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.

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.

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, USAF Reserve (Ret.)

Dr. Walter D. Broadnax, Ph.D.

Dr. Kathryn I. Clark, Ph.D.

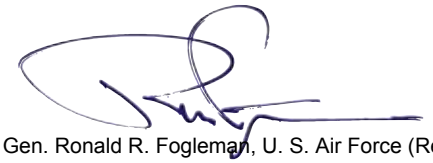
Mr. Benjamin A. Cosgrove

Dr. Dan L. Crippen, Ph.D.

Mr. Joseph W. Cuzzupoli

Dr. Charles C. Daniel, Ph.D.


Dr. Amy K. Donahue, Ph.D.


Gen. Ronald R. Fogleman, U. S. Air Force (Ret.)

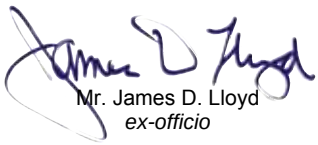

Ms. Christine H. Fox


Col. Gary S. Geyer, U. S. Air Force (Ret.)


Col. Susan J. Helms, U. S. Air Force


Mr. Richard H. Kohrs


Ms. Susan Morrisey Livingstone


Mr. James D. Lloyd
ex-officio


Lt. Gen. Forrest S. McCartney, U. S. Air Force (Ret.)


Dr. Rosemary O'Leary, J.D., Ph.D.


Dr. Decatur B. Rogers, P.E., Ph.D.


Mr. Seymour Z. Rubenstein


Mr. Robert B. Sieck


Mr. Thomas N. Tate


Dr. Kathryn C. Thornton, Ph.D.


Mr. William Wegner

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.

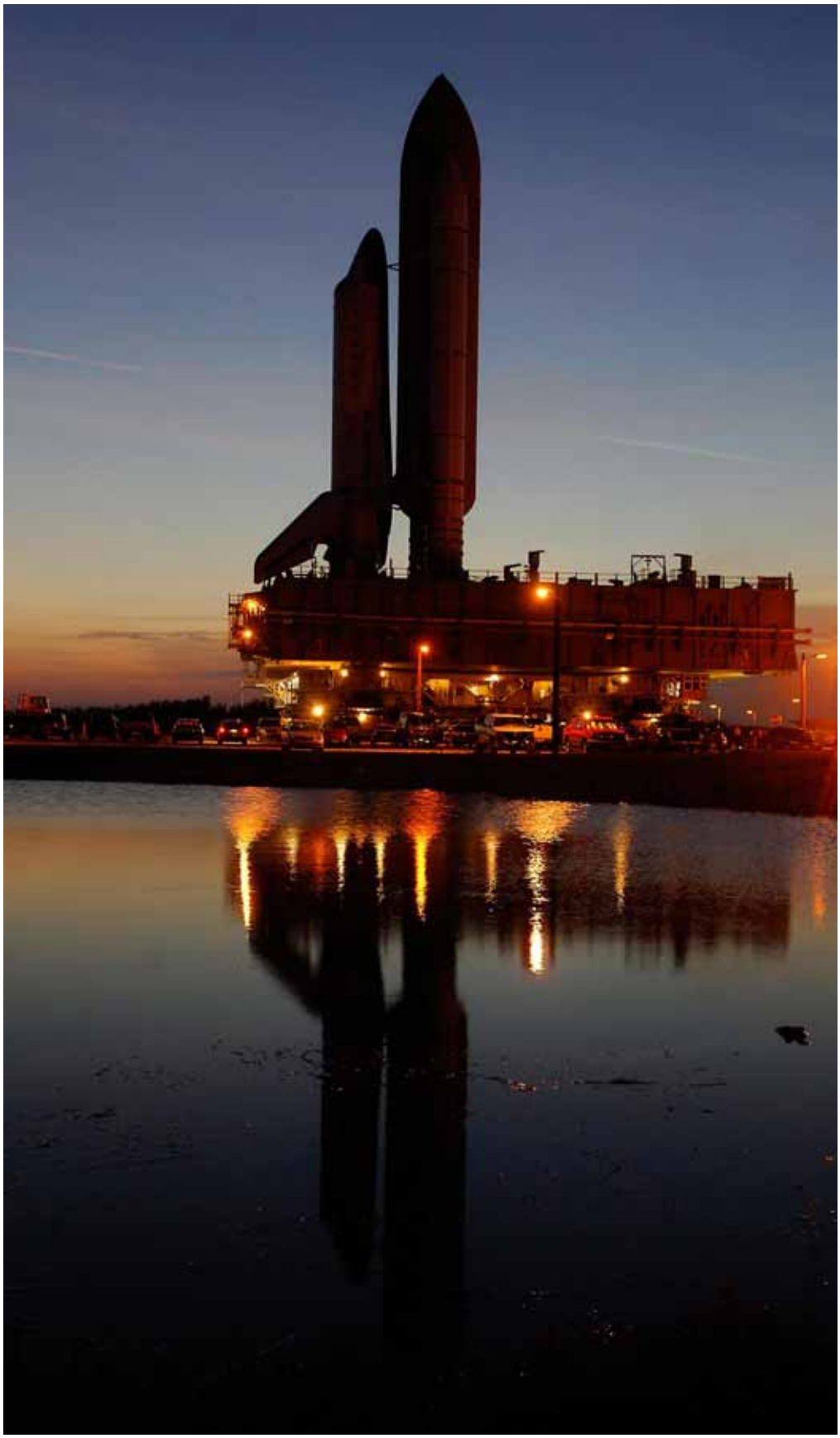
Section 4 describes open work the RTF TG will transition to the Aerospace Safety Advisory Panel (ASAP) or other appropriate organizations.

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 nosecap. 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 nosecap, 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 nosecap 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*.