS would have been preferable and the OBSS was chosen due to the short time before the targeted launch date.
3. The decision to stay with the STA-54 tile repair material was made on the apparent near-term availability of this material and not because anybody believed it was the best possible choice.
4. Both Shuttle and ISS teams reworked flight manifests, schedules, and analysis many more times than should have been necessary due to this lack of an integrated approach to resolving the real issues and planning a realistic timeline to launch. This also resulted in repeated coordination with the international partners.

True research and development (R&D) efforts – such as TPS repair – should not have been a constraint to the launch of STS-114 unless the Agency felt the capabilities to be provided by these R&D efforts were so important they could not risk lives without them. Additionally, NASA should have evaluated their return-to-flight activities and determined which efforts were not progressing as originally intended, then been completely honest with itself, higher authority, and the Task Group that they would not be able to meet those recommendations within the funding and schedule constraints imposed on the program. Schedules for R&D activities are difficult to predict, and perhaps should be the rationale to not include them as return-to-flight criteria.

Rigor Example 2

On August 27, 2004, one year after the release of the CAIB report, the Space Shuttle Program signed PRCBD S062246 approving the *Post-STIS-107 Return-to-Flight Design Certification Review Plan and Procedures* document, NSTS 60524. The proclaimed purpose of this document was to “define the activities and procedures for accomplishing the Space Shuttle Program (SSP) Design Certification Review (DCR) process for Return-to-Flight after the *Columbia* accident. This plan establishes the requirements, responsibilities, preliminary schedule, general implementation guidelines, and success criteria required to complete the post-STIS-107 RTF DCR process and document the review results.”

This document directed a tiered DCR process to formally demonstrate that new or modified systems, software, supporting processes, and operations meet the program design, safety, performance, and operational requirements levied upon the item in question. The process also required demonstration that “appropriate certifications have been performed” at lower levels. The document specifically recognized that the “tiered DCR process being conducted for RTF is not classical in nature as more content than simple certification of hardware is reviewed. The SSP is utilizing this process to cover other major topics, such as standard operational and process changes, which would otherwise be discussed at a Flight Readiness Review (FRR).” The design to be certified during the DCR was to include all changes occurring after the STIS-107 Certificate of Flight Readiness (CoFR) was signed on January 9, 2003.

Ironically, the effect seems to have been largely the opposite. Instead of pulling FRR material forward into the DCRs, many of the projects/elements, and the program itself, stated during their DCRs that reviews of several activities would be deferred until the FRR. This seems too late in the process to be making critical decisions.

In all, the 60-page document was an attempt to instill some discipline into the return-to-flight process. However, during fact finding, we noted that while a program-wide process for DCRs existed, it was not imposed on the various projects – each project and the Space Shuttle Program executed DCRs in different manners with wide variances in the scope, execution and rigor for the various project and system-level DCRs. In response to a question from a Task Group member on this wide variability, the Systems Engineering and Integration Office indicated they didn’t set any standard processes because MSFC and JSC operate differently – this from the organization that put together the DCR process originally.

Additionally, a senior Space Shuttle Program official at one point denied the existence of a document governing the DCR process, despite the fact that he approved NSTS 60524. It is a concern that processes put in place specifically for the return-to-flight effort can be ignored so cavalierly without consequence.

During early 2005, the program decided that since they would likely not be able to “certify” the debris aspects of the Space Shuttle system, the term Design Certification Review was no longer appropriate. Instead, a series of newly termed Design Verification Reviews (DVR) were held. These seemed to suffer a rough start; during the first DVR, when asked about the availability of data and documentation to support the review, the program responded that none was available. When asked about the success criteria for the review, the response from the program was that none had been established. Interestingly, NSTS 60524 was never updated to reflect the newly-coined DVR process.

On one hand, the rigorous DCR process was ignored by many; on the other hand, there were too many of these reviews. Various parts of the program did not have all the necessary work completed in time for scheduled DCRs, so there ended up being multiple DCRs for each project/element to cover all the work. Rather than 12 System Reviews (6 DCRs and 6 DVRs – and none of these covered TPS repair), it likely would have been a better use of resources (particularly the reviewers’) to delay the System DCR/DVR until all the work was complete.

The degree of rigor employed during the return to flight effort has varied with the individual projects. At the one extreme are activities like the SRB Bolt Catcher redesign and, to a lesser extent, the modifications to the External Tank thermal protection system. Both of these projects exhibited a formal and documented approach to the establishment of requirements and execution of their design review and certification processes. Both the SRB Bolt Catcher and the ET had formal plans for their various reviews, formal data packages, a formal issue review process, formal pre-boards and boards, and well-documented formal findings.

The other extreme includes activities such as Orbiter TPS repair, which have been extremely convoluted. While presentation material for the repair efforts was developed for the Orbiter DCR II held in February 2005, the material was not covered at that meeting. At the System DCR II later that month, it was stated that repair techniques would not be addressed in the DCR/DVR process, because there were no Level II requirements to have a repair capability. This was even though the DCR process was supposed to cover all changes since the STS-107 CoFR, criteria that certainly applied to the repair techniques.

Perhaps the most revealing behavior observed during the design reviews was at the Program DCR at KSC on April 19, 2005. This “review,” like many witnessed during the return-to-flight effort, was not so much a review as it was a status briefing. No technical questions were asked by the Board; no technical responses given. With the single exception of the SSME Project, each project and element simply presented a high-level summary of their current status, including open work; SSME attempted to describe a technical problem and request help in resolving it, without much success. The final certification was conditional on the “satisfactory completion of identified open work,” but nobody before, during, or after the meeting kept track of the open work presented by the projects/elements. This meeting validated the CAIB observation of engineering and decisions via PowerPoint presentation rather than technical detail and rigor.

Risk Example 1

The Space Shuttle Program has, in the past, too often accepted risks that should have been mitigated; this trend appeared to continue during the return-to-flight effort. It appears to us that what the CAIB wrote (Vol. I, p. 193, F7.4-5) is still applicable today: “Risk information and data from hazard analyses are not communicated effectively to the risk assessment and mission assurance processes. The Board could not find adequate application of a process, database, or metric analysis tool that took an integrated, systemic view of the entire Space Shuttle system.”

Ultimately, few programmatic responsibilities are more important than identifying and assessing risk and determining if it is acceptable from both a cumulative and integrated perspective. As the Space Shuttle became “operational,” NASA did not sustain the risk identification, assessment, management capabilities, or mindset required for what in reality was a developmental vehicle operating in a high-risk environment. Prior flight history became an accepted risk rationale. The perceived risk level during the launch of STS-107 was not aligned with the facts regarding the actual debris environment, just as the perceived risk for *Challenger* had not been aligned with the true state of the o-rings. Nevertheless, the issues were considered *accepted risks* that had potentially catastrophic consequences, but with a remote likelihood of occurrence. Despite this perception, in reality the risks should have been considered unacceptable – potentially catastrophic consequences with a good likelihood of occurrence.

This should have initiated a design change, either to eliminate the debris environment or to modify the Orbiter to withstand the resulting debris environment, in accordance with the Space Shuttle Hazard Reduction Precedence Sequence (NSTS 5300.4[1D-2] Section 1D201, Item 6, based on MIL-STD-882D, Section 4.4). This program-wide policy has as its first step, design action to eliminate the hazard:

Hazard Reduction Precedence Sequence. To eliminate or control hazards, the contractor shall use as a minimum the following sequence or combination of items:

- a. Design for Minimum Hazard. The major goal throughout the design phase shall be to ensure inherent safety through the selection of appropriate design features as fail operational/fail safe combinations and appropriate safety factors. Hazards shall be eliminated by design where possible. Damage control, containment and isolation of potential hazards shall be included in design considerations.*
- b. Safety Devices. Known hazards which cannot be eliminated through design selection shall be reduced to an acceptable level through the use of appropriate safety devices as part of the system, subsystem, or equipment.*
- c. Warning Devices. Where it is not possible to preclude the existence or occurrence of a known hazard, devices shall be employed for the timely detection of the condition and the generation of an adequate warning signal. Warning signals and their application shall be designed to minimize the probability of wrong signals or of improper personnel reaction to the signal.*
- d. Special Procedures. Where it is not possible to reduce the magnitude of existing or potential hazard through design, or the use of safety and warning devices, special procedures shall be developed to counter hazardous conditions for enhancement of ground and flight crew safety. Precautionary notations shall be standardized.*

It is recognized that any design change takes time to develop, implement, and certify; however, the specific design action could be underway while the program assesses the technical risk of continuing operations and maintains a focused awareness of the risk in each area. The program should not have the option of short-circuiting the process by skipping to “accepted risk” as was done before both *Challenger* and *Columbia*.

The goal is to change the design to completely eliminate the risk. As with all design actions – especially when dealing with high technology programs such as spaceflight – it is recognized that there will be limitations driven by the laws of physics and program resources. The Space Shuttle has a finite life (scheduled to be retired in 2010) and no program has, or will have, infinite resources. The best available technical solution should be sought without regard to schedule and resources limitations; these will come into play when the proposal is formally brought before program management (i.e., the PRCB). The modification should be installed at the earliest opportunity to remove the risk; however, in the interim, procedural mitigations could be used to minimize the risk of continuing to fly if an acceptable-risk rationale can be developed. This is the approach we expected to see in the *Integrated Risk Acceptance Approach For Return To Flight*, but did not.

Every risk (non-conformance) should be documented, have a documented rationale for limited acceptance, and a documented risk retirement plan with the objective of completely eliminating the risk. Again, it may not be feasible to retire all risk, but it is important for NASA to develop an understanding of what is involved in the resolution of non-conformances and the retirement of risk.

We do not feel that the program is currently using this process to mitigate or accept risks. For example, it took the current NASA Administrator’s personal intervention during a technical review held shortly after his appointment to force appropriate recognition by program management that the well known and recognized ice shedding from the External Tank was, in fact, potential critical debris and should be treated as such. His further direction finally forced the slip of STS-114 to the July 2005 launch window in order to incorporate necessary

technical control measures (i.e., the forward LO2 feedline bellows heater). Absent the Administrator's direct action, STS-114 might very well have launched with the physical cause of *Columbia's* loss (ET bipod ramp foam) fixed, but with an identified, yet unacknowledged, risk to vehicle and crew.

NASA should return to compliance with its long-established procedures for addressing risks. There are enough risks in the "unknown-unknowns" without unnecessarily increasing risk by not promptly and rigorously resolving the "known-knowns" and "known-unknowns."

Risk Example 2

We do not believe the risk assessment processes in place within the Space Shuttle Program are sufficiently robust. One telling sign is the program's development of a document entitled, *The Integrated Risk Acceptance Approach For Return To Flight*, which the Space Shuttle Program points to as a response to inquiries regarding risk assessment and risk management. The document appears to be intended for the uninitiated reader rather than a being a technical document for use by the program.

The main text of the May 2005 version consists of 41 pages that are essentially a chronology of events leading to the current state written more for a general primer than a serious treatise on institutional process and rigor necessary for consistent, successful risk management. The Residual Risk Matrix contained in an additional 18 pages of Appendix A lists remaining tasks or "Objectives" rather than identified areas of risk. The remaining three columns delineating "Evidence of Objective Completion," "Remaining Risk," and "Acceptance Rationale," in order are populated by items which are frequently vague and require considerable suspension of belief to conclude a particular risk acceptable. As an example, under "Remaining Risk" on page A-3 the last item states:

"Although these efforts will in all likelihood reduce the potential for flow of liquid nitrogen through the flange and reduce the potential for foam loss in flight, there is no quantitative means to demonstrate this as fact. Previous foam divot formation in the flange area produced foam debris below the current allowable. NASA has considered and accepted this risk."

The corresponding "Acceptance Rationale" states simply, and somewhat glibly, "Acceptable Risk." Unfortunately, this raises more questions than it answers, such as:

How does one conclude reduction, "...in all likelihood...?"

What "...previous foam divot formation...?" Flight? Ground Test?

What is "...the current allowable...?"

How was "...allowable." determined?

Finally, how did NASA consider and accept the risk? As a follow on, what is the plan to reassess or correct if existing risks are accepted?

Requirements Example 1

The NSTS 07700 (the top-level specification for the program) requirements are substandard in a number of areas: they are not individually numbered to facilitate referencing an individual requirement (i.e., there are multiple "shalls" per paragraph); they are often stated in an ambiguous and untestable fashion; and there is inconsistent use of terminology such as "shall," "will," and "must." Given the 2010 retirement of the Space Shuttle, it does not make

sense to go back and correct existing requirements; however, those requirements modified or added as part of the return to flight effort and any subsequent requirements changes should adhere to industry-standard requirements practices. This includes documenting the verification and validation criteria at the same time as the requirement (before implementation begins), a practice not in evidence in the requirements documents made available to the RTF TG. Additionally, on multiple occasions the Task Group asked about the ability to have an auditable trail from Level II (NSTS 07700) requirements and directives down to the implementing actions on the floor. The Task Group was informed that the Program Configuration Management System did not allow for such an auditable trail.

Nor does the program seem to know how to change requirements. For example, there is a requirement in NSTS 07700 for zero debris “that would jeopardize the flight crew, vehicle, mission success, or would adversely impact turnaround operations” (Book X, 3.2.1.2.14). After it was determined that the External Tank would continue shedding debris of a potentially critical size, the program decided – after 113 flights – they needed to change or waive the requirement. The first change was to add a requirement that the External Tank could not shed debris that generated impacts larger than 1,500-ft/lbs (NSTS 07700, Book X, 3.2.1.2.14.4.1). This requirement later turned out to be inadequate since the Orbiter could not be certified to withstand impacts that large. In response, a permanent waiver to this Level II requirement was proposed stating “This requirement is waived for the External Tank.” However, this generated controversy within the program and an alternate proposal was brought forward to eliminate the need for any debris waivers by adding an “exception” (see Requirements 2) to the top-level NSTS 07700 requirement. The Task Group does not know the status of either proposal since the PRCB does not publish minutes of their meetings. As late as the second Program DCR (June 2005), program management was attempting to establish the mechanism for documenting requirements and exceptions; by this time the hardware was on the pad.

Requirements Example 2

How do you meaningfully track requirements when you do not understand the definitions of programmatic terms? For instance, at the STS-114 Flight Readiness Review, the Space Shuttle Program attempted to define the terms “Waiver,” “Deviation” and “Exception.” Within the documentation listed, there were 11 definitions for “Waiver,” 7 for “Deviation,” and 5 for “Exception;” some definitions were combinations of the terms. Sometimes there were multiple definitions for a single term with in one volume of NSTS 07700 – and even worse, sometimes within the same paragraph of NSTS 08171!

Standard definitions for many engineering terms exist in industry and academia; NASA should adopt these standard definitions wherever possible and use them consistently. For instance, like the CAIB, the Task Group found that the “in-family/out-of-family” designators a continuing source of confusion. Unfortunately, NASA seems to place a low priority on maintaining standard terms and definitions. The following entry was found in a list of NASA Handbooks at Headquarters: “NHB 5300.4(1G) NASA Assurance Terms and Definitions – Has been deleted – Long term plans call for development of a NASA-Standard for definitions.” We have no idea when these “long-range plans” will come to fruition.

Models Example 1

NASA has in the past maintained certain models in formal requirements documents (e.g., NSTS 07700) and employed well-recognized processes for developing and using analytical models. However, during the return-to-flight effort, there has been an enormous expenditure of time and resources – amounting to tens of millions of dollars – without the discipline of a formal development plan, clear objectives, explicit plans for verification and validation, thorough outside review, documented ICDs between models, or a good understanding of the limitations of analytical systems employing multiple, linked deterministic models. Validation

and verification planning has been left to the end of the process rather than the beginning. Early peer reviews were limited to the question of appropriateness for the proposed task and never reassessed or reconstructed post-development. Even the belated efforts by the NESC are not classic peer reviews. Outside peer reviews would highlight, for example, the extreme difficulty, if not impossibility, of forming an end-to-end conclusion on the confidence interval inherent in any particular result. Even more troubling, in many instances historical flight data was not used during the initial stages of model development.

On several occasions, members from the NESC and RTF TG expressed concern regarding the development and use of debris models. We observed that development test data was being used rather than verification test data in attempts to verify models. It should be noted that the development test data was obtained over widely varying test conditions. Analytical models have essentially driven the return-to-flight effort; however, industry and academic standards and methods for developing, verifying, and validating the models have not been used. In addition, no sensitivity analyses had been conducted and no empirical data from flight history had been incorporated in the models or their validation. Suggestions to use flight history, probabilistic techniques, and sensitivity analysis were disregarded. A formal request for a stand-down to evaluate the completed works was ignored.

All the while, the External Tank was being modified to meet requirements established by preliminary and interim model outputs. In December 2004, a modified External Tank meeting these interim requirements was shipped to the Kennedy Space Center with the understanding that if the final requirements determined by the modeling effort resulted in smaller debris allowables, the next tank in line would be modified to meet the more stringent requirements, a so called “trailing tank” concept. For various reasons, the program decided to abandon the trailing tank concept before the second tank was shipped to the Kennedy Space Center.

Models Example 2

Progress has been made by the ET Project to reduce the risk of critical debris during ascent. Many of these changes were made on the basis of debris-flow modeling and transport analysis. Initial analysis and simulation of the Orbiter showed that the RCC could withstand impacts up to 1,500-foot-pounds, a figure that was turned into a requirement for the ET Project. The tools that produced these initial estimates had not been verified or validated, yet their output was used to develop and build flight hardware. Further impact testing of actual RCC, however, showed that 1,500-foot-pounds are far greater than the RCC can actually withstand reliably. This knowledge came too late, and the ET Project had already modified External Tanks based on the original 1,500-foot-pound number.

In an attempt to justify both numbers – the larger number given to the ET Project and the lower number for the Orbiter Project – a complex effort was undertaken to develop a Capability over Environment (C/E) analysis, using several of the models already being developed. In this case, the “capability” is the size and speed of impact the Orbiter can withstand, while the “environment” is the amount of debris coming off the External Tank (and other sources). Numerically, a value of “1.0” implies the hardware can withstand the environment – but just. Normally a factor of safety, often “1.4” in the Space Shuttle Program, is required for additional margin.

The C/E approach was first introduced to the RTF Task Group during the September 2004 Plenary. The program provided the results of the initial assessment that indicated critical debris was a particular size, but admitted that the uncertainties were several orders of magnitude on either side. On February 17, 2005, the then-current C/E analysis was presented to the program; in almost all cases the C/E was less than 1.0, meaning that the capability of the Orbiter to withstand damage was less than the amount of debris in its expected flight environment. This analysis had been done using “worst-on-worst” conditions corresponding to certification levels; something everybody agreed was unlikely to occur in real life, but in

accordance with the ground rules laid out when the C/E analysis began. The next day, at the Spaceflight Leadership Council meeting, it was presented that if the worst-on-worst C/E was less than 1.0, the program would look at best-estimate C/E.

It should be noted that determining exactly what factor of safety was provided by the models is a bit challenging. For instance, each of the component models in the C/E worst-on-worst analysis had a factor of safety of 1.4 built into it, therefore a combined C/E of 1.0 in reality still had an adequate factor of safety. This became more problematic with the “best-estimate” analysis, where estimates of more likely performance (for both the Orbiter and the External Tank) were used. Keeping track of the ever-changing differences in inputs between worst-on-worst C/E and best-estimate C/E was difficult; there was little agreement in the community on what factors should be included in the best-estimate version.

At the beginning of the Delta Design Verification Review (April 26-27, 2005), the rules stated that if the “best-estimate” of Orbiter capability relative to debris environment (C/E) was less than 1.5, then the likelihood on the standard program 4x3 risk matrix would be “infrequent,”

Standard “4 by 3” risk chart used by the Space Shuttle Program.

PROBABLE	ACCEPTED RISKS	ACCEPTED RISKS	UNACCEPTABLE RISK
INFREQUENT	ACCEPTED RISKS	ACCEPTED RISKS	ACCEPTED RISKS
REMOTE	CONTROLLED	ACCEPTED RISKS	ACCEPTED RISKS
IMPROBABLE	CONTROLLED	CONTROLLED	CONTROLLED
	MARGINAL	CRITICAL	CATASTROPHIC

and if 1.5 or greater it would be categorized as “remote.” For example, for the LO2 intertank flange closeout, the best-estimate C/E was 1.1, which should have classified the risk as “infrequent.” However, many argued that the problem was sufficiently well understood that it could be put in the “remote” category despite its low best-estimate C/E. Others said it should be “infrequent” since that is what the process dictated, and that it involved “old”

foam and therefore contained a greater uncertainty. At that point, Space Shuttle Program management pronounced that the best-estimate C/E value of 1.5 determining an “infrequent” vs. “remote” rating was only a guideline, not a rule. The middle of a design review does not seem an appropriate time to be changing the rules.

The arbitrary nature of the requirements/fulfillment process is demonstrated by the February 2005 changes in approach (from “worst-on-worst” to “best estimate”) and reduction in factors of safety to make the numbers come out right. When asked during the RTF TG March 2005 Plenary if the tank will change when results from the modeling are finally available, the answer was “... no, that’s why we’re changing the models so we don’t have to change the tank.”

The program continued to develop and make decisions on analysis techniques, such as best-estimate C/E, which used non-standard approaches. This history of the C/E logic raises questions regarding the management of the return-to-flight effort. Fortunately, this approach was abandoned when the Program reluctantly initiated probabilistic analyses on additional critical areas at the direction of the new Administrator. Analytical models have essentially driven (and delayed) the return-to-flight effort even though industry and academic standards and methods for developing, verifying, and validating the models have not been used.

Models Example 3

During the reviews of the probabilistic analysis efforts, requests were made by several people, including Task Group members, to clearly state the assumptions going into these models. It was not until the end of the 6-week review effort that the assumptions to some of the models used for this activity were recorded; for some of the models, no comprehensive set of assumptions were ever documented. By their nature, these models are complex and sophisticated analysis tools. Therefore, the quality of the original assumptions is important; they should be written down and consistently applied.

Leadership Example 1

A clear example of a lack of budgetary restraint was demonstrated by the management of the TPS repair projects. For an extended period of time, there were few constraints placed on the development teams, and money was spent on the development of almost any idea that was proposed. Only when the large-scale RCC rigid overwrap repair effort was finally deemed untenable was it removed from the list of options being considered for STS-114. At the direction of the Space Shuttle Program, during late 2004 the Orbiter Project Office initiated a study to eliminate some of the repair options in an attempt to focus manpower and budget on the most promising techniques. This resulted in resources being expended to generate proposals, and an evaluation team worked over the winter holidays to develop a recommendation on which options to select. Ultimately the Orbiter Project Office brought forward two tile repair options and a single RCC repair option to Space Shuttle Program management. Nevertheless, six options (two for tile repair and four for RCC repair) were actually considered by the program, and only one RCC option was ultimately dropped. Surprisingly, although a stated reason for performing the down-select was to reduce expenditures, cost estimates were explicitly excluded from the factors used in the decision.

Several months later, when two cost Change Requests (CR) for continued tile and RCC repair development were brought to the PRCB (asking for nearly \$100M for the last 5 months of FY05), the CR sponsor objected to suggestions that the program needed to consider if this was how limited resources should be spent. In the end, the only criteria that determined how much would be spent on the two CRs was whether all the money could be spent by the end of the fiscal year, not whether this was a wise use of limited program resources.

A.3 Observations by Mr. Joseph W. Cuzzupoli and Mr. Richard H. Kohrs

NASA's aggressive future plans require experienced personnel from both government and government contractors. To meet the challenges ahead for the U.S. Space Program, NASA would be wise to bring back experienced, ex-NASA employees with development engineering expertise to fill the many holes left in the Agency.

The utilization of operational-type management and engineers made the return to flight of the Space Shuttle difficult. Nevertheless, the result was enormously positive for NASA. They got there! We are proud of the NASA management and engineering teams for this most successful accomplishment.

A.4 Observations by Dr. Charles C. Daniel

When performing a post accident investigation, it is of primary importance to be able to establish the "root cause" of the failure condition. In the case of the *Columbia* accident, the physical cause was isolated by the CAIB to a release of foam from the bipod ramp of the External Tank. However, the exact release mechanism (root cause) for the foam was never successfully replicated. The ET Project decided to remove the bipod ramp foam, thus eliminating the potential for this specific release; this action did not, however, address the release mechanism of other areas of thermal protection system foam applied using similar processes. The ET Project established the adhesive/cohesive mechanism as the "most probable" failure mode for producing debris release. All of the design and process changes implemented were intended to reduce the risk associated with the adhesive/cohesive failure mode. Although other failure modes were identified, they were not the focus of the return to flight activity. The assumption was made that these failure modes had not occurred on prior flights, and therefore would not in the future. Unless the specific failure root cause can be established and eliminated, all failure modes must be addressed and closed out.

A.5 Observations by Ms. Susan Morrissey Livingstone

The RTF TG Charter focused specifically on the 15 CAIB return-to-flight recommendations. With respect to these 15 recommendations, many NASA residual issues and planned future actions remain. In addition, the CAIB had 14 other recommendations, as well as numerous other important findings and observations. The NASA Implementation Plan further added yet other “raise the bar” actions. Finally, NASA determined that the CAIB report had many valuable “lessons learned” applicable to the agency as a whole. NASA needs to capture and integrate these lessons learned and planned future actions and determine how they will effectively monitor fulfillment and/or reassess and adjust them.

In terms of the specific CAIB RTF recommendations, I offer the following additional supplementary observations.

- 1. R3.4-1, 3.4-1, 3.4-3, 6.4-1:** In highly complex systems, integration of multiple sources of data and the translation of such data into meaningful forms that support decision making remain a critical, but challenging requirement, particularly in making time sensitive, integrated risk vs. risk trades. Upon RTF of the Shuttle, this is particularly true given the enhanced imagery, inspection, and potential repair capabilities post-Columbia. NASA’s refinements in its Shuttle risk mitigation and risk management approach, to include the future of CSCS/LON, are critical parts of this integrated process. The Space Shuttle Program’s development of the OIP/Annex (see section 2.2 of this report) represents significant forward progress in providing a framework for such integration, as well as providing an integrated risk vs. risk methodology. Continued flight-to-flight verification of and refinement in these documents can serve as an important metric of post-RTF progress in these areas. Over time, NASA decisions to retain and further improve required performance or resolution enhancements in Shuttle imagery and inspection (e.g., LDRI and post-OBSS), along with the continued development and training of the thermal Protection System Management Working Group and Mission Management Team in their use, might also be good metrics to track.
- 2. R3.4-1:** To fully ensure Mission Management Team pre-launch evaluation of the R3.4-1 assets, NASA might wish to consider defining minimum requirements for them in the Operations and Maintenance Requirements System Document, rather than the Kennedy Space Center Program Requirements Document.
- 3. R4.2-3:** I strongly recommend continued NASA attention to strengthening its quality assurance program. The work of the Government Mandatory Inspection Point Independent (GMIP) Assessment Team and their January 22, 2004, *Independent Assessment Final Report* provides a good beginning. This CAIB recommendation combined with R4.2-5 more than clearly underscored the important need for clarity and standardization of processes, standards, and terminology within and between NASA elements and programs.
- 4. R6.2-1:** Pressure for under budgeting and overly aggressive scheduling must be recognized and mitigated by senior leadership. As a significant part of this effort, NASA needs to address the required size and capability mix of its future workforce, to include commensurate leadership and managerial capabilities. Since the most critical part of “resources” is human capital, NASA faces a challenge in terms of addressing the skills and talents (in-house and outsourced) required to successfully fulfill the Space Shuttle Program and transition to the Vision for Space Exploration. As the CAIB noted, the Space Shuttle was being treated as an “operational” instead of a “developmental” program, and over time, NASA management and workforce was skilled accordingly. Based on the Agency’s experience in the return-to-flight effort, NASA will need to determine the extent that management and engineering skill sets and processes required

of a developmental program have atrophied or been lost and the corrective action needed. Such an assessment also needs to address the contractor workforce, to include supervisory chains to ensure appropriate direct NASA leadership and managerial oversight of critical work functions.

5. **R6.3-1:** While our Final Report addresses forward work for the Shuttle MMT, necessary coordination between the Space Shuttle Program and the International Space Station (ISS) Program remain another “work in progress”. The primary mission of the Space Shuttle is to complete assembly and provide logistical support to the ISS. Given this fact, it is imperative that effective communication and integration occurs between these two organizations. Frequently, pre-flight decisions made by the SSP have an impact on planning by the ISSP. Similarly, ISS issues have a direct bearing on SSP operations. Although the JPRCB exists to manage this process, NASA needs to determine if it adequately provides the overall integration that needs to occur. Additionally, during real-time mission operations, significant coordination and discussion are required among the two flight control and mission management teams relative to anomalies with the Orbiter that may affect current and future ISS operations and vice versa. During RTF TG observations of MMT simulations, fully effective demonstration of this needed SSP-ISS integration activity was not clear. Indeed, for most of the Shuttle MMT simulations over the past 2 years, limited involvement by the ISS Program in the MMT simulation training was evident. Future MMT training events need to fully exercise and reinforce the importance of an integrated Station-Shuttle mindset.
6. **R6.4-1:** Given post-RTF remaining work on debris reduction, Orbiter hardening, and repair techniques, NASA will need an effective plan for prioritizing such work. At a minimum, NASA will need to analyze the costs and benefits (to include risk reduction value) of planned future work – and the trades within and between – for further ET debris liberation reduction work, further Orbiter hardening phases, and additional work to mature tile and RCC repair capabilities. As a part of this analysis, objective success criteria for each should be established along with requirements for verification, validation and certification. Peer review in this analysis would be helpful, particularly in determining potential impacts on flight accepted risk rationale from an STS-114 baseline.
7. **R10.3-1:** NASA should determine if use of the full capability of the standardized, high resolution cameras would be beneficial for close-out photography.

A.6 Observations by Mr. James D. Lloyd, *ex-officio*

Over the past two years of the RTF TG charter, I believe we have witnessed the coalescence of an entire Agency around a single goal in a crises caused by a catastrophic accident that killed seven members of the NASA family and destroyed a national resource. Since the *Columbia* accident, NASA has consistently placed safety above regard for cost or schedule in our efforts to return the high-performance, yet fragile, Space Shuttle system to flight. At the same time, NASA has begun phasing out the Space Shuttle which is scheduled to complete its mission of assembling the International Space Station in 2010.

There are a number of behaviors that stem from NASA’s core values of safety, integrity, excellence, and care for the NASA family. Attention to detail is one of the most important. This is a trait demanded from the “touch” labor force and technicians when dealing directly with aerospace flight hardware; unfortunately, we had to re-learn that it is also required of engineers and managers at other levels of the organization. We must continually remind ourselves that human space flight is hard, expensive, and risky. But it is worth doing.

It is likely that as we fly more missions that are successful on the Space Shuttle, there will be a temptation to reduce the funding for the Program which could lead to a relaxation in our

engineering rigor. At first, it will be fairly easy to deflect these urges to economize by pointing to the CAIB report. We must remain vigilant to prevent success from breeding complacency, and then failure. This progression is a well-documented phenomenon that is repeated for almost any complex system. Today's strong stance against cutting resources for operating successful programs will almost certainly regress. Because of NASA's "can do" spirit, we will likely take on the challenges of fewer resources and constrained schedules to meet the goals set for us by our leaders. NASA needs to guard against shortchanging the processes that will help us to identify and prevent the next accident. To ensure that we do not repeat our past mistakes, we must continue to capture the knowledge that we gain and overcome the obstacles presented by problems we encounter as we operate and eventually complete the mission of the Space Shuttle. The challenge for NASA and our stakeholders in the Space Shuttle Program is to understand the paradox that success will breed new challenges and to be wise enough to know that we cannot perform human space flight "on the cheap." This same approach will apply as much to the crew exploration vehicle now being conceived.

With a management team humbled by failure, with a new philosophy for independent technical authority (ITA), with a substantial new capability to perform in-depth and independent engineering test and analysis (the NASA Engineering and Safety Center), with a reformed safety and mission assurance organization, with a new energy and focus for system engineering, and with an Aerospace Safety Advisory Panel ready to receive the "battle flag" from the Return To Flight Task Group, we believe we already have, or are building in, the right amount of tension to counter any significant back-sliding for the next several years. This combination of management wisdom and independent thinking may keep us from collectively falling back into the dangerous "group think" posture that the CAIB described. We need to continue both an environment for healthy dialog and a culture of dissent for each present and future program. If we are able to preserve the combination of NASA's can-do attitude and an unflinching attention to the engineering details, we will be able to fulfill the vision for exploration while successfully completing the tasks assigned to the Space Shuttle Program.

A.7 Observations by Lt. Gen. Forrest S. McCartney

Recovery from a major aerospace accident is always a very painful experience, especially if human life is lost. The personnel involved in the investigation and oversight of the recovery should be carefully chosen and have experience in related activities (such as aircraft, space hardware development, weapons systems development, space operations, underwater naval activities, etc). The accident investigation report should be carefully written and focused on the root cause of the accident, since the recovery team normally reacts to the recommendations in a very aggressive way (which was certainly the case for the *Columbia* accident). Any oversight group (such as the RTF TG) has the responsibility to evaluate the recovery team's efforts from a very difficult viewpoint. A phrase sometimes used is "to call balls and strikes" or, said another way, to focus on the results of the recovery team's actions – not the motions of the recovery team in implementing their recovery actions.

While some of us might have approached the recovery process in a different way, the end result is what counts. In my opinion, The NASA Headquarters leadership and Space Shuttle Program Office have done their best to implement the actions they believe will lead to a safe return to flight. The entire Space Shuttle work force is dedicated to accomplishing the work necessary for safely returning to flight. They are to be congratulated on their efforts.

A.8 Observations by Dr. Rosemary O'Leary

The CAIB criticized NASA for an organization culture that tends to suppress dissent. Indeed, the issue of how NASA managers handle dissent within the organization permeated many of the RTF TG items presented in this report. To be more specific, the more significant challenge

facing NASA is a form of dissent suppression called “groupthink.” Groupthink is an insular decision-making process in which decision makers are so wedded to the same assumptions and beliefs, that they ignore, discount, or even ridicule information to the contrary (Janis 1972). Symptoms of groupthink include overestimations of the group’s power and morality, closed-mindedness, and pressure toward uniformity.

As former NASA Administrator Sean O’Keefe put it, the biggest battles at NASA are not between the Agency and Congress, as some might think. They’re between and among the diverse disciplinary groups who work in parallel “silos.” Sometimes diverse opinions and judgments are crushed or shouted down, but they are more often automatically deemed improbable or ignored. The dismissing of other viewpoints happens so quickly and is sometimes so subtle that as a leader it is very tough to address.

The opinions and judgments developed by individual teams often follow a different logic path than other teams. Hence, when another viewpoint is expressed by an “outsider” or someone questions the result, NASA employees often dismiss the opinions offered because they don’t take the time to understand the rationale or path taken. More troublesome, as the Integrated Vehicle Assessment Sub-Panel observed during fact-finding on March 30, 2005, sometimes the parallel silos are so poorly integrated that no discussion or connection ensues. Even worse is what the task group discussed at that same meeting: “malicious compliance” where lip service is given to gathering different viewpoints and analyses, yet it is not done in reality.

Despite these challenges, many NASA employees at all levels are quick to dismiss the importance of an improved organization culture and the need for organizational change. Thus, one of the problems facing the new NASA Administrator, Mike Griffin, is how to change the culture of the Agency from one of malicious compliance, parallel silos, and lack of horizontal communication where different ideas are quickly dismissed, to one that embraces a diversity of views and uses those differing viewpoints for constructive change.

My work as a member of the RTF TG over the last two years coincided serendipitously with the writing of my forthcoming book on dissent in organizations (O’Leary, 2006). As a part of this effort, in 2005, I surveyed some members of the RTF TG, members of the National Academy of Public Administration (NAPA – an independent, non-partisan organization chartered by Congress to assist federal, state, and local governments in improving their effectiveness, efficiency, and accountability), and alumni of the Maxwell School of Syracuse University (the oldest – and top ranked – school of public affairs in the country). I asked them about the value of dissent in organizations, but more importantly how to manage dissent. Of the 216 current and former managers who responded, 213 indicated that dissent, when managed properly, was not only positive, but essential to a healthy organization.

From these 216 surveys came dozens of suggestions for how to manage dissent and how to address groupthink in NASA. I present some of them here with the hope of furthering the discussion about dissent at NASA:

1. Embrace dissent. This means inviting a diversity of opinion from the people around you. Never surround yourself with people who are just like you.
2. Always insist upon someone voicing the dissenting opinion. Always.
3. Create an organization culture that accepts, welcomes, and encourages candid dialogue and debate. Cultivate a questioning attitude by encouraging staff to challenge the assumptions and actions of the organization.
4. Set up a regular process to receive dissent. Be accessible. Have an open door policy. Insist that employees come to you first. Allow employees to dissent in

civil discourse in group meetings or in private through memos or conversations: some people who have great ideas that challenge the status quo do not like to publicly display them.

5. Implement two-way evaluations where managers evaluate employees and employees evaluate managers. Managers who are involved in groupthink do so without realizing it. Often times lower level employees can see it, label it, and draw attention to it.
6. Make available options for addressing all types of problems to all people in the workplace, including employees, supervisors, professionals, and managers. A systemic structure that coordinates and supports multiple access points and multiple options and integrates effective conflict management practices into daily organizational operations should be provided. Persons who are knowledgeable and trustworthy for approaching with advice about a conflict or the system should be easily identified.
7. Encourage the resolution of conflict and collaborative problem solving at the lowest level through direct discussion and negotiation.
8. Listen. The hallmark of a strong leader is to be a good listener. Don't just hear the dissent, but to probe it, evaluate it, challenge the underpinnings (without discarding it out of hand), and make a reasoned decision on whether the dissent has a viable position.
9. Understand the formal and the informal organizations. The informal organization, generally, is that which may not manifest itself on an organization chart or in official documents. Examples include histories and connections between and among employees, traditions, power bases, and how the organization has learned to cope with challenges. The informal organization may be more difficult to identify than the formal, but it is often the environment within which dissent grows and develops.
10. Separate the people from the problem. Approach the issues on the merits and people as human beings. Fisher, Ury and Patton (1991) reinforce this in their best selling book *Getting to Yes* where they advise to separate the relationship from the substance, deal directly with the people problem, and strive to solve collaboratively the problem at hand.
11. Use peer review. Experts such as the National Science Foundation, NAPA, FACA committees, consultants, and university professors can help sort out the diversity of analyses and opinions that naturally arise from a healthy organization.
12. Allow the process that encourages diversity views enough time to fully run its course, but create dissent boundaries and know when to stop. Dissent is important, but a leader has to know when to say "enough." Then sit down with staff and explain how and why you made your decision.

Dissent exists in every organization to some degree. The point is to create and promote a workplace climate in which dissent is constructively addressed and resolved, and groupthink is kept in check. NASA needs to learn how to tap into the potentially insightful, creative ideas and energy of dissenters: They may be canaries in the coal mine telling the leaders that something is awry.

These ideas of those I surveyed are in keeping with much of the classic and current literature in organization theory and management. Slater and Bennis (2003), for example, espouse more democratic organizations that have the following characteristics:

- Full and free communication, regardless of rank and power.
- A reliance on consensus, rather than the more customary forms of coercion or compromise to manage conflict.
- The idea that influence is based on technical competence and knowledge rather than on the vagaries of personal whims or prerogatives of power.
- An atmosphere that permits and even encourages emotional expression as well as task-oriented acts.
- A basically human bias, one that accepts the inevitability of conflict between the organization and the individual, but which is willing to cope with and mediate this conflict on rational grounds.

A NASA organization culture that counteracts groupthink by welcoming “diversity thinking” is essential. Kingdon (2003: p. 183) sees the “free-form process” triggered by diversity thinking as promoting creativity and an opportunity for new and innovative ideas to emerge. Diversity thinking yields entrepreneurs who often act as brokers, negotiating among people, yielding couplings that might never have occurred in a more structured setting. These couplings, or linkages of workers outside their immediate workgroups, often yield new ideas (Erard, 2004).

Scholars who have empirically studied career public servants routinely find that they are largely highly principled, hard working, responsive, and functioning professionals. NASA is no exception. If NASA can continue to work on improving its organization culture to embrace dissent and banish groupthink, it has a fighting chance of remaining one of our premier public organizations.

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A.9 Observations by Mr. Seymour Z. Rubenstein

During the recovery from the *Columbia* accident, it was apparent that NASA was going to require a significant number of development engineers to accomplish the recommendations of the CAIB. The dominant makeup of the technical force was test, and flight and ground operations personnel. This is true at NASA and its major contractors. During the investigation period, a great deal of help was derived from “the graybeards.” However, when it came time to develop the fixes, systems engineers, development engineers, manufacturing engineers, and contractors with development experience were in short supply. As a result, some of the work



Discovery lifts-off from the Kennedy Space Center as STS-114.



Discovery during ascent with both Solid Rocket Boosters and all three Space Shuttle Main Engines at full throttle.

